

User Experience and Information Systems Development

Examining the user's dynamic cognitive changes in the
digital environment of businesses and public
organizations

University of Piraeus
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Studies
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DOCTORAL DISSERTATION

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English Summary

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The usability and effectiveness of digital public services have become increasingly important as municipalities rely more heavily on online platforms to deliver services and communicate with citizens. Despite this transition toward digital governance, many municipal websites remain difficult to navigate, fragmented in their information structure, and poorly aligned with citizens' needs. Understanding how users interact with and experience municipal digital platforms is therefore essential for improving the accessibility and effectiveness of public digital services.

The aim of this dissertation is to investigate the user experience of Greek municipal digital platforms and to examine the cognitive and behavioral processes that occur during user interaction with these systems. The research adopts a multi-method approach that combines traditional usability evaluation methods with neurophysiological techniques in order to provide a comprehensive understanding of citizens' digital experiences in the public sector. In addition, the dissertation introduces a novel neuroscientific metric, the Neuro-Cognitive Engagement Score (NCES), designed to quantify users' engagement and cognitive involvement when interacting with digital systems by integrating neurophysiological and behavioral indicators.

Chapter 2 presents a preliminary investigation of usability challenges in Greek municipal websites. Using traditional UX evaluation approaches, this exploratory study examines whether early signs of usability deficiencies can be identified in municipal digital environments. The results reveal recurring usability problems, including complex navigation structures, inconsistent information architecture, and limited accessibility of key services. These findings provide an initial indication that municipal digital platforms may not sufficiently support citizens' interaction needs.

Building on these initial observations, **Chapter 3** conducts a large-scale systematic evaluation of Greek municipal digital platforms. This study analyzes a substantially larger sample of municipal websites and incorporates citizen-oriented insights in order to assess how effectively municipal platforms support user interaction. The findings reveal widespread usability challenges across municipalities, highlighting structural inconsistencies in information architecture, service accessibility, and digital service integration.

While traditional UX evaluation methods provide valuable insights into usability problems, they cannot fully capture the cognitive and emotional processes underlying user interaction. For this reason, **Chapter 4** extends the investigation beyond conventional UX research by incorporating neurophysiological techniques. Using electroencephalography (EEG) and eye-tracking, the study examines how users cognitively and emotionally experience Greek municipal websites while interacting with real municipal digital platforms. The findings reveal patterns of attention allocation, cognitive load, and engagement during user interaction.

Within this context, the Neuro-Cognitive Engagement Score (NCES) is proposed as a composite indicator capable of capturing the intensity of users' cognitive engagement in digital environments.

Drawing on the insights generated from the previous studies, Chapter 5 advances a design-oriented contribution aimed at improving citizen interaction with municipal digital services. Instead of proposing a single unified platform, the dissertation introduces a neurocognitive-informed design framework that bridges empirical findings and design practice. The framework is operationalized through a set of design principles and conceptual interface prototypes, developed to address the usability challenges identified in earlier chapters. These design interventions emphasize improved navigational clarity, reduced cognitive load, and enhanced accessibility of public digital information systems. All design elements are grounded in both UX findings and neurophysiological evidence related to user engagement and interaction patterns.

Overall, this dissertation contributes to the fields of User Experience Research, Information Systems Development, and Digital Governance by integrating traditional usability evaluation, large-scale UX analysis, and neurophysiological research methods. The findings highlight the importance of user-centered design in public sector digital platforms and provide practical recommendations for improving citizens' interaction with municipal digital services. Furthermore, the introduction of the Neuro-Cognitive Engagement Score (NCES) offers a novel methodological approach for assessing user engagement in complex digital environments.



Περίληψη

(Greek Summary)



Η χρησιμότητα και η αποτελεσματικότητα των ψηφιακών δημόσιων υπηρεσιών αποκτούν ολοένα και μεγαλύτερη σημασία, καθώς οι δήμοι βασίζονται όλο και περισσότερο σε διαδικτυακές πλατφόρμες για την παροχή υπηρεσιών και την επικοινωνία με τους πολίτες. Παρά τη μετάβαση προς την ψηφιακή διακυβέρνηση, πολλές δημοτικές ιστοσελίδες παραμένουν δύσχρηστες, με κατακερματισμένη δομή πληροφοριών και περιορισμένη υποστήριξη των αναγκών των χρηστών. Συνεπώς, η κατανόηση της εμπειρίας των πολιτών κατά την αλληλεπίδρασή τους με τις δημοτικές ψηφιακές πλατφόρμες αποτελεί κρίσιμο παράγοντα για τη βελτίωση της προσβασιμότητας και της αποτελεσματικότητας των δημόσιων ψηφιακών υπηρεσιών.

Σκοπός της παρούσας διδακτορικής διατριβής είναι η διερεύνηση της εμπειρίας χρήστη στις ψηφιακές πλατφόρμες των ελληνικών δήμων και η κατανόηση των γνωστικών διεργασιών που ενεργοποιούνται κατά την αλληλεπίδραση των χρηστών με τα συστήματα αυτά. Η έρευνα υιοθετεί μια πολυμεθοδολογική προσέγγιση που συνδυάζει παραδοσιακές μεθόδους αξιολόγησης UX με νευροφυσιολογικές τεχνικές, με στόχο την παροχή μιας ολοκληρωμένης κατανόησης της εμπειρίας χρήστη στις ψηφιακές δημόσιες υπηρεσίες. Παράλληλα, η διατριβή προτείνει έναν νέο νευροεπιστημονικό δείκτη αξιολόγησης εμπειρίας, τον **Neuro-Cognitive Engagement Score (NCES)**, ο οποίος συνδυάζει νευροφυσιολογικά δεδομένα και γνωστικές μετρήσεις με σκοπό την αποτύπωση της έντασης της εμπλοκής και της γνωστικής επεξεργασίας των χρηστών κατά την αλληλεπίδρασή τους με ψηφιακά συστήματα.

Στο **Κεφάλαιο 2** παρουσιάζεται μια προκαταρκτική διερεύνηση των προβλημάτων χρησιμότητας σε ιστοσελίδες ελληνικών δήμων. Μέσω παραδοσιακών μεθόδων αξιολόγησης UX πραγματοποιείται μια αρχική διάγνωση πιθανών δυσκολιών στη χρήση των δημοτικών ψηφιακών πλατφορμών. Τα αποτελέσματα αναδεικνύουν επαναλαμβανόμενα προβλήματα χρησιμότητας, όπως περίπλοκες δομές πλοήγησης, ασυνεπή αρχιτεκτονική πληροφορίας και περιορισμένη προσβασιμότητα βασικών υπηρεσιών.

Στο **Κεφάλαιο 3** πραγματοποιείται μια μεγάλης κλίμακας συστηματική αξιολόγηση των ψηφιακών πλατφορμών των ελληνικών δήμων. Η ανάλυση βασίζεται σε σημαντικά μεγαλύτερο δείγμα δημοτικών ιστοσελίδων και ενσωματώνει δεδομένα που σχετίζονται με την εμπειρία των πολιτών, προκειμένου να αξιολογηθεί σε ποιο βαθμό οι δημοτικές πλατφόρμες υποστηρίζουν αποτελεσματικά την αλληλεπίδραση των χρηστών. Τα ευρήματα αναδεικνύουν συστηματικές προκλήσεις στη σχεδίαση και την οργάνωση των ψηφιακών υπηρεσιών των δήμων.



Παρότι οι παραδοσιακές μέθοδοι αξιολόγησης UX προσφέρουν σημαντικές πληροφορίες για τα προβλήματα χρηστικότητας, δεν αποτυπώνουν πλήρως τις γνωστικές και συναισθηματικές διεργασίες που λαμβάνουν χώρα κατά την αλληλεπίδραση των χρηστών με τις ψηφιακές πλατφόρμες. Για τον λόγο αυτό, στο **Κεφάλαιο 4** η έρευνα επεκτείνεται πέρα από τις παραδοσιακές μεθόδους αξιολόγησης UX μέσω της χρήσης νευροφυσιολογικών τεχνικών. Με τη χρήση ηλεκτροεγκεφαλογράφου (EEG) και τεχνολογίας καταγραφής οφθαλμικών κινήσεων (eye-tracking), εξετάζονται τα γνωστικά και συναισθηματικά μοτίβα που αναδύονται κατά την αλληλεπίδραση των χρηστών με πραγματικές δημοτικές ιστοσελίδες. Τα αποτελέσματα προσφέρουν βαθύτερη κατανόηση της κατανομής της προσοχής, του γνωστικού φορτίου και του επιπέδου εμπλοκής των χρηστών κατά τη χρήση των ψηφιακών δημόσιων υπηρεσιών.

Αξιοποιώντας τα ευρήματα των προηγούμενων μελετών, το Κεφάλαιο 5 προτείνει μια σχεδιαστικά προσανατολισμένη συμβολή με στόχο τη βελτίωση της αλληλεπίδρασης των πολιτών με τις ψηφιακές υπηρεσίες των δήμων. Αντί της πρότασης μιας ενιαίας ψηφιακής πλατφόρμας, η διατριβή εισάγει ένα νευρογνωστικά τεκμηριωμένο πλαίσιο σχεδιασμού, το οποίο γεφυρώνει τα εμπειρικά ευρήματα με την πρακτική του σχεδιασμού. Το προτεινόμενο πλαίσιο υλοποιείται μέσω ενός συνόλου αρχών σχεδιασμού και εννοιολογικών πρωτοτύπων διεπαφής, τα οποία αναπτύχθηκαν για να αντιμετωπίσουν τα προβλήματα ευχρηστίας που εντοπίστηκαν στα προηγούμενα κεφάλαια. Οι σχεδιαστικές αυτές προτάσεις εστιάζουν στη βελτίωση της σαφήνειας πλοήγησης, στη μείωση του γνωστικού φορτίου και στην ενίσχυση της προσβασιμότητας των ψηφιακών δημόσιων υπηρεσιών. Όλα τα στοιχεία του σχεδιασμού βασίζονται άμεσα τόσο σε ευρήματα UX όσο και σε νευροφυσιολογικά δεδομένα που σχετίζονται με την εμπλοκή και τα μοτίβα αλληλεπίδρασης των χρηστών.

Συνολικά, η παρούσα διατριβή συμβάλλει στους τομείς της **Έρευνας Εμπειρίας Χρήστη, των Πληροφοριακών Συστημάτων και της Ψηφιακής Διακυβέρνησης**, προτείνοντας μια ολοκληρωμένη προσέγγιση αξιολόγησης της εμπειρίας χρήστη που συνδυάζει παραδοσιακές μεθόδους UX με νευροεπιστημονικές τεχνικές. Επιπλέον, η εισαγωγή του δείκτη **Neuro-Cognitive Engagement Score (NCES)** προτείνει ένα νέο πλαίσιο μέτρησης της εμπλοκής των χρηστών σε ψηφιακά περιβάλλοντα, συμβάλλοντας στην ανάπτυξη πιο ανθρωποκεντρικών και αποτελεσματικών ψηφιακών δημόσιων υπηρεσιών.

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1

Chapter 1

General Introduction

1.1 The Rise of the Digital Era

The COVID-19 pandemic accelerated digital transformation globally. Both governmental and private entities have increasingly adopted Information and Communication Technologies (ICT) to provide better, faster, and more inclusive services. According to ITU (2019), 53.6% of the world's population, namely 4.1 billion people, were using the internet by the end of 2019. This number has since grown significantly due to the pandemic. In Germany, for instance, 60.12 million out of 69.06 million citizens were active internet users by August 2020 (statista). Simultaneously, companies like eBay and PayPal reported significant increases in user engagement and revenue during this time, illustrating a widespread shift to digital behavior and expectations (statista). These trends reveal the growing demand for user-friendly applications that meet the rising standards of digital consumers.

1.2 Digital Challenges in Public and Private Sectors

Since 2010, the "Digital Agenda for Europe" has been a cornerstone of the European Commission's agenda. The Digital Agenda for Europe includes actions such as digitalization and the availability of public sector information in a transparent, efficient, and non-discriminatory manner. "Europe's public sector expenditure should be utilized to foster innovation while boosting the efficiency and quality of public services," according to the above (EC, 2010).

However, businesses and government bodies alike face challenges when integrating user-centered digital solutions. While some multinational corporations (e.g., Amazon, Google, Apple) have successfully leveraged emerging technologies, such as artificial intelligence (AI), machine learning (ML), the network of things (Internet of Things - IoT), or augmented reality (AR), for strategic innovation (Annacone, 2019), many others lag behind due to low maturity in innovation management and resistance to integrating research-led design (Fogliette – Tereo, 2018). In the late 2000s, enterprises from many industries began to discuss a failure to employ digital technologies to promote development, making the aforementioned work extremely demanding. Not only interface designers, but also management in the computer and electronic application sectors, are gradually recognizing the benefits of user-centered design (e.g., Gruhn et al., 2002).

At the same time, public sector digital initiatives often focus on technical implementation rather than user needs. The Hellenic Ministry of Administrative Reconstruction (2014) emphasized the importance of increasing citizen participation and trust

in digital services. Nevertheless, outdated platforms, non-intuitive design, and limited accessibility persist across many municipal websites, especially in Greece.

Every day, the corporate sector makes major investments in technology with the expectation of a return, while customers themselves have raised their expectations of what they anticipate from an application. Some multinational companies, may be better at acquiring and using technology than others, but technological disparities are not the most fundamental barrier to effectively completing digital transformation in today's digital environment.

According to Raskin (2000), a user-centric interface is a humane interface when it responds to people's needs and takes into account their weaknesses. However, even though specialized professionals (programmers, designers, information architects, etc.) are well aware of the technical parameters in their field, they often fail to expand their knowledge and practices into human psychology.

The essential step of ensuring that the design adequately considers established and universal psychological data is usually omitted from the product development process and limited to industry standards (i.e. common best practices derived from competitor analysis in a particular industry). Similarly, project methodologies often fail to take advantage of global findings due to cost and time management considerations.

On the contrary, regarding the improvement of a system, most companies strictly aim at the optimization of the conversion rate, monitoring and testing microelements, with the aim of increasing the rates, which is a basic Marketing strategy for most of them. But despite their importance, business goals go beyond these specific percentages. In matters related to sustainability and growth of each brand, other factors are equally important and should be equally investigated.

To improve digital interfaces, organizations must look beyond technical functionality and account for the psychological and cognitive dimensions of user experience. This involves designing interfaces not only for efficiency and usability, but also for fostering emotional engagement, trust, and memory retention, elements that are crucial for digital adoption and satisfaction. The increasing complexity of human-computer interaction and the frequent shortcomings in effective digital tool usage have given rise to interdisciplinary fields such as Cognitive Psychology, Neuroscience, Behavioral Economics, Software Ergonomics, and Educational Technology. These domains contribute to updating and enriching both academic literature and practical frameworks for digital design.

1.3 The Business Value of UX

User Experience (UX) is increasingly recognized as a strategic business asset. The customer's priority is already at the heart of many organizations' strategy, stemming from the user's expectations. The study of user experience (UX), taking into account business goals, focuses on optimizing the overall (end-to-end) experience of users - customers, in order to increase the satisfaction of visitors, allowing the achievement of different - equally important goals, such as brand recall, user sentiment for the brand, acceptance, trust, engagement & loyalty and customer retention.

User satisfaction and the positive experience resulting from customers' contact with a company's website are critical for the success of a business (i.e Malik et al., 2018). Consequently, by improving the parameters that affect the quality of the overall experience, the following can be achieved:

- Increased conversion rates
- Improved customers' perception of the company (Brand Perception)
- Achieved Trust
- Enhanced Customer Retention
- Customer Engagement
- Achieved Customer Loyalty
- Elevated sales/income (Revenue)
- Improved Increase ROI

According to the American research company Forrester, every dollar invested in UX design can return a 100% return on investment. Having mentioned above the parameters that are affected by the quality of the overall experience, and by extension contribute to the success of a business, the question that arises is how to achieve the above. The 5 primary strategies for these achievements are explored below.

Cost and time savings in development. Given the evolving technology, changing business goals as well as increasing user requirements, the UX/UI design of any product or software is a continuous process of change and evolving work. Extensive market research of the product, its capabilities and other various design details, including user behavior early in the development process results in a well thought out and planned design as well as functionality plan that reduces redesign time and cost and error correction.

Eliminating Support Costs. If planning is inadequate, a chain reaction occurs. All of the additional effort and support is required as a consequence of a poorly designed application

and results in high expenses. Focusing on UX design decreases support costs by 90%, with around \$100 returned to the organization for every \$2 invested on it. 50% of a developer's time is spent reworking already completed work, which costs the firm up to 100 times more. For example, re-execution of various basic elements (components & features), or readjustment of all webpages based on the user's behavior and desires (redesign). A well-designed program early in the process, on the other hand, functions across all areas of interest, avoiding the need to substantially redesign the interface at regular intervals. An equally essential component is that UX/UI design encompasses more than just the "look and feel" of the program, but most importantly it includes various aspects as a whole, such as the functionality, usability and/or usefulness/relevance of the content.

Revenue Growth. Interface aesthetics play an important role in attracting customers as well as stimulating their curiosity and attention. According to recent findings, almost 75% of people place their judgments on the visual design of an app. Therefore, a circular effect is formed: a well-designed app is bound to attract users (increase traffic) resulting in conversion, which in turn leads to the acquisition of new customers (increase customer base) and User Experience & its correlation with e-democracy

to purchase a product from mobile-friendly websites, with mobile users 5x more likely to abandon a job if the page is not mobile-optimized, while 61% of users they move to another site if they don't immediately find what they're looking for. Likewise, optimized eCommerce pages receive up to a 30% rise in revenues, a 50% drop-in bounce rate, and a 70% increase in product sales. Elements such as how quickly a page loads, how simple the information layout is to comprehend, how engaging its content is, and smart navigation all contribute to the app's success, placing the whole user experience at the foreground. Customers select quality, which is described as a strong feature set mixed with an eye-catching appearance. Customers are thus more likely to receive a high-quality app at a high price, such as Apple products.

Retention of Customers. Because both customers and businesses value a great user experience, UX design may be a crucial difference between firms. Google's founders, for example, completed usability classes at Stanford University; Amazon has a 100-to-0 return on customer experience-advertising funding; and Airbnb sets a \$10 million value on user experience to prevent expenses from possible loss of actual value. At the same time, customer experience will exceed price and product as the most critical Brand difference in 2020. Since UX / UI design serves people, designers must consider themselves to be one of them. For example, the mapping of the user's behavior and needs as a result of research (UX Research), the visual/graphical representation of his journey through the application (user journey

mapping), fold points of the optimal experience, resulting in the customer becoming loyal to the application and considering it as a resource to which it can return when needed. Customers are 15% less likely to switch brands when the user experience is optimized.

Increased Productivity. This is a subjective element that depends entirely on the company and how it maximizes productivity through an effective UX / UI design. In general, though, a high-performance program provides for productivity in terms of "progress." This progress is only achievable when an outstanding UX / UI design increases user engagement, conversion, and allows developers to add new features. As a result, all departments and teams may simply focus on future website optimization measures.

1.4 From Cognitive Science to Digital Interaction

The fields of cognitive psychology, neuroscience, and human-computer interaction provide valuable frameworks for understanding how users engage with digital systems. Information processing theory describes the brain as a system that encodes, stores, and retrieves environmental stimuli. Digital interactions often trigger executive functions (e.g., attention, working memory, decision-making), primarily involving the prefrontal cortex (Pavlou et al., 2008; Gazzanica et al., 2010).

Within this neurocognitive framework, the concept of User Experience (UX) becomes even more significant, encompassing all the feelings, ideas, beliefs, preferences, perceptions, actions, and physical and psychological states that a person undergoes before, during, and after interacting with a digital product or system (ISO 9241-210, 2009). UX is thus understood as a holistic and multifactorial phenomenon shaped by both the cognitive architecture of the user and the design quality of the digital interface.

In relation to system performance, Nielsen (2000) argues that the system performance has a significant impact on user adoption of software. The term performance implies not only speed and technical errors - i.e. the technical characteristics of the product - but also the overall response of the system to universal human information processing principles (e.g. Hussain et al., 2018), a discussion that will be developed in the following chapter.

In response to the complexity of UX, User Experience research has been divided into two main approaches, the first dealing with the emotional - hedonic aspects of the experience, such as visual aesthetics, beauty, and pleasure of use (Hassenzahl, 2003, 2008 ; Hassenzahl & Tractinsky, 2006), while the second studies the pragmatic characteristics of the interactive product, such as usability, usefulness, or safety (Hassenzahl, 2003, 2008 ; Hassenzahl & Trac

(Hartson & Pyla, 2012; Bevan, 2008; Grandi et al., 2017; ISO 13407, 1999; Albert and Tullis, 2013). The significance of memory in both approaches is noteworthy.

To further explore the connection between cognitive function and system interaction, the field of Information Systems and Cognitive Neuroscience provides valuable insights. Human systems information processing refers to a technique for studying human cognition and behavior that emerged in the early 1950s as an alternative to behaviorism.

The approach's major principle is that the human mind can be described as an information processing system that encodes information stimuli from the environment as they enter the organism (input encoding), manages, and operates on them (operation), stores them (storage), retrieves them from memory (retrieval), and ultimately produces a reaction to the environment (output production). The architecture and the function of these subsystems governing the above processes are indirectly studied using various behavioral, psychophysiological, and non-invasive brain-imaging methods (Proctor & Wu, 2012).

Empirical Observation & Cognitive Control. Cognitive control is the human information processing control system that comprises all of the executive processes required to regulate behavior. These are mental abilities that entail planning and controlling the flow of information (Gazzanica et al., 2010). Executive functions involve fundamental cognitive processes such as attentional control, cognitive inhibition, and inhibitory control, working memory, and cognitive flexibility, among others. The prefrontal cortex (PFC) has long been associated with the regulation of executive functions (i.e. Burgess & Stuss, 2017; Stuss & Alexander, 2000). The dorsolateral PFC is associated with online information processing, such as the integration of different dimensions of knowledge and behavior (Lezak et al., 2014), and it plays a crucial role in the perception of usability of a web page due to the user's sequential execution of operations on it (Pavlou et al., 2008). The second section (orbitofrontal cortex - OFC) is critical in more abstract concepts such as automatic movement control and suspension (inhibition control), internal maintenance of an image / scene / scenario, monitoring and regulation of behavior.

Working Memory, Visual Perception, and Attention. One of the most appropriate applications for evaluating cognitive load while interacting with an interface has been identified as eye-tracking approach (Zagermann et al., 2016). Such metrics connect working memory load to the frequency and duration of screen fixations. Recently, researchers used eye-tracking technology to study the decision-making of people who had a responsible role in a company, through the management of financial information systems (Martin et al., 2019). According to their findings, by maintaining high rates of memory capacity (avoiding its

cognitive load) and viewing images, such as charts, for a longer time, even the most inexperienced investors achieved a higher performance of their under-study behavior. Advancing the reasoning, both the search task (search task) and the information system jointly affect the degree of cognitive resources consumed (Gwizdka, 2010) by the user. Although the increase in cognitive fatigue activates different neural networks depending on the individual's age and the nature of the task performed, an activity is almost exclusively observed in areas of the frontal cortex (Martin, 2014), a conclusion found to be consistent with a number of other studies (e.g. Brosnan et al., 2018).

Response Inhibition and Information Processing Speed. Braun et al., (2007) investigated how speed of executive functioning combined with anticipated affective mood affects consumers' ability to process inconsistent information in an already information-overloaded digital environment. Emphasizing the mental representation schema “Compatible vs. Incongruent Information – Affective Mood, the researchers explained that participants who possessed a negative brand mood showed lower reaction times in managing the system's incompatible conflicting information. In both physical and digital contexts, age is an additional component that suppresses the cognitive function of several processes, including attention, retrospective or working memory. A large body of behavioral evidence (i.e., Bunce et al., 1993; Stoltzfus et al., 1993?) suggests that the most likely cause of this impairment is related to the inability to control the inhibition (inhibition control) of the influences that the individual receives from unrelated contradictory information. Other research has found that error processing and inhibitory control enable behavior to be modified to task demands (Norman et al., 2019). At the same time, physiological measurements have revealed a link between the user's heart rate and inhibition capacity, with researchers (Moretta et al., 2019) indicating that the lower the heart rate, the more degraded inhibitory control appears to be (Problematic Internet Use - PIU).

Compatibility, Usability, and Mobility. In Neuroscience, object affordances are commonly addressed, which are connected to the potential of action with reference to a given item, such as seeing an icon with one's photo and knowing that when people click on it, they would be transferred to their account's environment (My Account). As a result, the individual is offered the chance to conduct an action toward an item through the processing of certain stimuli (Mike et al., 2004). Recent brain imaging discoveries (i.e. Mike et al., 2004; Shinkareva et al., 2011) show that two visual streams combine to generate a compatible mental representation of movement. The involvement of the visual processing system is evident together again. Motion compatibility is paramount to the overall user experience when

interacting with a device, web page or application, such as mouse movement, mobile devices, and upper limb movements.

Emotion. Emotion can be seen as a part of the cognitive system and human reasoning and is critical for effective decision making. The use of the Internet for commercial transactions is constantly increasing. Efficient and secure systems form the basis of these transactions. Empirical evidence suggests that when a consumer is emotionally charged, namely feeling fear or greed (Loos et al., 2010), financial decisions are hindered, since the user's perception of usefulness for the product is affected (Pavlou et al., 2008).

Smartphone and social media Usage. The digital device decisively affects the way a person communicates with others, or simply has fun. According to recent estimates, there are 2.5 billion smartphone users globally, while the use of social networking platforms is overwhelming and equally typical of the new age, with Facebook users approaching 2 million accounts, or WhatsApp 1.5 million users. Businesses' capacity to market their products using social media is impressive. Despite the infant relationship between neuropsychological research and social media, preliminary evidence links the aforesaid occurrence to the human rewarding system. Recent fMRI studies have linked the nucleus accumbens to the understanding of why people "hunt" for "Likes" online (i.e. Montag, 2019). Other previous studies (i.e., Sherman et al., 2018; Montag et al., 2017) found that processing photographs from an Instagram account with a high versus low number of "Likes" resulted in greater ventral striatal activity areas in the human brain, where the nucleus accumbens is found. In general, this area in mammals has been frequently connected to the psycho-emotional motivation and reward system (seeking activity & emotional/motivational system) (Montag & Panksepp, 2017; Ikemoto & Panksepp, 1999).

1.5 UX, e-Government and e-Democracy

One of the primary goals of the European Commission and the Greek government is the creation of sustainable e-Government systems that offer transparent, efficient, and impartial digital services that will operate in accordance with the rules of social policy and democracy, while reconnecting citizens with the government (EC, 2010). This goal gained further urgency with the acceleration of digitalization during the COVID-19 pandemic. However, despite considerable public investment in e-government over the previous decade, citizen usage of such services remains restricted, offering a major challenge to national governments (Perez-Morote et al., 2020).

A recent study by Perez-Morote et al., (2020), explored how factors like e-government assessment, trust, and digital inequality influence usage patterns across 27 European countries from 2010 to 2018. Their findings indicated that the majority of citizens remain unfamiliar with the digital activities of their local governments (Zheng & Schachter, 2017; Nam, 2014; Park et al., 2013; Reddick, 2011). The study revealed a positive correlation between citizen satisfaction with digital services and the likelihood of their usage. In essence, the more positively citizens perceive their interaction with e-government platforms, the more likely they are to return and engage. This highlights the central role of User Experience (UX) in promoting civic participation.

Beyond usability, trust emerges as a crucial component in citizen adoption of digital public services. Nulhusna et al. (2017) and Alzahrani et al. (2018) emphasized that citizens are more likely to use platforms they perceive as trustworthy. Similarly, Zuiderwijk et al. (2020), studying open government data policies in the Netherlands, found transparency to be a key factor in public trust and system usability.

Other researchers have focused on citizen acceptance of public systems. Fernandes et al. (2013) found that even digitally literate users often struggled to retrieve information and were reluctant to recommend the Ministry of Labor's employment site. Such findings point to UX deficiencies as barriers to adoption. To address this, researchers like Adiyarta et al. (2018) proposed models aimed at improving system acceptance through better user-centered design.

Furthermore, research by Hussain et al. (2019) on Malaysia's MyEG mobile app, a tool for citizens to complete everyday municipal tasks such as paying traffic fines, demonstrated that mobile governance solutions can significantly enhance citizen satisfaction. The study emphasized that trust, mobility, and secure transactions from any location or device are strong predictors of perceived service quality.

In summary, across both centralized and local systems, user experience plays a pivotal role not only in technical efficiency but also in public perception, inclusivity, and civic engagement. Municipal websites, as frontlines of e-democracy, must therefore be designed with psychological, emotional, and cognitive user needs in mind, not only technical performance.

1.6 Objectives and Research Contribution

To advance the rationale of this research, a deeper understanding is required of the components that shape effective interactions between users and digital technologies. Anchored

in the emerging field of Neuro-Information Systems (NeuroIS)¹, this doctoral thesis, by adopting a multidisciplinary approach, aims to advance the scientific understanding of how users experience municipal digital platforms by integrating principles from UX design, cognitive science, and neuroscience.

The core objectives are: (1) to assess the current state of User Experience across Greek municipal websites using both traditional UX auditing methods and neuro-informed tools; (2) to explore unconscious user responses through the application of EEG, eye-tracking, and implicit memory testing, thus capturing dimensions often missed by self-report instruments; (3) to introduce and pilot the Neuro-Cognitive Experience (NCE) Index, an original algorithm that combines neurophysiological metrics and subjective feedback into a unified evaluative score; (4) to translate these insights into actionable design recommendations through the development of a prototypical "HUB Municipality Portal" that addresses observed UX deficiencies; and (5) to propose a conceptual framework, namely the UX Multimodal Perceptual MindMap, connecting design elements with cognitive and emotional processes to inform future digital service design in both public and private sectors.

The thesis contributes to bridging the gap between traditional usability approaches and emerging neuroscience-driven methodologies, reinforcing the importance of user-centered design in contexts that directly affect democratic participation, inclusion, and digital service efficacy.

¹ **Neuro-Information-Systems (NeuroIS):** is a field of information systems, which is based on Neuroscience, neurophysiological knowledge and tools, in order to better understand the development, use and impact of technologies and information systems (Dumont et al ., 2018; Riedl & Léger, 2016; Riedl et al., 2010)

2

Chapter 2

Do Greek Municipal Websites Exhibit Early Signs of UX Deficiencies?

Exploring Usability Challenges in Greek Municipal Websites:
A Preliminary Evaluation

This chapter has been published as:

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Abstract

This study examines the user experience (UX) of Greek municipal websites, marking the first comprehensive review of local e-Government services in Greece. Using Lighthouse and an Adapted UX Audit Assessment, it identifies factors beyond citizens' digital skills that hinder platform adoption. The findings reveal widespread deficiencies, with no municipality scoring above 55%, reflecting significant usability and functionality challenges. Technical Performance and Missing Features, both scoring below 50%, emerge as key contributors to low user acceptance. The study highlights the need for improvements in feedback mechanisms, multilingual support, and accessible help sections to enhance e-democracy and user satisfaction. Recommendations for strategic website overhauls to boost engagement and foster democratic participation are also discussed, alongside limitations and future research directions.

Keywords: e-democracy, e-municipalities, usability, user experience (ux), system performance

INTRODUCTION

In recent years, the concepts of Digital Transformation and e-Government have become central to public discourse. Numerous national, European, and international institutions have engaged in research, innovation, and financial initiatives to facilitate the public sector's digital transition. Both the European Commission and the Greek government have prioritized developing sustainable e-Government systems, aiming to digitize public institutions and foster a digitally inclusive society (Ministry of Administrative Reconstruction, 2014). These efforts are fundamentally geared towards creating a transparent, efficient, and non-discriminatory digital interface that promotes social policy and democracy, reconnecting citizens with their government (European Commission, 2010).

Digitization involves transforming traditional, non-digital services, processes, or information into digital formats, making them accessible online (Aslanov & Mirzagayeva, 2022). This transformation is crucial for modernizing government operations, enhancing service delivery, and improving overall efficiency (United Nations, 2021). It involves adopting technologies to create digital platforms, databases, and systems that facilitate online public services (Vial, 2019). High digitization rates indicate successful technological integration into government processes, resulting in convenient and efficient digital services for the public. Conversely, low digitization rates suggest a reliance on traditional methods, highlighting areas for improvement and the need to accelerate digital transformation to meet citizens' evolving expectations (Schmutz, Sonderegger, & Sauer, 2016, 2017).

Penetration refers to the degree of adoption and utilization of these online channels by citizens to access government services (EC, 2020). It serves as a key metric for assessing the success of digital transformation and e-Government initiatives, reflecting the level of engagement and interaction between the public and government agencies through digital platforms (Perez-Morote et al., 2020). A high penetration rate signifies widespread acceptance and use of e-Government services among citizens, highlighting the effectiveness of digital initiatives in reaching the target audience. Conversely, a low penetration rate suggests potential challenges or barriers in adopting digital services, necessitating efforts to promote and enhance the accessibility and user-friendliness of online platforms.

Understanding the factors influencing digitization and penetration is crucial for policymakers and government agencies to tailor strategies and improve the effectiveness of e-Government initiatives, ensuring broader citizen participation and fostering a more efficient and inclusive digital public service delivery system.

User-centricity, an essential aspect of digital transformation, refers to designing and implementing digital solutions that focus primarily on the needs, preferences, and experiences of end-users. It involves gathering user feedback and incorporating user insights throughout the development process to ensure that digital services are intuitive, efficient, and user-friendly (Knijnenburg et al., 2012; Schumacher et al., 2010). By prioritizing user needs, organizations can enhance overall user experience, increase user satisfaction, and drive higher adoption rates of digital services, ultimately leading to successful digital transformation (Riedmann-Streitz, 2018; Corrigan & Miller, 2011; Petrovic & Siegmann, 2011).

Greece has made notable strides in the digital transformation of its public sector in recent years. The United Nations reported significant progress, predicting an impressive digitization rate of 86% by 2020 (UN, 2018). The European eGovernment Benchmark of 2020 validated this progress, indicating substantial growth despite Greece's digitization rate being lower than that of the EU27+UK. The same report commended Greece's performance in user-centricity, including online availability, usability, and mobile-friendliness of public systems.

However, Greece faces challenges in penetration, referring to the extent of citizens' utilization of online government services. The European Commission's assessments (EC, 2020, 2021) revealed a persistent deficiency in digitization levels and only a marginal improvement in penetration. Despite transitioning from a "Non-Consolidated eGov" scenario in 2020 to an "Unexploited Scenario" in 2021, Greece still exhibits limited utilization of digital services. Factors contributing to these challenges include insufficient digital skills, moderate quality of government digital services, and inadequate broadband infrastructure.

This research seeks to investigate the underlying dynamics between governmental digital services and their successful adoption by citizens. By adopting a human-centered approach, this study focuses on the user experience (UX) of Greek e-Municipalities, emphasizing the factors influencing website acceptance and system effectiveness. It aims to explore the relationship between user-centricity and e-Government penetration, considering how enhancing users' learnability and digital skills can improve system acceptance. The study's objectives are 1. to review Greece's performance in digitization and e-participation, 2. To identify determinants that enhance user acceptance, and 3. pinpoint factors influencing citizens' engagement with e-Government services. This comprehensive understanding will provide valuable guidance for policy formulation and future research in digital transformation within Greek e-Municipalities.

By addressing these research objectives, this study aspires to shed light on the critical dimensions of digital transformation in Greek e-Municipalities, offering insights for informed policy-making and contributing to the broader discourse on e-Government development.

THEORETICAL BACKGROUND

1.1 Enhancing Citizen e-Participation through Digital Transformation

The integration of Information and Communications Technology (ICT) in public administration aims to enhance citizen empowerment and participation in governance processes. E-empowerment, as defined by Macintosh (2004), involves leveraging technology to enable citizens to participate actively in decision-making, thereby influencing the political agenda from the bottom-up. This approach shifts the perception of citizens from mere consumers of public services to active policymakers, fostering a more inclusive and democratic governance structure. According to Wimmer (2007), e-empowerment increases citizens' influence, control, and involvement in policymaking, thus reinforcing democratic principles.

The COVID-19 pandemic has further underscored the necessity of adopting modern digital technologies to advance e-participation and collaborative policy-making. Consequently, various criteria are used to assess e-participation levels globally, at the European level, and locally, providing insights into current statuses and identifying areas for optimization.

1.2 Global and European Assessments of Greece's Digital Performance

The United Nations conducts a biennial e-Government study to monitor the global evolution of e-participation (UN, 2018). This study employs a three-level model of e-participation to transition individuals from passive to active engagement, ultimately leading to genuine empowerment. A key component of this assessment is the E-Participation Index (EPI), which evaluates the availability and relevance of participatory services on government websites. The EPI assesses the use of electronic services for public information provision (e-information), stakeholder contact (e-consultation), and involvement in decision-making processes (e-decision making).

Using the EPI, the UN ranks countries to provide insights into global trends in citizen engagement (UN, 2014; 2016). Greece has shown significant progress in e-participation, climbing from the 65th position in 2016 to the 34th in 2018, with notable improvements across all EPI categories (Costopoulou et al., 2021).

Similarly, the European Community considers User Centricity as one of the fundamental benchmark factors (EC, 2021; 2020). This factor evaluates the degree to which

services and information are available online, the level of support provided during the online journey, and whether public websites are optimized for mobile devices. Greece has demonstrated substantial growth in User Centricity, particularly in usability and mobile-friendliness, although challenges remain in online availability.

Table 1. Comparison of Greece's User Centricity (UC) parameters with EU27+FOR 2018-2019 and corresponding growth rates since 2016-2017 (EC, 2020)

Assessment Parameters	EU27+ Average Scores (2018-2019)	Greece's Average Scores (2018-2019)	Growth Rate (since 2016-2017)
Online Availability	86.8%	84%	+8
Usability	90.5%	93%	+7
Mobile Friendliness	76.3%	71%	+15
Overall UC	86.5%	85%	+9

Despite this progress, Greece continues to face challenges in penetration and digitization. The 2020 European Commission report categorized Greece under the "Non-Consolidated eGov" scenario, highlighting its limited utilization of ICT opportunities and lower performance compared to the European average.

Figure 1. Greece's growth trend from 2016 to 2019, as measured against a European Benchmark of 27+ UK Countries (2020). Reference: EC Report, 2020

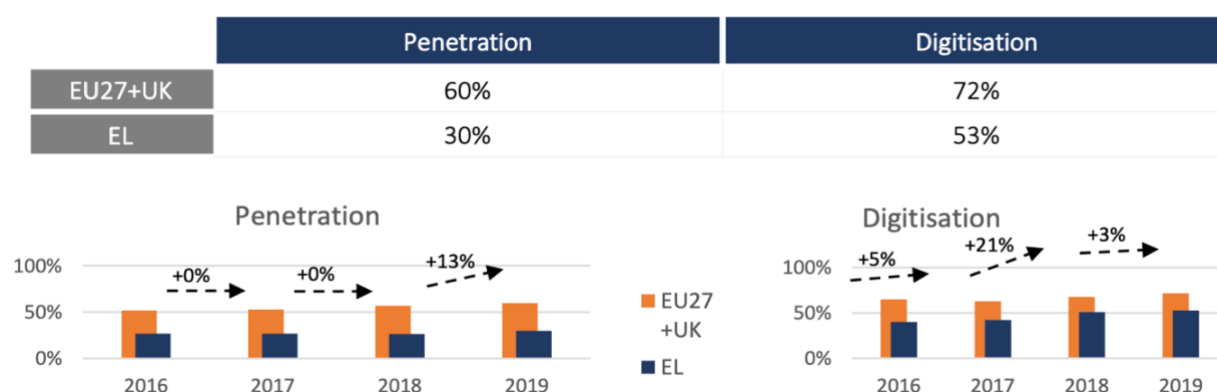
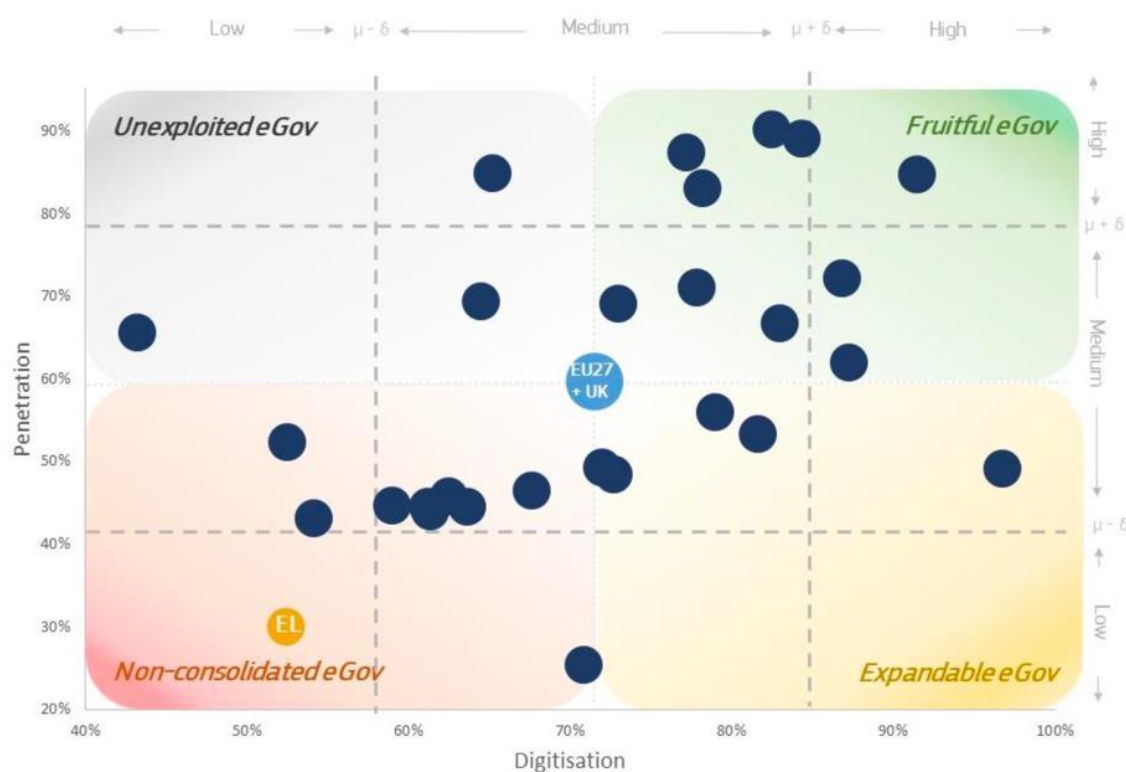


Figure 2. Penetration and Digitization Matrix. Greece's position in terms of Penetration and Digitization, as measured against a European Benchmark of 27+ UK Countries (2020). Reference: EC Report, 2020



In 2021, the European Commission report identified Greece in the "Unexploited eGov" scenario, reflecting a medium level of penetration but still lagging in digitization. Despite an increase in penetration levels, Greece's overall digitization processes remain underdeveloped, indicating substantial room for improvement.

Table 2. Comparison of Greece's User Centricity (UC) parameters with 27+ UK for 2019-2020 and corresponding growth rates since 2018-2019 (EC, 2021).

Assessment Parameters	EU27+ Average Scores (2019-2020)	Greece's Average Scores (2019-2020)	Growth Rate (since 2018-2019)
Online Availability	87.2%	79%	-5
User Support	88.4%	93%	0
Mobile Friendliness	91.2%	83%	+12
(Overall) UC	88.3%	85%	0

A paradox arises from these reports: despite increased penetration, Greece's digitization levels have not kept pace. This discrepancy suggests that factors beyond digital literacy, such as system usability and user-centric design, play critical roles in effective e-Government service adoption.

Therefore, evaluating and enhancing these factors are crucial for Greece to fully realize the potential of its e-Government initiatives, improving both citizen engagement and the effectiveness of public service delivery.

1.3 Maturity Models and Digital Performance Assessment

The examination of maturity models and digital performance assessments reveals crucial insights into the adoption and effectiveness of e-participation at both national and local levels in Greece. The differences between global, national, and local assessments underscore the varying degrees of digital maturity and the unique challenges faced by municipalities in integrating advanced e-Government technologies.

1.3.1 Global vs. Local Assessments

The E-Participation Index (EPI) provides a comprehensive overview of e-participation adoption at the national level. While it offers valuable global data, it may not be fully suitable for assessing local government practices due to the unique cultural and operational contexts that exist at the municipal level (Steinbach et al., 2019). Recognizing this limitation, the UN proposed the Local Online Service Index (LOSI), which aims to evaluate local e-government practices by considering these cultural characteristics (UN, 2018). However, the applicability of LOSI across diverse local environments is still under investigation, indicating a need for further refinement and standardization.

1.3.2 Insights from Local Studies

Costopoulou et al. (2021) conducted a study using the Citizen Web Empowerment Index (CWEI) to assess e-information, Web 2.0 tools, e-consultation, and e-decision-making processes at the local level in Greece. Their findings indicated small-to-medium-scale improvements in digital engagement. However, they also highlighted that the integration of advanced digital technologies by municipalities is still in its early stages. The study recommended that municipalities explore new technologies such as mobile apps, social media, and big data to enhance citizen participation. This suggests that while there are positive trends, significant work remains to achieve comprehensive digital transformation at the local level.

Similarly, Ntaliani et al. (2017) investigated electronic and mobile participation within 325 Greek municipal governments. Their research revealed substantial room for improvement in developing clear strategies for incorporating mobile technology into civic engagement.

Despite some progress, the findings emphasized the need for more robust and coherent strategies to fully leverage mobile technologies in fostering citizen participation.

Taken together, the findings from these studies highlight the varying levels of maturity and digital performance between national and local government e-participation initiatives. The current state of e-participation maturity models and digital performance assessments underscores a significant disparity between national and local levels. This disparity ranges from providing a broad, global perspective on national e-participation adoption to offering services at the local level that have a slow pace of integrating advanced digital technologies, such as mobile apps, social media, and big data.

1.4 Differences in e-Governmental Sites and Local Government Sites (Municipalities)

Previous studies (Alexopoulos et al., 2018; Costopoulou et al., 2017; Lappas et al., 2015) have examined e-Government progression within Greek municipalities. Their comprehensive analysis reveals significant differences in citizens' perspectives on e-Governmental sites compared to local government (municipal) sites in Greece. These differences are rooted in the varying levels of interactivity, accessibility, and overall service quality provided by these platforms.

1.4.1 One-way Information vs. Interactive Capabilities

Lappas et al. (2015) established a framework for evaluating e-Government based on residents' preferences, revealing that Greek municipalities primarily offered one-way information and limited interaction capabilities. The authors posed the factor that Greek municipalities primarily offer one-way information dissemination. Municipal websites are often limited to providing static content such as municipal information, tourist attractions, council member details, and mayoral information. This one-way flow of information does not facilitate interactive engagement or transactional capabilities, which are crucial for fostering active citizen participation and engagement. The lack of interactive features, such as online forms for feedback, discussion forums, or real-time communication tools, restricts the ability of citizens to engage dynamically with local governments.

In contrast, based on the same report, e-Governmental sites at the national level have shown a greater inclination towards incorporating interactive capabilities. National platforms are more likely to offer comprehensive e-services, including e-consultation, e-decision-making, and other participatory tools that enable citizens to interact more directly with government services and policies. This interactivity is a key factor in enhancing user satisfaction and promoting a sense of involvement among citizens (Lappas et al., 2015)

1.4.2 Slow Pace of Development in Municipalities

Costopoulou et al. (2017) highlighted the slow pace of e-Government development within Greek municipalities compared to the progress observed at the national level. While there has been some focus on enhancing e-information, local government sites still lack essential features such as online polls and reputation systems. These tools are vital for gauging public opinion and building trust through transparent and responsive governance. The absence of such features indicates a significant gap between the potential of e-Government services and their actual implementation at the municipal level.

On the other hand, national e-Governmental sites have made more strides in integrating advanced features that support comprehensive user engagement and participation. This disparity suggests that while national initiatives may benefit from more resources and centralized policies, local governments struggle with limited capacities and slower adoption rates.

1.4.3 ICT Infrastructure and Domain-Specific Progress

Alexopoulos et al. (2018) identified barriers in Smart Cities development, noting improvements in ICT infrastructure but limited progress in health, transportation, and security domains. These authors detected notable improvements in ICT infrastructure within Greek municipalities, such as the implementation of free Wi-Fi in public areas and the upgrading of hardware and software in municipal departments. However, significant barriers remain, particularly in sectors such as health, transportation, and security. The limited progress in these critical domains further exacerbates the gap between local government capabilities and citizen expectations.

In comparison, national e-Governmental sites tend to have better-developed infrastructure and broader domain coverage, reflecting more holistic digital transformation strategies. This comprehensive approach ensures that citizens can access a wider range of services efficiently, thereby enhancing the overall user experience and trust in e-Government initiatives.

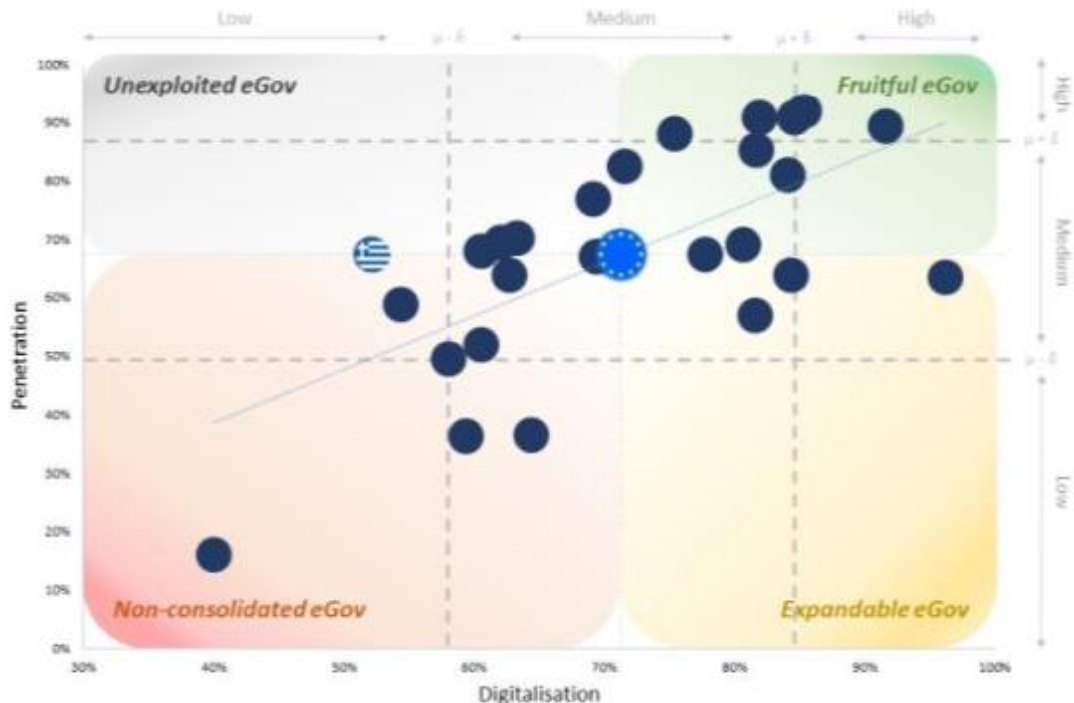
Taken together, the differences in citizens' perspectives on local versus e-Governmental sites are largely influenced by the levels of interactivity, the pace of development, and the comprehensiveness of ICT infrastructure. Local government websites often lag behind national platforms in providing interactive, user-friendly, and fully functional e-services. This gap highlights the need for targeted research methods to further elaborate on users' perspectives

and the evaluation of users' adoption of such systems. Understanding these perspectives will enable the development of strategies to enhance the digital capabilities of municipalities, ensuring they can meet the evolving needs and expectations of their citizens.

1.5 Usability and Learnability as Unified Concepts

Usability is a multifaceted concept encompassing both technical and user perception aspects. It includes how efficiently a system performs tasks, its intuitive interface, and its ability to facilitate user interactions (Hartson & Pyla, 2012; Albert & Tullis, 2017; Bevan, 2008). However, usability also involves the human aspect of design—how comfortable, enjoyable, and meaningful the interaction is for the user. It hinges on factors like aesthetics, clarity of information, and the ability to cater to diverse user needs and preferences. Thus, a system's usability extends beyond technical proficiency to include psychological and emotional dimensions of user satisfaction and engagement (Hassenzahl & Tractinsky, 2006; Hassenzahl & Ullrich, 2007).

Figure 3. Penetration and Digitization Matrix. Greece's position in terms of Penetration and Digitization, as measured against European Benchmark of 27+ UK Countries (2021). Reference: EC Report, 2021



When it comes to e-Services, issues related to navigation and information architecture are crucial. An intuitive structure ensures that users can easily access the services they require,

enhancing the overall user experience. Conversely, a poorly designed layout can deter users, undermining the adoption and success of e-Services (Sönmez et al., 2024).

Usability also includes critical content and features. Missing content can lead to user dissatisfaction and hinder their ability to accomplish tasks efficiently. Trust and credibility are integral components of usability, established through design elements, accurate information, and a transparent user interface (i.e. Elshan et al., 2022). Technical bugs can significantly impact usability, frustrating users and leading to negative perceptions of the e-Services (Van Riel et al., 2001).

In conclusion, evaluating factors such as navigation, information architecture, content completeness, trust, and technical reliability is paramount when investigating the usability and learnability of e-Services. Understanding and improving these elements are essential for designing systems that meet user needs and expectations. Prioritizing these factors ensures that e-Services are not only functional but also user-friendly, thereby promoting higher adoption rates and greater user satisfaction. Therefore, comprehensive evaluations of these factors should be integral to any usability and learnability assessment, guiding the development of more effective and engaging digital services.

1.6 User Centricity, User Acceptance, and Usability Levels

Scholars emphasize the importance of trust and user experience in effective e-Government utilization (Fernandes et al., 2013; Tan, Benbasat & Cenfetelli, 2008). Vasilikopoulou (2017) conducted a comprehensive assessment of Greek e-Government sites, identifying several usability challenges:

1. Absence of a unified central portal leading to confusion and mental discontinuity.
2. Lack of information about each site's purpose and available e-services.
3. Disconnect between e-Government websites and real-world processes.

Based on these observations, usability issues are anticipated across various aspects of Greek municipal websites. An adapted UX Audit Assessment will identify additional usability challenges that hinder full system utilization.

User-centered design is crucial for addressing usability challenges. Fernandes et al. (2013) found that educational level and technology familiarity do not significantly impact e-Government penetration. Instead, system performance plays a critical role in shaping the overall user experience, influencing factors like speed, visual aesthetics, and ease of use (Hassenzahl & Ullrich, 2007; Tan, Benbasat & Cenfetelli, 2008).

Taken together, these insights highlight the critical importance of user centrality, user acceptance, and usability levels in the effective implementation of e-Government services. The identified usability challenges, such as the absence of a unified central portal, lack of clear information, and disconnect with real-world processes, underscore the need for a user-centered design approach.

In conclusion, evaluating factors such as system performance, speed, visual aesthetics, and ease of use is essential when investigating user centrality, user acceptance, and usability levels of e-Government services. Addressing these factors through user-centered design can significantly enhance the overall user experience, thereby promoting higher adoption rates and greater user satisfaction. Understanding and improving these elements are crucial for designing e-Government systems that meet user needs and expectations. Therefore, comprehensive evaluations of these factors should be integral to any usability assessment, guiding the development of more effective and engaging e-Government services.

1.7 Quality of System Evaluation

Evaluating the quality of system performance is crucial for understanding user adoption and overall user experience in e-Government services. This evaluation encompasses emotional and practical aspects such as visual aesthetics, usability, usefulness, and security, which are critical for designing effective and user-friendly digital platforms.

1.7.1 Performance

System performance plays a pivotal role in determining user adoption and overall user experience. Performance encompasses both emotional aspects, such as visual aesthetics and attractiveness, and practical considerations, including usability, usefulness, and security (Hassenzahl & Ullrich, 2007; Hassenzahl & Tractinsky, 2006). Technical factors, like speed and system characteristics, are also integral (Hartson & Pyla, 2012; Albert & Tullis, 2017; Bevan, 2008). Research by Tan, et al. (2008) in the United States demonstrated a link between website performance and user satisfaction. Their evaluation encompassed several criteria, including Tangibles (web interface), Reliability (functionality consistency), Responsiveness (accessibility across devices and times), and Empathy (content personalization). Slower websites often led to frustrating user experiences (Tan, et al., 2008). Similarly, Jati and Dominic (2009) found that the speed of e-Government portals significantly influenced perceived quality and usability.

Adhering to Web Content Accessibility Guidelines (WCAG) can enhance user experience by improving perceived usability, ease of use, interaction, and trust (Schmutz, Sonderegger, & Sauer, 2017). The Lighthouse tool assesses adherence to WCAG as well as

other critical categories, including search engine optimization (SEO), best practices, and performance, providing an objective assessment of factors impacting e-Government quality, such as perceived ease of use and usefulness, attractiveness, interaction, privacy, and trust (Barnes & Vidgen, 2006; Kaisara & Pather, 2011; Papardomichelaki & Mentzas, 2012; Daştan, 2015; Belanche, et al., 2014; Rasyid & Alfina, 2017; Karunasena & Deng, 2012; Desmal, et al., 2019).

1.7.2 Search Engine Optimization (SEO)

SEO metrics are instrumental in assessing website quality, considering factors such as content quality, delivery speed, and cross-device accessibility (Hanlon, 2022). SEO aims to evaluate website usability in terms of design, architecture, and content to enhance search engine visibility and attract quality traffic (Drivas, et al., 2019). Empirical validation of SEO's impact on user experience indicates that optimized websites can prolong user visits, ultimately enhancing the overall user experience (Egri & Bayrak, 2014). Ensuring search engine optimization becomes imperative, as unoptimized e-Government portals impede information access (Kopackova, et al., 2010).

Best Practices

The dimension of "Best Practices" pertains to adherence to coding and web development standards to ensure a positive user experience (web.dev, 2022). Compliance with these standards ensures technological currency, enhances website speed, and ensures security (web.dev, 2022). Notably, trust in e-Government is multifaceted, encompassing institutional-based trust, trust in stored data, trust in transactions, trust in services, trust in information, and confidence in systems (Papadopoulou, et al., 2010). This trust, often established through the application of cutting-edge technology and security protocols, reinforces the importance of adhering to best practices (Barnes & Vidgen, 2006; Kaisara & Pather, 2011; Belanche, et al., 2014; Papardomichelaki & Mentzas, 2012; Daştan, 2015; Papadopoulou, et al., 2010).

1.7.3 Accessibility

Accessibility evaluation in e-Government research involves the application of Web Content Accessibility Guidelines (WCAG) to assess portals, provide an explanation of the country's score on the United Nations Department of Economic and Social Affairs (UN DESA) e-Government development index (EGDI), and offer recommendations for enhancement (Paul, 2022). Automated tools are often employed for this purpose (Al Mourad, et al., 2019; Micheal, 2019; Kuzma, 2010; Paul, 2022). Adhering to accessibility requirements is essential, as it positively impacts task completion time, user perception of usability, aesthetics, workload, and

trustworthiness (Schmutz, et al., 2017). Automated tools are advocated for their ability to provide a more comprehensive assessment of website accessibility compared to expert evaluation (Brajnik, et al., 2010).

2. METHODS

2.1 Conceptual Framework

This research aims to identify critical factors influencing e-Government penetration by assessing the quality of digital services provided by Greek municipalities. The study employs two primary tools: the Lighthouse open-data tool and an adapted UX Audit Assessment. These tools evaluate the technical performance and usability of municipal websites, respectively, recognizing that both users' digital literacy and the design of the systems play crucial roles in effective e-Government service delivery.

2.2 Study Design

The study utilizes a mixed-methods approach, combining quantitative data from the Lighthouse tool with qualitative insights from the Adapted UX Audit Assessment. This approach allows for a comprehensive evaluation of both the technical and user-experience aspects of the municipal websites.

2.3 Sample Selection

Ten Greek municipal websites were selected for this study using a simple random sampling method. The selection criterion was a minimum population threshold of 60,000 residents within each municipality. This threshold ensures that the sample is representative of diverse user demographics and captures a wide range of user experiences. The selected municipalities include Rethimno, Metamorfosi, Thessaloniki, Oropos, Corfu, Limnos, Alexandroupolis, Trikala, Ioannina, and Korinthos.

2.4 Data Collection Tools

2.4.1 Lighthouse Tool

The Lighthouse tool, an automated website performance testing application, was used to assess the technical quality of the municipal websites. The evaluation focused on four key indicators:

- **Performance:** This includes metrics such as First Contentful Paint (FCP), Speed Index, Largest Contentful Paint (LCP), Time to Interact (TTI), Total Blocking Time (TBT), and Cumulative Layout Shift (CLS).

- **Accessibility:** Adherence to Web Content Accessibility Guidelines (WCAG) and other critical accessibility criteria.
- **Best Practices:** Compliance with coding and web development standards, user experience considerations, and security protocols.
- **SEO (Search Engine Optimization):** Factors such as mobile friendliness, content quality, and crawling and indexing capabilities.

Each municipal website's homepage was analyzed using the Lighthouse tool, as the homepage serves as a crucial entry point and typically shapes visitors' initial impressions.

2.4.2 UX Audit Assessment: An Adapted Version

The UX Audit checklist used in this study is an adapted and shorter version of a usability audit originally developed by Travis (2014). The original checklist consists of 247 statements across eight dimensions, designed to comprehensively evaluate website usability. For the purpose of this study, which focuses on evaluating municipality websites in Greece, the checklist was shortened to 50 statements grouped into five dimensions: Navigation & Information Architecture, Page Layout & Visual Design, Missing Features, Technical Performance, and Trust & Credibility. Each dimension contains 10 statements, with each statement rated on a scale of -1 to 1, where 1 indicates full satisfaction, 0 indicates partial satisfaction, and -1 indicates dissatisfaction.

This assessment focused on five critical areas:

- a) **Navigation & Task Orientation:** Evaluating the efficiency of the website's navigation system and the organization of information. This aspect evaluates the efficiency of the website's navigation system and information organization, ensuring that users, regardless of their level of digital maturity, can easily find the relevant content and complete desired tasks. Intuitive navigation contributes to the learnability of the system, allowing users to quickly adapt to its structure and functionalities.
- b) **Layout & Visual Design:** Assessing the visual appeal and user-friendliness of the design, including typography, color schemes, and imagery. This assessment seeks to create a visually appealing and user-friendly design. Clear and consistent visual cues aid users in understanding the website's layout and interactions, which is especially beneficial for users with lower digital literacy levels.
- c) **Missing Features:** Identifying essential features or functionalities that are absent on the website. By providing all necessary tools and functions, the system becomes more accessible to users of varying levels of experience, enabling

- **Technical Performance:** Uncovering and resolving technical difficulties or glitches that users may encounter. The fundamental difference between this metric and the “Performance” dimension measured by the Lighthouse tool is that the features examined here refer mostly to the design and the good system’s feedback (i.e. error/success messages, loading and progress indicators), as well as the proactive behavior of the system to prevent user’s errors.
- **Trust & Credibility:** Evaluating factors that influence user trust, such as the clarity and accuracy of information, privacy assurances, and credibility indicators.

2.5 Ensuring Content Validity & Reliability

2.5.1 Content Validity

To ensure content validity, the adapted checklist was reviewed by a panel of 7 UX experts. Each expert rated the relevance of each statement on a scale from 1 to 4 (1 = not relevant, 4 = highly relevant). The Item Content Validity Index (I-CVI) was calculated for each dimension by determining the proportion of experts who rated the item as 3 or 4. The I-CVI scores for the dimensions were as follows: Navigation & IA (9.29), Page Layout & Visual Design (10), Missing Features (10), Technical Performance (10), and Trust & Credibility (10). The Scale Content Validity Index (S-CVI), representing the average of the I-CVI scores for each dimension, was calculated to be 0.93 for Navigation & IA and 1.00 for the other dimensions. The overall I-CVI and S-CVI for the checklist were 9.858 and 0.986, respectively. These results indicate that the adapted checklist has high content validity, with most items being rated as highly relevant by the experts, ensuring that the checklist effectively covers the necessary aspects of usability for the evaluation of municipality websites in Greece.

Table 3. Descriptive Statistics. Mean, Standard Deviation (SD) for each UX Audit dimension

	Mean	SD	Min	Max
Navigation & Task Orientation	3.46	0.63	2	4
Page Layout & Visual Design	3.60	0.49	3	4
Missing Features	3.60	0.49	3	4
Technical Performance	3.61	0.49	3	4
Trust & Credibility	3.63	0.49	2	4

2.5.2 Reliability

To ensure the reliability of the UX audit tool, an Intraclass Correlation Coefficient (ICC) analysis was conducted using ratings provided by a panel of 7 UX experts. Each expert

rated the relevance of 50 items across 5 dimensions. The ICC was calculated using a two-way mixed-effects model for consistency, using IBM SPSS statistics package, version 29.

The results indicated a moderate level of agreement among the experts. The average measures ICC was 0.420, with a 95% confidence interval ranging from 0.136 to 0.635, suggesting moderate reliability when considering the mean ratings of the experts. However, the single measures ICC was low (0.094), indicating substantial variability in individual ratings.

In addition, Cronbach's Alpha for the entire scale was calculated to assess internal consistency. The overall Cronbach's Alpha was 0.420, reflecting moderate consistency across the items. While this value is below the commonly accepted threshold of 0.7, it is considered acceptable for exploratory studies and provides valuable insights for further refinement of the UX audit tool.

Figure 4. Intraclass Correlation Coefficient (ICC), Using SPSS Software, indicating the reliability of the Adapted UX Audit Checklist

Intraclass Correlation Coefficient							
	Intraclass Correlation ^b	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.094 ^a	.022	.199	1.723	49	294	.003
Average Measures	.420 ^c	.136	.635	1.723	49	294	.003

Two-way mixed effects model where people effects are random and measures effects are fixed.

- The estimator is the same, whether the interaction effect is present or not.
- Type C intraclass correlation coefficients using a consistency definition. The between-measure variance is excluded from the denominator variance.
- This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

2.6 Data Analysis

2.6.1 Quantitative Analysis

Descriptive statistics were used to analyze the data collected from the Lighthouse tool. Mean scores and standard deviations were calculated for each of the four key indicators (Performance, Accessibility, Best Practices, SEO) to identify areas requiring improvement.

2.6.2 Qualitative Analysis

The qualitative data from the UX Audit Assessment were analyzed using pattern and classification analysis. This involved cleaning the data, identifying recurring themes, grouping related data, and categorizing them into broader topics. A Response Frequency Analysis was conducted to determine the frequency and severity of identified issues, allowing the researchers to prioritize and address critical usability challenges.

3. RESULTS

3.1 System Performance

Descriptive statistics show differences in the mean scores across all dimensions (Table 3). Specifically, Performance Errors exhibit the highest level of difficulty, ($M = 5$, $SD = 0.9$), followed by Accessibility ($M = 4.7$, $SD = 2.2$), and Best Practices compliance ($M = 3.2$, $SD = 1.7$) and SEO ($M=1.4$, $SD=1$). These findings emphasize the need for targeted improvements in each area to optimize the overall performance and user experience of the examined websites.

Table 3. Descriptive Statistics. Mean, and Standard Deviation (SD) for each Lighthouse Indicator

	Mean	SD	Min	Max
Performance	40.60	24.35	11.00	86.00
Accessibility	80.50	11.68	62.00	98.00
Best Practices	75.50	12.98	54.00	92.00
SEO	86.70	9.56	70.00	100.00

The initial analysis of Accessibility, SEO, Best Practices, and Performance as shown in Table 4, showed that in terms of accessibility, 20% of the assessed e-Government portals perform well, 80% perform at a medium level, and no website was found to function poorly. Similar findings were made for “Best Practices”, where no websites performed poorly, 10% of e-Government portals performed well, and 90% performed at a medium level. Approximately half of the portals examined, namely 50% receive a medium score in terms of "SEO," and the other 50% performs well. The primary problem of the portals appears to be "Performance," as none of the e-Government portals under examination perform well, just 30% perform medium, and 70% perform poorly.

Table 4. Classification of e-Government Quality based on Lighthouse Analysis

	Performance		Accessibility		Best Practices		SEO	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Bad	7	70%	0	0%	0	0%	0	0%
Medium	3	30%	8	80%	9	90%	5	50%
Good	0	0%	2	20%	1	10%	5	50%
Total	10	100%	10	100%	10	100%	10	100%

3.1.1 Performance

The initial assessment of e-Government portal performance revealed a diverse landscape. The rendering speed of these portals was measured across six dimensions (Table 5): First Contentful Paint (FCP), Speed Index, Largest Contentful Paint (LCP), Time to Interact (TTI), Total Blocking Time (TBT), and Cumulative Layout Shift (CLS).

In terms of FCP, which gauges the time it takes to render initial images and content after a user's navigation, a mere 10% of the portals performed well, while the majority (60%) exhibited a medium performance level. A similar trend was observed in the Speed Index, where 50% of the portals displayed a suboptimal performance.

Largest Contentful Paint (LCP), a metric assessing perceived load speed and user assurance, revealed that 60% of portals scored a medium rating, while 30% performed poorly. TTI, which measures the time for a page to become fully interactive, witnessed 30% of portals performing poorly, with only 10% achieving a good rating.

Total Blocking Time (TBT), an indicator of user input responsiveness, displayed a mixed landscape with 50% of websites demonstrating medium performance, 20% ranking poorly, and 30% performing well. Cumulative Layout Shift (CLS), evaluating visual stability, showed that 52% of portals scored well, with 40% ranking medium and 40% performing poorly. This metric is particularly crucial for ensuring a satisfying user experience.

Table 5. Frequencies of Performance Classification in the e-Government Portals

		Good	Medium	Bad	Total
First Contentful Paint	Frequency	1	6	3	10
	Percent	10	60	30	100
Speed Index	Frequency	1	4	5	10
	Percent	10	40	50	100
Largest Contentful Paint	Frequency	1	6	3	10
	Percent	10	60	30	100
Time to Interactive	Frequency	1	6	3	10
	Percent	10	60	30	100
Total Blocking Time	Frequency	3	5	2	10
	Percent	30	50	20	100
Cumulative Layout Shift	Frequency	2	4	4	10
	Percent	20	40	40	100

3.1.2 Accessibility

Regarding accessibility (Table 6), the assessment unveiled areas of both strength and improvement. Notably, a substantial majority (80%) of e-Government portals exhibited a

medium level of performance, while none were found to perform poorly in the category. Areas such as "Tables & Lists" and "Best Practices" displayed robust performance, with 80% and 90% of portals, respectively, showcasing no errors.

However, challenges emerged in the "Contrast" category, with 90% of portals facing issues related to insufficient color contrast between text and background. This concern can hinder individuals with limited vision from discerning critical elements.

The most prominent accessibility issues surfaced in "Navigation," "ARIA," and "Labels & Names." Navigation challenges encompassed issues like duplicated element IDs and improper tab index values, potentially causing screen readers to skip essential content. ARIA, which aims to enhance screen reader comprehension, revealed lapses in providing accessible names for buttons and alternative attributes for images. "Labels & Names" revealed shortcomings in naming links and frames, impacting screen reader functionality.

Table 6. Frequencies of Number of Accessibility Errors occurred in the e-Government portals

		No of Errors detected				
		.00	1	2	3	Total
Contrast	Frequency	1	9	0	0	10
	Percent	10	90	0	0	100
Names & Labels	Frequency	1	1	4	4	10
	Percent	10	10	40	40.0	100
Tables & Lists	Frequency	8	1	1	0	10
	Percent	80	10	10	0	100
ARIA	Frequency	6	3	0	1	10
	Percent	60	30	0	10	100
Navigation	Frequency	6	3	0	1	10
	Percent	60	30	0	10	100
Best Practices	Frequency	9	1	0	0	10
	Percent	90	10	0	0	100

3.1.3 Best Practices

The evaluation of best practices showcased a predominance of medium-level performance, with 90% of portals falling into this category. Frequencies of the detected errors as shown in Table 7, reveal that the "General" category, emphasizing user experience and functionality, witnessed the most common issues. Approximately half (50%) of the portals exhibited unresolved problems due to insufficient security controls and browser errors.

Under "User Experience," concerns included low-resolution images on homepages and images displayed in incorrect aspect ratios, potentially impacting user perception. In "Trust &

Security," issues emerged related to portals linking to unsafe external destinations and the absence of HTTPS, posing potential security risks. Finally, the category of "Browser Compatibility" revealed that three portals lacked the HTML doctype, causing unexpected rendering.

Table 7. Frequencies of Number of Best Practices Errors occurred in the e-Government Portals

		No of errors detected			Total
		0	1	2	
User Experience	Frequency	6	3	1	10
	Percent	60	30	10	100
Trust & Security	Frequency	4	3	3	10
	Percent	40	30	30	100
General	Frequency	0	5	5	10
	Percent	0	50	50	100
Browser Compatibility	Frequency	7	3	0	10
	Percent	70	30	0	100

3.1.4 SEO

In the realm of Search Engine Optimization (SEO), the e-Government portals exhibited a commendable overall performance. Frequencies in Table 8 show that, in terms of Mobile Friendliness, which ensures usability across devices, the majority (70%) of portals were free from faults. However, issues were noted related to sizing adaptability on all devices.

Crawling and indexing, essential for search engine discoverability, encountered minimal problems. The sole identified issue was the blocking of the homepage from indexing, limiting search engine crawling.

Content-related issues centered on a lack of meta descriptions for documents and missing alternative attributes for images, which can affect search engine optimization.

Table 8. Frequencies of Number of SEO Errors occurred in the e-Government Portals

		No of Errors detected			Total
		0	1	2	
Mobile Friendliness	Frequency	7	3	0	10
	Percent	70	30	0	100
Content	Frequency	2	6	2	10
	Percent	20	60	20	100

Crawling & Indexing	Frequency	9	1	0	10
	Percent	90	10	0	100

3.2 System Usability

Descriptive statistics reveal variations in the mean scores across all evaluated usability dimensions (Table 9). Specifically, the Navigation & Task Orientation dimension showed relatively consistent performance across the municipalities ($M = 0.07$, $SD = 0.2$), with scores ranging from -0.4 to 0.5. The Page Layout & Visual Design dimension revealed significant differences and greater variability in the design quality ($M = -0.17$, $SD = 0.4$), with scores ranging from -0.8 to 0.8. The Missing Features dimension presented substantial discrepancies in the availability of key features across different municipalities ($M = -0.10$, $SD = 0.6$), with scores ranging from -0.8 to 0.7. Technical Performance displays a slightly positive mean score ($M = 0.03$, $SD = 0.6$), with scores ranging from -1 to 1, suggesting varied technical execution. Lastly, the Trust & Credibility dimension achieves the highest performance ($M = 0.13$, $SD = 0.6$), ranging from -0.6 to 0.8, indicating that trust and credibility aspects are generally well-handled but still show room for improvement.

These findings emphasize the need for targeted enhancements in specific areas to optimize the overall user experience of the evaluated websites.

Table 9. Descriptive Statistics. Mean, and Standard Deviation (SD) for each Usability Dimension

	Mean	SD	Min	Max
Navigation & Task Orientation	0.07	0.2	-0.4	0.5
Page Layout & Visual Design	-0.17	0.4	-0.8	0.8
Missing Features	-0.10	0.6	-0.8	0.7
Technical Performance	0.03	0.6	-1.0	1.0
Trust & Credibility	0.13	0.6	-0.6	0.8

3.2.1 Navigation & Task Orientation

The Navigation & Task Orientation dimension shows a mixed performance across municipal websites. Negative scores for the logical ordering of navigation choices and tab placement (-0.4) suggest that users find the navigation structure unintuitive. Similarly, challenges in remembering information across sections (-0.4) and moving between pages (-0.1) may lead to frustration. On the positive side, accurate category labels (0.3) and minimizing screens per task (0.5) enhance efficiency and reduce cognitive load. However, slight positive

scores for jargon-free terminology and distinguishing required fields (both 0.1) suggest room for improvement. Overall, while some aspects are effective, critical areas need improvement to enhance usability and user experience.

Table 10. Descriptive Statistics. Mean, and Standard Deviation (SD) for each statement in the Navigation & Task Orientation Dimension

	Mean	SD	Min	Max
There is a convenient and obvious way to move between related pages and sections and it is easy to return to the home page	-0.1	0.9	-1	1
The information that users are most likely to need is easy to navigate to from most pages	0.2	1.0	-1	1
Navigation choices are ordered in the most logical or task-oriented manner	-0.4	0.8	-1	1
Navigation tabs are located at the top of the page, and look like clickable versions of real-world tabs	-0.4	0.8	-1	1
Category labels accurately describe the information in the category	0.3	0.8	-1	1
The terms used for navigation items and hypertext links are unambiguous and jargon-free	0.1	0.9	-1	1
Hypertext links that invoke actions (e.g downloads, new windows) are clearly distinguished from hypertext links that load another page	0.2	0.9	-1	1
The number of screens required per task has been minimized (2-5 clicks)	0.5	0.8	-1	1
Users of the site do not need to remember information from place to place	-0.4	1.0	-1	1
There is a clear distinction between “required” and “optional” fields on forms	0.1	0.7	-1	1

3.2.2 Page Layout & Visual Design

The Page Layout & Visual Design dimension reveals key areas for improvement in municipal websites. The lowest score (-0.8) for layout effectiveness in guiding users highlights a significant design issue. Negative scores for avoiding excessive text and multimedia (-0.5) and for the use of attention-attracting features (-0.3) suggest that many websites overwhelm users with unnecessary elements. On the positive side, consistent font usage and good balance between information density and white space (both 0.1) are handled adequately, and color is effectively used to structure content (0.3). However, mixed feedback on visual appeal (-0.1) and confusion with graphics (-0.1) indicates a need for a more cohesive and intuitive design.

Overall, while there are strengths in specific areas like font usage and color application, the overall layout and visual design require significant improvements to ensure a more user-friendly and visually appealing experience.

Table 11. Descriptive Statistics. Mean, and Standard Deviation (SD) for each Statement in the Page Layout Design Dimension

	Mean	SD	Min	Max
Excessive use of text, scripts, applets, movies, audio files, graphics and images has been avoided	-0.5	0.7	-1	1
The layout helps focus attention on what to do next	-0.8	0.4	-1	1
Things that are clickable (like buttons) are obviously pressable and do not have characteristics that suggest that they aren't	-0.2	0.6	-1	1
Fonts are used consistently and are readable (size, colors)	0.1	1.0	-1	1
There is a good balance between information density and use of white space	0.1	0.7	-1	1
The site avoids extensive use of upper case text	0.8	0.4	-1	1
Graphics will not be confused with banner ads	-0.1	0.7	-1	1
Colour is used to structure and group items on the page	0.3	0.8	-1	1
Attention-attracting features (such as animation, bold colours and size differentials) are used sparingly and only where relevant	-0.3	0.7	-1	1
The site is pleasant to look at	-0.1	0.7	-1	1

3.2.3 Missing Features

The Missing Features dimension highlights several critical gaps in municipal website functionality. The lowest score (-0.8) for feedback mechanisms indicates that users struggle to report issues or provide suggestions. Other key deficiencies include the lack of accessible help sections, multilingual support, and updated calendars (all scoring -0.6), which are vital for user engagement. However, strengths were noted in the availability of contact information (0.7), functional social media links (0.6), and up-to-date downloadable resources (0.4). Despite these positives, the negative scores for the search bar functionality (-0.3) and form operations (-0.1) suggest inconsistent user experiences. Overall, while some aspects are well-handled, significant improvements are needed in feedback mechanisms, multilingual support, and other essential features to enhance usability and functionality.

Table 12. Descriptive Statistics. Mean, and Standard Deviation (SD) for each Statement in the Missing Features Dimension

	Mean	SD	Min	Max
The website includes a functional search bar that provides relevant results.	-0.3	0.7	-1	1
The site provides essential contact information (email, phone, address) that is easily accessible and up-to-date.	0.7	0.7	-1	1
The site offers a clear and functional feedback mechanism for users to report issues or provide suggestions.	-0.8	0.4	-1	1
All forms and submission processes (e.g., contact forms) are operational and user-friendly.	-0.1	0.7	-1	1
The site offers accessible help or FAQ sections to assist users with common issues.	-0.6	0.5	-1	1
The site ensures all forms of processes (e.g., accessing PDFs, financial info etc.) are operational and user-friendly.	0.1	0.9	-1	1
The site supports multiple languages, allowing users to switch between different languages seamlessly.	-0.6	0.7	-1	1
The site includes social media links that are functional, allowing users to connect with the website on various platforms.	0.6	0.7	-1	1
The site offers downloadable resources (e.g., PDFs, documents) that are up-to-date and relevant.	0.4	0.8	-1	1
The site includes a calendar or event scheduling feature that is relevant to citizens regularly updated and easily accessible.	-0.6	0.7	-1	1

3.2.4 Technical Performance

The Technical Performance dimension reveals both strengths and areas for improvement in municipal websites. As Table 13 shows, the highest score (1.0) indicates that sites effectively avoid horizontal scrolling, and proper line spacing (0.6) enhances usability. However, significant issues include the lack of customized 404 error pages (-1.0), which frustrates users, and insufficient warnings for slow-loading pages and delays (both -0.7). Other negative aspects are inadequate progress indicators and user confirmations (both -0.2), indicating a need for better user support. While some areas like immediate feedback (0.2) and page loading times (0.2) are handled reasonably well, overall, there is a clear need for better error handling and feedback mechanisms to improve the technical performance and user experience.

Table 13. Descriptive Statistics. Mean, and Standard Deviation (SD) for each Statement in the Technical Performance Dimension

	Mean	SD	Min	Max
The user is warned about large, slow-loading pages (e.g. “Please wait...”), and the most important information appears first	-0.7	0.9	-1	1
The site can be used without scrolling horizontally (design errors & bugs)	1.0	1.0	-1	1
The site uses a customised 404 page, which includes tips on how to find the missing page and links to “Home” and Search	-1.0	0.8	-1	1
Pages load quickly (5 seconds or less)	0.2	0.8	-1	1
The site provides immediate feedback on user input or actions	0.2	0.8	-1	1
The site keeps users informed about unavoidable delays in the site’s response time (e.g. when opening a heavy file, i.e. municipality's financial statements)	-0.7	0.9	-1	1
The site provides good feedback (e.g. progress indicators or messages) when needed	-0.2	0.9	-1	1
User confirmation is required before carrying out potentially “dangerous” actions (e.g. deleting something)	-0.2	0.8	-1	1
The site provides good system feedback (e.g. success/error messages)	0.1	1.0	-1	1
There is a line space of at least 2 pixels between clickable items and the Fitt's Law is ensured	0.6	0.7	-1	1

3.2.5 Trust & Credibility

The Trust & Credibility dimension reveals mixed results for municipal websites. The highest score (0.8) indicates strong attention to content quality, with few typographic errors or spelling mistakes. The avoidance of pop-up ads (0.4) and the presence of trustworthy individuals behind the sites (0.4) also positively impact credibility. However, the lowest score (-0.6) for preventing user errors suggests that many websites fail to support users effectively, reducing trust. Issues with visual design alignment and handling duplicate search results (both -0.2) further highlight areas needing improvement. While some aspects, like clear governmental backing (0.2) and content freshness (0.3), are generally positive, they vary across sites. Contacting someone for assistance scored neutrally (0), indicating inconsistency. Overall, while content quality and ad management are strengths, improvements in user error prevention, design consistency, and search functionality are needed to enhance trust and credibility.

Table 14. Descriptive Statistics. Mean, and Standard Deviation (SD) for each Statement in the Trust & Credibility Dimension

	Mean	SD	Min	Max
The content is up-to-date, authoritative and trustworthy	0.2	0.9	-1	1
It is clear that there is a real governmental organisation behind the site (e.g. there is a physical address or a photo of the office)	0.2	0.6	-1	1
The site avoids advertisements, especially pop-ups.	0.4	0.8	-1	1
It is easy to contact someone for assistance and a reply is received quickly	0	0.8	-1	1
The content is fresh: it is updated frequently and the site includes recent content	0.3	0.8	-1	1
The site is free of typographic errors and spelling mistakes	0.8	0.4	-1	1
The visual design complements the status of the municipality and any offline communication messages	-0.2	0.6	-1	1
There are real people behind the organisation and they are honest and trustworthy (look for bios)	0.4	0.8	-1	1
The search results page does not show duplicate results (either perceived duplicates or actual duplicates)	-0.2	0.8	-1	1
The site does a good job of preventing the user from making errors	-0.6	0.5	-1	1

3.2.6 Municipalities' Usability Distribution

Table 15 presents the overall scores (%) achieved by each municipality in the Adapted UX Audit, along with the Grand Average scores (%) for each dimension of the assessment. Figure 4 shows the distribution of overall UX audit scores across the municipalities under investigation. The results indicate that Alexandroupolis (73%) and Trikala (71%) are the top performers, followed by Ioannina (68%), Metamorfosi (67%), and Thessaloniki (58%). On the other end, Limnos (41%), Oropos (40%), Corfu (34%), Rethimno (24%), and Korinthos (20%) show the lowest scores, underperforming across all dimensions.

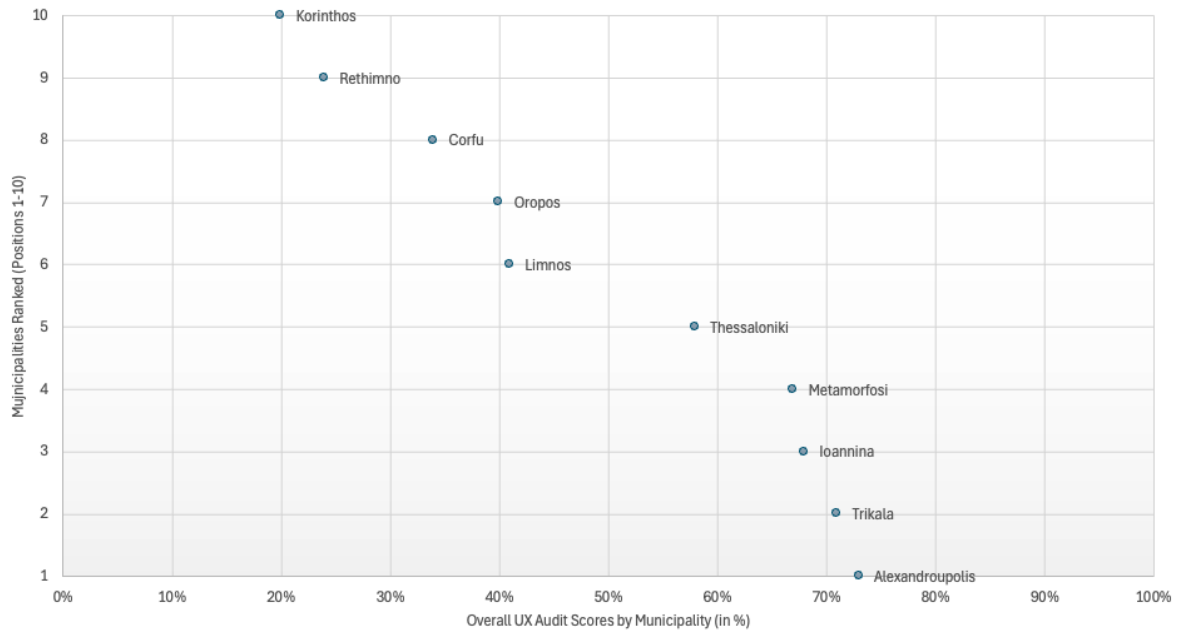
Specifically, Alexandroupolis leads with a 73% overall score, excelling in Page Layout & Visual Design (85%) and Technical Performance (75%), indicating a well-rounded UX. Trikala follows with 71%, performing exceptionally in Navigation & Task Orientation (95%) and Trust & Credibility (85%), though it is held back by low Technical Performance (25%). Ioannina (68%) and Metamorfosi (67%) demonstrate balanced but unremarkable performance,

with Ioannina being strong in Navigation & Trust but weaker in Technical Performance (40%). Thessaloniki (58%) shows moderate, consistent scores across all dimensions. Limnos (41%), Oropos (40%), Corfu (34%), and Rethimno (24%) struggle, particularly in Page Layout & Visual Design and Missing Features, contributing to their low UX scores. Korinthos ranks the lowest at 20%, underperforming across all dimensions.

Table 15. Overall Scores (%) achieved by each municipality, along with the Grand Average Scores (%) for each dimension of the Adapted UX Audit

Municipality	Navigation & Task Orientation	Page Layout & Visual Design	Missing Features	Technical Performance	Trust & Credibility	Overall Score
Alexandroupolis	75%	85%	60%	75%	70%	73%
Trikala	95%	85%	65%	25%	85%	71%
Ioannina	85%	65%	65%	40%	85%	68%
Metamorfosi	70%	75%	60%	65%	65%	67%
Thessaloniki	65%	45%	65%	50%	65%	58%
Limnos	50%	30%	30%	50%	45%	41%
Oropos	45%	60%	30%	30%	35%	40%
Corfu	20%	45%	25%	50%	30%	34%
Rethimno	25%	10%	20%	55%	10%	24%
Korinthos	15%	20%	20%	20%	25%	20%
Grand Average (dimension)	55%	52%	44%	46%	52%	

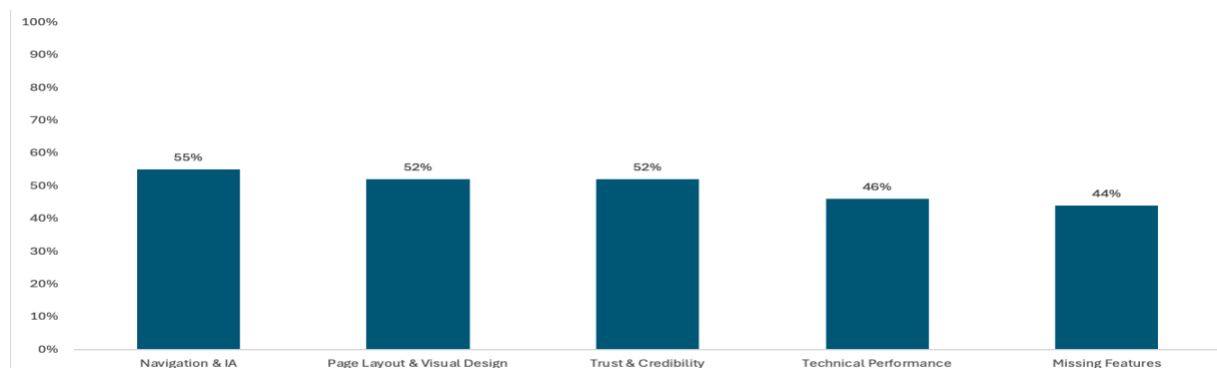
Figure 4. Distribution of Overall UX Audit Scores across Municipalities under Investigation



3.2.7 Dimension-specific Results

Continuing with the dimensions of the Adapted UX Audit Assessment, the Navigation & Task Orientation dimension shows significant variation, with Trikala scoring 95% and Korinthos only 15%. Technical Performance is particularly low, averaging 46%, with Trikala's score of 25% being notably poor. Page Layout & Visual Design also requires improvement, with an average score of 52%. Overall, the highest averages are in Navigation & Task Orientation (55%) and Trust & Credibility (52%), while Missing Features (44%) and Technical Performance (46%) lag behind, highlighting significant gaps in features and reliability (Figure 5).

Figure 5. Average Scores for each dimension achieved by Greek Municipalities



4. DISCUSSION

Previous assessments by the European Commission (EC, 2021; 2020) have consistently highlighted significant deficiencies in Greece's digitization efforts, with only marginal

improvements in digital penetration, or the successful adoption of these systems by citizens. These reports primarily attribute the challenges to insufficient digital skills among Greek citizens, moderate quality of government digital services, and inadequate broadband infrastructure.

This study aimed to further explore the factors influencing the adoption of governmental digital services, focusing specifically on the user experience (UX) of Greek e-Municipalities. The objective was to build on the EU findings by investigating additional factors beyond digital skills that might limit system adoption. To achieve this, the study employed two key tools: the Lighthouse tool, for assessing technical performance, and the Adapted UX Audit Assessment, which evaluated broader aspects of user experience. This dual approach allowed for a comprehensive examination of digital penetration from both technical and UX perspectives.

The investigation sought to understand how user-centricity and enhancements in user learnability and digital skills could drive greater system acceptance. The study's objectives were to review Greece's performance in digitization, identify determinants of user acceptance, and pinpoint factors influencing citizen engagement with e-Government services.

4.1 Systems Performance – Lighthouse

The findings from the Lighthouse tool directly correlate with the broader issue of user acceptance in e-Government services. User acceptance is highly dependent on the quality of the user experience (references), which is shaped by various factors, including performance, accessibility, adherence to best practices, and search engine optimization (SEO).

1. **Performance as a Barrier to Acceptance:** The significant performance issues identified, such as slow load times and poor responsiveness, are likely to impede user acceptance. Users expect fast and reliable interactions with digital services, and when these expectations are not met, frustration ensues. This frustration can lead to users abandoning the service, thereby reducing overall acceptance and penetration of e-Government services (i.e. Kelly et al., 2023; Bansah, & Darko Agyei, 2022; Wang et al., 2020, Venkatesh et al., 2016; Venkatesh et al., 2012)
2. **Accessibility and Inclusivity:** While the accessibility scores are relatively strong, issues such as poor contrast can alienate users with visual impairments, impacting their ability to engage with the service. Ensuring that all citizens, regardless of their abilities, can access these services is crucial for broad user acceptance. The medium-level

performance in accessibility indicates that there is still work to be done to ensure these portals are truly inclusive (i.e. Chau & Lai, 2003).

3. **Best Practices and User Trust:** The adherence to best practices, particularly in areas like user experience and security, directly impacts user trust and, by extension, user acceptance. When users encounter low-resolution images, browser compatibility issues, or insecure connections, their trust in the service diminishes. A lack of trust can be a significant barrier to acceptance, as users are less likely to engage with or return to a service they perceive as unreliable or unsafe (i.e. Taherdoost, 2018; Al-Omari et al., 2012).
4. **SEO and Discoverability:** Good SEO practices ensure that these services are easily discoverable by users, which is the first step in user engagement. The mixed performance in SEO highlights that while some portals are easily found, others may not be as accessible through search engines, limiting their reach and, consequently, user acceptance (i.e. Schilhan et al., 2021).

In summary, the technical deficiencies identified by the Lighthouse tool—especially in performance and adherence to best practices—pose significant challenges to user acceptance. To foster greater acceptance and penetration of e-Government services, these technical issues must be addressed. Enhancing performance, ensuring robust accessibility, adhering to best practices, and improving SEO will not only improve the user experience but also build the trust and reliability necessary for users to fully embrace and regularly use these digital services.

4.2 System Usability - Adapted UX Audit Assessment

The Adapted UX Audit Assessment reveals several critical insights into the usability and overall user experience of Greek municipal websites, which directly influence user acceptance.

1. **Navigation & Task Orientation:** The mixed performance in this dimension, with mean scores ranging from -0.4 to 0.5, highlights significant variability in how effectively users can navigate municipal websites. Negative scores for the logical ordering of navigation choices and tab placement indicate that many users might struggle to find their way through these websites. Such issues can lead to frustration, reducing the likelihood of users accepting and regularly using these digital services. The slight positive scores in areas like minimizing screens per task suggest that some municipalities are managing to reduce cognitive load, but these successes are not widespread.

2. **Page Layout & Visual Design:** This dimension showed substantial variability, with scores ranging from -0.8 to 0.8. The lowest scores in layout effectiveness suggest that many websites fail to guide users intuitively, which is a significant barrier to user acceptance. Overwhelming users with excessive text and multimedia content detracts from the user experience, making the websites less appealing and harder to use. Although there are some strengths in consistent font usage and color application, the overall design often lacks cohesion, which is necessary to make the website visually engaging and easy to navigate.
3. **Missing Features:** The most critical gaps identified in this dimension include the lack of feedback mechanisms, accessible help sections, and multilingual support, particularly in regions that consistently host a significant number of tourists or refugees, such as Limnos, Corfu, and Rethimno. These deficiencies are significant barriers to user acceptance, as they directly impact the user's ability to interact effectively with the website. Users are likely to become frustrated if they cannot easily find help or provide feedback. The inconsistent availability of key features across different municipalities suggests that while some websites may handle these aspects well, others fall short, leading to a fragmented user experience across the country.
4. **Technical Performance:** Although there are some strengths in this dimension, such as avoiding horizontal scrolling and maintaining proper line spacing, significant issues remain. The lack of customized 404 pages and insufficient warnings for slow-loading pages are major pain points that can lead to user frustration. If users encounter broken links or slow-loading pages without adequate feedback, they are less likely to view the service as reliable, which negatively impacts their overall acceptance (Kingsnorth, 2022).
5. **Trust & Credibility:** This dimension shows that while content quality is generally well-handled, there are areas where trust could be improved. Issues like the failure to prevent user errors and inconsistencies in visual design undermine the credibility of these websites. Trust is a crucial factor in user acceptance; if users do not trust the website to function correctly or to keep their data secure, they are unlikely to use it consistently (i.e. Taherdoost, 2018; Al-Omari et al., 2012).

The findings from the Adapted UX Audit Assessment suggest that while some dimensions of user experience are managed adequately, there are significant areas in need of improvement. User acceptance is heavily influenced by the ability of a website to provide a seamless, intuitive, and trustworthy experience. The variability in performance across municipalities

indicates that not all Greek municipal websites offer a consistent level of service, which can lead to uneven adoption rates. To increase user acceptance, municipalities need to focus on enhancing navigation, improving visual design, ensuring the availability of critical features, and addressing technical performance issues. These improvements will not only make the websites more user-friendly but also build the trust and reliability necessary for users to fully engage with and accept these digital services.

4.3 Dimension-specific Insights

The findings from the evaluation of Greek municipal websites suggest a significant disconnect between the design of these digital platforms and the principles that drive user acceptance. The consistently low scores across all dimensions, with no municipality exceeding 55% in any category, reflect a broader issue with how these websites are structured and maintained. Despite Navigation & Task Orientation emerging as the best-performing dimension, the fact that it only averages 55% highlights a serious deficiency in meeting even the most basic usability standards that are crucial for user satisfaction and acceptance.

This poor performance in critical dimensions such as Technical Performance and Missing Features, which both scored below 50%, is particularly concerning. These dimensions are directly related to the practical and functional aspects of user interaction with the websites. For users to accept and regularly engage with e-Government services, they need to experience seamless navigation, reliable technical performance, and access to all necessary features, including multilingual support and feedback mechanisms. The absence or poor execution of these elements can significantly hinder user acceptance, as citizens may find these platforms frustrating, unreliable, and ultimately unusable.

Moreover, the lack of accessible help sections and feedback mechanisms—especially in regions like Limnos, Corfu, and Rethimno that host a substantial number of tourists and refugees—further complicates user engagement. These gaps not only reduce the effectiveness of the websites but also alienate users who may require additional support due to language barriers or unfamiliarity with digital platforms. Without addressing these issues, user acceptance is likely to remain low, as citizens will be less inclined to utilize systems that do not adequately meet their needs.

In conclusion, the low performance across all dimensions of the Adapted UX Audit underscores the necessity for a comprehensive overhaul of Greek municipal websites. Improving usability, technical reliability, and the inclusion of critical features is essential for increasing user acceptance. If citizens are to fully embrace e-Government services, these

platforms must be designed with their needs and experiences at the forefront. Therefore, addressing these deficiencies should be a priority for policymakers and web developers alike, aiming to create a more user-centric digital government that fosters higher engagement and satisfaction among users.

4.4 Recommendations

Taken together, several recommendations for policymakers, government entities, and digital agencies can be concluded to improve the user experience and acceptance of local Greek municipal websites:

1. **Conduct Comprehensive UX Audits:** Regularly perform user experience audits using tools like the Adapted UX Audit and Lighthouse to identify and address usability issues. This should be a continuous process to ensure that municipal websites meet evolving user needs and expectations.
2. **Prioritize Usability Enhancements:** Focus on improving Navigation & Task Orientation, as even this best-performing dimension scored only 55%. Ensure that navigation is intuitive, logical, and designed to minimize user frustration. Clear categorization and easy access to essential information should be prioritized.
3. **Enhance Technical Performance:** Address the critical gaps in technical performance by ensuring faster loading times, reducing errors, and improving system feedback mechanisms. Implement robust testing protocols to catch and fix issues such as slow-loading pages, poor system feedback, and the absence of customized error pages.
4. **Improve Accessibility and Inclusivity:** Develop and enforce guidelines to make municipal websites more accessible, particularly in regions with diverse populations like Limnos, Corfu, and Rethimno. This includes adding multilingual support, accessible help sections, and easy-to-find contact information.
5. **Incorporate Feedback Mechanisms:** Establish effective feedback channels on municipal websites to allow users to report issues, suggest improvements, and receive timely responses. These mechanisms are crucial for ongoing improvement and user satisfaction.
6. **Update and Maintain Content:** Ensure that content on municipal websites is regularly updated, accurate, and free from typographical errors. This is essential for building and maintaining trust with users.

7. **Invest in User-Centric Design:** Collaborate with UX professionals to design websites that prioritize user needs. This includes creating visually appealing layouts that are free from unnecessary distractions, using consistent and readable fonts, and balancing information density with white space.
8. **Train and Educate Municipal Staff:** Provide training for municipal staff on the importance of digital literacy and UX principles. Staff should be equipped to maintain and update websites effectively, ensuring they remain user-friendly and functional.
9. **Engage with Citizens:** Involve citizens in the design and testing phases of municipal website development. This could include user testing sessions, surveys, and focus groups to gather feedback directly from the end-users.
10. **Set Benchmarks and Monitor Progress:** Establish clear benchmarks for website performance across all dimensions of UX, including navigation, technical performance, and accessibility. Regularly monitor progress against these benchmarks and make necessary adjustments to meet or exceed them.
11. **Foster Collaboration Across Municipalities:** Encourage knowledge-sharing and collaboration between municipalities to adopt best practices and learn from each other's successes and challenges in website development and maintenance.
12. **Allocate Sufficient Resources:** Ensure that sufficient budget and resources are allocated to the development and maintenance of municipal websites. Investing in high-quality digital infrastructure is crucial for providing citizens with reliable and effective e-Government services.

By implementing these recommendations, policymakers and digital agencies can significantly improve the user experience of Greek municipal websites, leading to higher user acceptance and greater engagement with e-Government services.

5. LIMITATIONS & FUTURE STUDIES

Since this study represents a first step in evaluating the user experience and technical performance of local government websites in Greece, it is important to acknowledge several limitations that may impact the generalizability and comprehensiveness of the findings.

1. **Sample Size and Scope:** The study focused on a limited number of Greek municipal websites, which may not fully represent the broader landscape of e-Government

services across the entire country. A more extensive sample could provide a more comprehensive understanding of the user experience in different regions.

2. **Lack of Longitudinal Data:** The study provides a snapshot of the current state of municipal websites but does not track changes or improvements over time. A longitudinal approach could offer insights into how these websites evolve and whether implemented changes lead to better user acceptance.
3. **User-Centric Perspective:** While the study emphasizes user experience, it may not fully capture the perspectives and challenges faced by the municipalities themselves, such as resource constraints, administrative priorities, or technical limitations. A more balanced approach that considers both user and provider perspectives could provide a more holistic view.
4. **Focus on Website Evaluation:** The study primarily evaluates the user experience of municipal websites without considering other digital channels or platforms that municipalities may use to engage with citizens (e.g., mobile apps, social media, or offline services). As a result, the conclusions may overlook important aspects of the overall digital experience offered by the municipalities.
5. **Potential Subjectivity in UX Audit:** The Adapted UX Audit Assessment, despite its structured approach, may introduce some subjectivity in evaluating certain dimensions, particularly those related to visual design and user interface elements. Since different evaluators might interpret design quality and usability differently, reliability analyses suggest the need for refining the checklist to improve rater consistency. Future research should consider increasing the number of items or revising the existing ones to enhance the tool's reliability and ensure more robust and accurate evaluations.

6. CONCLUSION

This study represents a foundational effort in examining the user experience and digital adoption challenges of local e-government services in Greece, focusing on municipal websites. The findings reveal significant shortcomings across all dimensions of user experience, particularly in Technical Performance and Missing Features, which are critical to fostering user acceptance and engagement. Despite some strengths in areas like Navigation & Task Orientation, the overall low scores indicate that fundamental usability principles are not adequately applied. To bridge these gaps and foster e-democracy, there is a clear need for a comprehensive redesign of these digital platforms, ensuring they meet the diverse needs of citizens. Future research should explore these issues across all Greek municipalities to provide

a more detailed understanding of the broader landscape and to guide the development of more user-centric e-government services. Addressing these issues will be vital for achieving greater digital penetration, enhancing citizen engagement, and supporting the democratic process in the digital age.

7. APPENDIX

Table 16. UX Audit Assessment. Adapted Questions per Dimension

Navigation & Task Orientation	Page Layout & Visual Design	Missing Features	Technical Performance	Trust & Credibility
There is a convenient and obvious way to move between related pages and sections and it is easy to return to the home page	Excessive use of text, scripts, applets, movies, audio files, graphics and images has been avoided	The website includes a functional search bar that provides relevant results.	The user is warned about large, slow-loading pages (e.g. “Please wait...”), and the most important information appears first	The content is up-to-date, authoritative and trustworthy
The information that users are most likely to need is easy to navigate to from most pages	The layout helps focus attention on what to do next	The site provides essential contact information (email, phone, address) that is easily accessible and up-to-date.	The site can be used without scrolling horizontally (errors)	It is clear that there is a real governmental organisation behind the site (e.g. there is a physical address or a photo of the office)
Navigation choices are ordered in the most logical or task-oriented manner	Things that are clickable (like buttons) are obviously pressable and do not have characteristics that suggest that they are	The site offers a clear and functional feedback mechanism for users to report issues or provide suggestions.	The site uses a customised 404 page, which includes tips on how to find the missing page and links to “Home” and Search	The site avoids advertisements, especially pop-ups.
Navigation tabs are located at the top of the page, and look like clickable versions of real-world tabs	Fonts are used consistently and are readable (size, colors)	All forms and submission processes (e.g. contact forms) are operational and user-friendly.	Pages load quickly (5 seconds or less)	It is easy to contact someone for assistance and a reply is received quickly

Category labels accurately describe the information in the category	There is a good balance between information density and use of white space	The site offers accessible help or FAQ sections to assist users with common issues.	The site provides immediate feedback on user input or actions	The content is fresh: it is updated frequently and the site includes recent content
The terms used for navigation items and hypertext links are unambiguous and jargon-free	The site avoids extensive use of upper case text	The site ensures all forms of processes (e.g., accessing PDFs, financial info etc.) are operational and user-friendly.	The site keeps users informed about unavoidable delays in the site's response time (e.g. when opening a heavy file, i.e. municipality's financial statements)	The site is free of typographic errors and spelling mistakes
Hypertext links that invoke actions (e.g. downloads, new windows) are clearly distinguished from hypertext links that load another page	Graphics will not be confused with banner ads	The site supports multiple languages, allowing users to switch between different languages seamlessly.	The site provides good feedback (e.g. progress indicators or messages) when needed	The visual design complements the status of the municipality and any offline communication messages
The number of screens required per task has been minimised (2-5 clicks)	Colour is used to structure and group items on the page	The site includes social media links that are functional, allowing users to connect with the website on various platforms.	User confirmation is required before carrying out potentially "dangerous" actions (e.g. deleting something)	There are real people behind the organisation and they are honest and trustworthy (look for bios)
Users of the site do not need to remember information from place to place	Attention-attracting features (such as animation, bold colours and size differentials) are used sparingly and only where relevant	The site offers downloadable resources (e.g., PDFs, documents) that are up-to-date and relevant.	The site provides good system feedback (e.g. success/error messages)	The search results page does not show duplicate results (either perceived duplicates or actual duplicates)

Chapter 3

How Usable Are Greek Municipal Digital Platforms at Scale?

Assessing the User Experience of Greek Municipal Digital Platforms:
A Large-Scale Systematic Evaluation

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Abstract

This study investigates the digital presence and User Experience of local government websites in Greece, challenging the widespread assumption that low e-Government adoption is primarily due to citizens' digital illiteracy. Instead, it explores whether usability and design limitations serve as key barriers. Employing a mixed-methods approach, the research combines a qualitative survey with 26 participants, focusing on citizens' perceptions, emotional responses, and expectations, with a large-scale UX Audit of 138 municipal websites. The audit, based on a customized evaluation framework, assessed nine usability dimensions including navigation, content quality, accessibility, and interactivity. Findings reveal widespread inconsistencies in interface design, non-functional features (e.g., search, forms), and limited multilingual support, resulting in low overall performance. Survey participants expressed frustration, disengagement, and low trust toward their local governments' digital presence, despite increased digital maturity. Striking regional disparities were also observed, pointing to fragmented design practices and a lack of centralized digital governance. This systemic disconnect between citizens and public digital platforms highlights the urgent need for national-level standards and inclusive service design strategies. Improving usability, accessibility, and relevance of municipal websites is not only a matter of efficiency but also of democratic participation and digital equity.

Keywords: citizens' experience, municipal websites, user experience, digital inclusion, public service design

INTRODUCTION

The relationship between digital governance and civic engagement has become increasingly central in the era of public sector digitization. As local governments strive to modernize their services and improve accessibility, municipal websites are emerging as critical tools for fostering transparency, participation, and trust. Yet, the effectiveness of these digital platforms in supporting meaningful citizen interaction remains an open question.

To begin with, e-democracy as a general concept lacks a single, universally agreed-upon definition, as highlighted by Coleman and Norris (2005). Various interpretations have since attempted to frame it within the broader context of digital interaction between citizens and government institutions (i.e. Backus, 2001; Hacker and van Dijk, 2000). When it comes to local e-democracy specifically, the OECD (2020) defines it as the use of digital tools and online platforms by local governments to foster civic participation, promote transparency, and enhance collaboration between citizens and municipal authorities. It encompasses a range of practices, from providing access to public information to enabling digital consultations, feedback mechanisms, and online service delivery (Ali, 2023). In the context of municipalities, e-democracy initiatives can serve as enablers of democratic engagement by offering citizens opportunities to influence local decisions, report issues, or access essential services without physical presence (Rodríguez Bolívar, 2016). However, the effectiveness of such initiatives often depends on the design, usability, and relevance of the digital systems in place (Ali, 2023; Aichholzer and Rose, 2020, Mihova, 2019). Therefore, e-democracy at the local level is not only a matter of digital access, but also of meaningful interaction supported by functional and user-friendly digital environments.

User Experience (UX) in the context of municipal websites refers to the quality of users' interactions with local government digital services, including aspects such as usability, accessibility, task efficiency, trustworthiness, and emotional response (Goldsmith, 2018). Good UX design in e-overnment platforms ensures that users can easily navigate content, complete tasks efficiently, and feel confident and satisfied throughout their digital journey (Almarashdeh and Alsmadi, 2016; Alshamsi et al., 2016; Galvez and Youngblood, 2016). Inadequate UX, on the other hand, can create barriers to access and frustrate users, leading to disengagement from public digital services altogether (Bataineh et al., 2017; Galvez and Youngblood, 2016; Huang and Benyoucef, 2014). Since municipal websites act as key gateways for citizens' interaction with their local governments, their design quality directly influences both user adoption and trust in public administration (Jun et al., 2014; Voutinioti, 2013; Scott, 2006). In this light, evaluating the UX of such platforms becomes critical to

understanding how well they support citizens' needs and promote broader goals of digital inclusion and democratic participation (Abdurahman, 2022).

Previous studies on digital governance have primarily emphasized top-down implementations of e-Government platforms and the technical preparedness of public administrations (Balaji, 2025; Milacovich, 2021; Mergel et al., 2019; Cordella and Tempini, 2015; Dunleavy, 2005). However, the actual effects of these initiatives on public sector transformation remain contested (Baldwin et al., 2012; Kuhlmann and Bogumil, 2021; Nicholls, 2019). While the literature acknowledges the potential of digitalization to reshape governance processes, further empirical research is needed to uncover the mechanisms and sources of institutional change (Mahoney and Thelen, 2009), as well as its implications for organizational dynamics and performance outcomes.

In the Greek context, attention has often centered on barriers to adoption such as digital illiteracy, outdated infrastructures, and fragmented service delivery (Anastasopoulou et al., 2025; Chairistanidis and Rusu, 2024; Chourmouziadis, 2024; EC, 2020; Choudrie et al., 2018; Katsikas and Gritzalis, 2017). More recently, the discourse has shifted toward examining the maturity level of digital platforms (Patergiannaki and Pollalis 2024), as well as the overall quality of governmental municipal websites (Georgios and Nikolaos, 2021; Patergiannaki, 2023; Patergiannaki and Pollalis, 2022; 2021). These studies question the ongoing relevance of these systems to user needs (Patergiannaki and Pollalis, 2022) and emphasize the role of trust (Papadopoulou et al., 2010), in enabling user adoption. While several contributions have assessed the progress of central government platforms like gov.gr (Dimitreloy and Fouskas, 2023; Spinellis et al., 2022), the evaluation of local government websites, namely the municipal websites, particularly through the lens of user experience (UX), remains limited and fragmented.

Notably, a small number of technical audits have surfaced deficiencies in web performance, accessibility, and service availability across selected Greek municipalities (Panayiotou and Stavrou, 2019; Chatzopoulos, 2009, Patergiannaki et al., 2020). However, few studies have approached this issue through a comprehensive, citizen-centered framework that examines how design, usability, and content influence user trust and platform adoption at the local level (Tsatsani and Pollalis, 2024). Moreover, there is a marked absence of research that integrates qualitative citizen feedback with structured usability assessments across a broad regional sample. This has resulted in an incomplete understanding of the structural and experiential barriers that hinder engagement with municipal platforms.

Study Innovation

This study represents the first large-scale empirical investigation into the usability and User Experience (UX) of Greek municipal websites, employing a dual-method approach. It combines a citizen survey, designed to capture users' perceptions, expectations, and difficulties, with a customized UX Audit grounded in a tailored adaptation of David Travis's "Experts' Review Checkpoint List" (2014) for e-Government platforms. Applied to 138 municipalities, this framework moves beyond previous research that primarily emphasized technical or institutional barriers, drawing attention instead to the critical impact of design quality and functional relevance in either enabling or hindering local e-democracy. In doing so, the study introduces a replicable UX Audit tool that can be used for ongoing evaluations of public-sector digital services. To the best of our knowledge, this is the most extensive citizen-oriented UX assessment of local e-Government services in Greece to date, offering diagnostic insights alongside actionable recommendations for policy development, service design, and public administration.

LITERATURE REVIEW

1.1 Importance of Municipal Websites for Citizen Interaction & Participation

Municipal websites serve as the primary digital interface between local governments and citizens, playing a central role in enabling everyday interactions, delivering public services, and promoting civic participation. In democratic societies, especially within the framework of e-democracy, these websites are not merely administrative tools but essential infrastructures for ensuring transparency, accountability, and inclusiveness at the local level. Through municipal portals, citizens can access critical information, such as council decisions, budgets, and local initiatives, while also completing key administrative tasks—from submitting forms and paying fees to booking appointments and filing requests. More importantly, well-designed municipal websites can act as participatory channels, offering features like e-consultations, surveys, or feedback mechanisms that allow residents to voice their opinions and co-shape local decision-making.

The strategic value of municipal websites has been further amplified by broader trends in digital governance, where local authorities are expected to act not only as service providers but also as facilitators of dialogue and community engagement. In rural or geographically isolated areas, such as remote islands or mountainous municipalities, digital platforms may represent the only practical means of communication with local authorities, making their reliability and accessibility even more crucial. This function is especially vital in contexts with vulnerable populations (e.g., elderly citizens, migrants, or refugees), who may rely on digital

access to seek services, information, or social support. Thus, municipal websites are increasingly positioned as key determinants of digital inclusion and citizen empowerment. Their quality, usability, and relevance directly affect citizens' sense of connection to local governance, their ability to navigate bureaucratic processes, and their overall trust in institutional responsiveness.

However, the potential of municipal websites to foster participation and inclusion is contingent on the extent to which they are designed with citizens in mind. Without accessible navigation, clear content structures, and language options, these platforms risk reinforcing existing inequalities and excluding less digitally literate users. As such, the role of User Experience (UX) design becomes central, not only as a technical matter but as a democratic imperative. Inadequate design or the complete absence of municipal websites limits opportunities for interaction, undermines transparency, and distances citizens from the political and administrative life of their communities. Ensuring that these digital touchpoints are functional, inclusive, and participatory is therefore essential for advancing local e-democracy and strengthening citizen–municipality relations in the digital era.

1.2 Digital Transformation in Local Governance

The integration of Information and Communications Technology (ICT) in public administration has become central to contemporary efforts to modernize governance and enhance citizen engagement. Digital transformation in the public sector extends beyond technical infrastructure, encompassing institutional change, new governance models, and a reconfiguration of the citizen–state relationship. Within this context, e-empowerment refers to the use of digital technologies to enable citizens to participate more actively in public decision-making processes, strengthening democratic engagement and bottom-up influence (Wimmer, 2007; Macintosh, 2004).

The COVID-19 pandemic further accelerated the demand for digital public services, underscoring the importance of e-participation and collaborative governance infrastructures. In response, international and European institutions have developed frameworks to assess digital government performance. At the global level, the United Nations' E-Participation Index (EPI), part of the e-Government Development Index (EGDI), evaluates government support for e-information, e-consultation, and e-decision-making (UN, 2018). Greece has demonstrated notable progress in this area, improving its EPI ranking from 65th in 2016 to 34th in 2018, with gains across all participation dimensions (Costopoulou et al., 2021; UN, 2016; 2014).

At the European level, digital government performance is assessed through the lens of User Centricity, which includes online availability, usability, mobile-friendliness, and user support (EC, 2021; 2020). Although Greece has improved substantially in usability and mobile optimization, reaching 93% usability and a 15% increase in mobile-friendliness between 2016 and 2019, it continues to face challenges in service availability and digitization consistency. As a result, Greece has been classified as a “Non-Consolidated” and later “Unexploited” e-government country, reflecting persistent structural gaps despite increased digital penetration (EC, 2021; 2020).

This apparent paradox, namely the high infrastructure penetration combined with limited service maturity, highlights the need to shift analytical focus from connectivity to service design, usability, and functional relevance. Consequently, research attention has increasingly turned toward the evaluation of digital service maturity, particularly at the local government level. Maturity models emphasize strategic alignment, interactivity, and responsiveness to citizen needs; however, Greek municipalities remain at uneven and often early stages of digital maturity, with limited service scope and weak alignment with user expectations (Patergiannaki & Pollalis, 2024).

To address local-level assessment challenges, instruments such as the United Nations’ Local Online Service Index (LOSI) have been introduced to evaluate municipal digital services while accounting for contextual variation (UN, 2018). Nevertheless, the applicability and consistency of LOSI across diverse local systems remain under discussion, suggesting the need for complementary evaluation approaches (Steinbach et al., 2019).

Empirical research at the municipal level in Greece further confirms these maturity gaps. Using the Citizen Web Empowerment Index (CWEI), Costopoulou et al. (2021) identified limited but emerging e-participation practices, primarily concentrated on e-information rather than interactive engagement. Similarly, Ntaliani et al. (2017) reported underdeveloped adoption of mobile technologies for civic engagement across Greek municipalities, emphasizing the absence of coherent implementation strategies.

A consistent finding across studies is the growing disparity between national and local digital platforms. While national portals such as gov.gr have advanced rapidly in usability, interactivity, and service coverage (Alexopoulos et al., 2018; Costopoulou et al., 2017), municipal websites largely remain informational and one-directional, offering limited interactive features such as online forms, feedback mechanisms, or participatory tools (Lappas et al., 2015). Despite selective ICT upgrades at the municipal level, progress in critical service

domains and participatory functionalities remains fragmented, resulting in low overall digital maturity (Alexopoulos et al., 2018).

These structural and experiential gaps underscore the importance of incorporating users' perspectives into the evaluation of municipal digital platforms. Understanding how citizens perceive the usability, relevance, and participatory potential of local e-Government services is essential for informing strategic service design and increasing adoption (Costopoulou et al., 2021; Lappas et al., 2015).

Based on these insights, the following hypothesis guides the present study:

H1. Despite national progress in digital transformation, citizens perceive local municipal websites as insufficiently developed to address their service needs or support meaningful e-participation.

1.3 User Experience in Governmental Websites

Usability is a multidimensional concept that encompasses both technical effectiveness and human-centered interaction. It refers not only to how efficiently a system performs its intended functions, but also to how intuitive, clear, and meaningful the overall User Experience is (Hartson and Pyla, 2012; Albert and Tullis, 2017; Bevan, 2008). Core usability dimensions include navigation, content accessibility, and information architecture, alongside perceptual and experiential elements such as aesthetics, clarity, trustworthiness, and emotional satisfaction (Hassenzahl & Tractinsky, 2006; Hassenzahl & Ullrich, 2007).

Within e-government contexts, usability and learnability are inherently interconnected. Citizens must not only complete tasks successfully but also understand the system's logic, navigate services efficiently, and trust the information provided. Greece is positioned within the "Unexploited eGov" quadrant of the European benchmark, characterized by medium digital penetration but low service digitalization. This imbalance suggests that although digital services are accessible, shortcomings in design quality and usability hinder sustained user engagement and adoption.

Prior research consistently demonstrates that usability deficiencies undermine the effectiveness of digital governance. Navigation and information architecture are frequently identified as critical pain points, with poor structure contributing to increased abandonment rates and reduced trust (Sönmez et al., 2024). Similarly, interface clarity, content transparency, and trust-supporting design cues are central to user satisfaction, while technical errors and incomplete information further diminish system reliability (Elshan et al., 2022; Van Riel et al., 2001).

These challenges are particularly salient at the municipal level, where citizens often seek rapid access to localized services and essential information. Vasilikopoulou (2017), examining Greek e-government services, identified three persistent barriers: the absence of a unified portal, unclear service-related information, and misalignment between online interfaces and offline administrative procedures. These findings align closely with the present study's UX Audit, which evaluates municipal websites across dimensions such as Navigation, Page Layout, and Task Orientation.

User-centered design has therefore been widely proposed as the primary strategy for improving e-Government adoption. Contrary to earlier assumptions emphasizing digital literacy or demographic factors, evidence suggests that system performance, specifically speed, visual clarity, and intuitive interaction, plays a more decisive role in acceptance and reuse (Fernandes et al., 2013; Tan et al., 2008). Citizens' willingness to engage with digital public services depends predominantly on usability rather than individual characteristics (Tsatsani & Pollalis, 2024).

Consequently, the systematic evaluation of interface design, content quality, navigational clarity, and technical reliability constitutes a foundational pillar of effective e-Government strategy. When these elements are adequately addressed, municipal websites can function not only as service delivery portals but also as mechanisms for trust-building, transparency, and democratic participation. These insights lead to the formulation of the following hypothesis:

H2. Municipal websites that demonstrate higher usability, reflected in effective navigation, intuitive layout, relevant content, and technical reliability, are more likely to be perceived by citizens as trustworthy and satisfactory.

1.4 Existing Studies on Greek Municipal Websites

Over the past decade, a growing body of academic and institutional research has examined the digital presence and performance of Greek municipalities, consistently identifying structural limitations in usability, content quality, and interactivity. A recurring finding is that municipal websites predominantly operate as static information repositories rather than dynamic platforms supporting e-services or citizen participation (Ntaliani et al., 2017; Lappas et al., 2015).

Lappas et al. (2015), in an analysis of 52 municipal websites, reported limited use of interactive tools, shallow content depth, and minimal support for citizen engagement. Essential features such as online forms, feedback mechanisms, and multilingual support were largely

absent. Similarly, Ntaliani et al. (2017) found that mobile access and mobile-oriented service design remained underdeveloped, reflecting weak strategic planning and limited responsiveness to evolving user needs.

A pilot study presented by Patergiannaki et al. (2020) evaluated 10 municipal websites using a combination of automated performance metrics and user-centered heuristic evaluation. Employing tools such as Lighthouse alongside Nielsen's usability principles, the study identified persistent issues in accessibility, navigation, and trust-related design elements. Navigation and information architecture emerged as the most problematic dimensions (19%), followed by page layout and visual design (14%) and performance-related errors (14%), indicating that usability shortcomings—rather than infrastructure alone—significantly constrain user satisfaction.

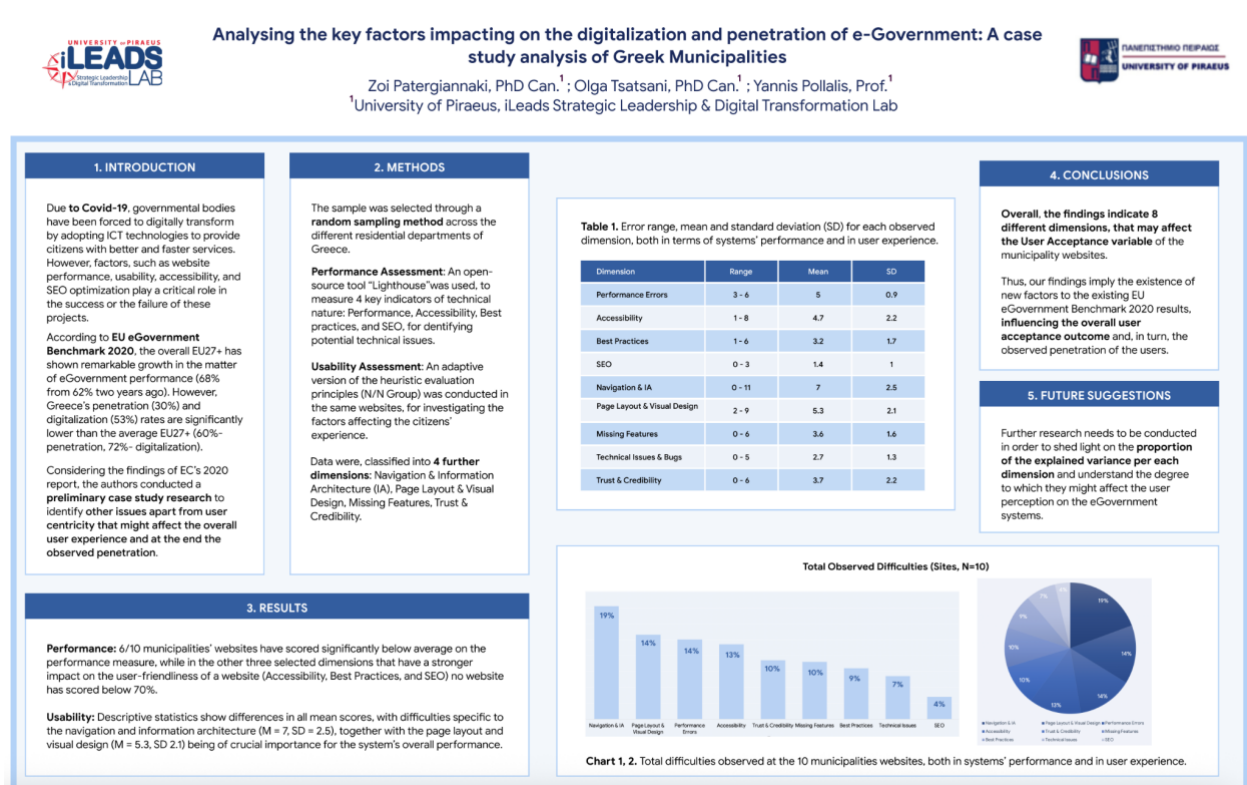
Building on these findings, Tsatsani and Pollalis (2024) conducted a follow-up study applying an Adapted UX Audit to the same set of municipalities. This approach integrated selected elements from David Travis's (2014) Expert Review Checkpoint List with UX research principles and performance metrics, constituting the first holistic User Experience evaluation of Greek municipal websites. Results revealed uniformly low UX performance, with no website exceeding a 55% overall score. Technical performance and feature completeness were particularly weak (<50%), with common deficiencies including the absence of multilingual options, help mechanisms, and feedback channels. These deficits extend beyond usability concerns, directly impacting trust, satisfaction, and opportunities for civic participation.

While national-level initiatives, such as the Citizen Web Empowerment Index (Costopoulou et al., 2021), have sought to assess transparency and citizen-oriented digital services, their scope remains limited and does not fully capture experiential usability dimensions. In contrast, the national platform gov.gr has evolved into a benchmark for integrated and user-friendly digital service provision. Municipal websites, however, continue to exhibit fragmented quality in navigation, content structure, and interface design, reinforcing a digital divide between national and local governance platforms (Alexopoulos et al., 2018).

Taken together, the accumulated evidence highlights persistent disparities in design quality, interactivity, and content relevance across Greek municipalities. These shortcomings motivate the following hypothesis:

H3. Despite infrastructure improvements, persistent usability issues in municipal websites—particularly in navigation, interactivity, and content relevance—limit user engagement

Figure 1. Summary of UX and technical findings from the poster presentation at the International Conference on e-Government and e-Justice, Amsterdam, 2020. (Patergiannaki et al., 2020)



Addressing this methodological and empirical gap, the present study constitutes the first large-scale UX usability assessment of Greek municipal websites, employing a standardized, multidimensional audit framework across 138 local government platforms. This approach enables systematic Benchmarking of UX quality, reveals regional inequalities in digital service delivery, and contributes a citizen-centered perspective to the advancement of local e-government services.

1.5 Study Objectives

The primary objective of this study is to investigate citizens' expectations, evaluate their experiences with municipal services, and assess the overall digital performance of municipal websites. This research incorporates two distinct analyses:

1. A qualitative survey exploring citizens' opinions, expectations, and pain points regarding their interactions with municipalities and their digital platforms;
2. An Adapted UX Audit of 138 Greek municipal websites, evaluating key usability dimensions such as Navigation, Task Orientation, Page Layout, Content Clarity, Trust, and technical reliability.

By synthesizing user perception with expert-led audits, the study aims to provide a comprehensive, data-driven understanding of the current state of local e-Government services in Greece and to offer actionable recommendations for improving their usability, accessibility, and citizen adoption.

METHODS

2.1 Study Design

This study employed a mixed-methods approach to provide a comprehensive evaluation of Greek municipal websites. The research combined qualitative data collection through a citizen survey with a systematic evaluation of website usability using an adapted UX Audit tool. The survey captured citizens' perspectives on the general effectiveness of their municipalities and their digital performance, focusing on their expectations, pain points, and prior experiences with municipal websites. This qualitative data provided valuable insights into user needs and satisfaction. Complementing this, the adapted UX Audit evaluated the User Experience of 138 municipal websites across Greece, representing a diverse sample of municipalities from different regions. The audit used a modified version of David Travis's "*Experts' Review Checkpoint List*" to assess key usability dimensions tailored to municipal services. This dual-method approach allowed for the integration of user feedback with objective usability metrics, ensuring a robust understanding of both the perceived and actual performance of municipal websites.

2.2 Survey

An online survey was conducted using Google Forms to gather insights into citizens' perspectives on Greek municipalities and their digital systems. The survey targeted a diverse sample and yielded 26 responses, focusing on two key domains: (a) citizens' perceptions of local government effectiveness and related service challenges, and (b) user perspectives on the digital performance of municipal websites. The survey was intentionally designed as a qualitative, exploratory component of the study, aiming to capture in-depth perceptions and experiential patterns rather than to provide statistically generalizable results.

The survey instrument included both closed- and open-ended questions. Quantitative data captured variables such as frequency of engagement, familiarity with municipal services, and evaluations of digital performance using a 5-point Likert scale (1 = very poor, 5 = excellent). Qualitative data allowed participants to freely express their expectations, satisfaction levels, and perceived service deficiencies.

Data analysis followed a mixed approach. First, quantitative data were cleaned and processed in Excel to calculate descriptive statistics (means, standard deviations, frequencies), enabling a basic summary of user familiarity and perceived performance. For the open-ended responses, a six-step thematic analysis procedure was applied based on the framework by Braun and Clarke (2006). This involved familiarization with the responses, generation of initial codes, grouping of codes into broader categories, iterative review and refinement of themes, definition and labeling of thematic constructs, and quantification of thematic frequency. Coding and organization were completed manually to ensure close engagement with the dataset. Participants' comments were ultimately categorized into themes such as general opinions, pain points, expectations, past experiences, emotional responses, and proposed website improvements.

This combined analytical process enabled both a structured quantitative overview and a deeper understanding of subjective citizen experiences. Overall, this phase of the study provides a user-centered lens through which to identify actionable insights for improving municipal digital services in Greece.

2.3 UX Audit Assessment

2.3.1 Original Expert Review Checkpoint List

The UX Audit tool used in this study is an adapted version of David Travis's "*Experts' Review Checkpoint List*" (2014), originally developed for e-commerce websites. The original checklist evaluates websites across nine dimensions: Homepage, Task Orientation, Navigation & Information Architecture, Forms & Data Entry, Trust & Credibility, Page Layout & Visual Design, Writing & Content Quality, Search, and Help, Feedback, Error Tolerance (Table 1). These dimensions include 247 individual statements that UX Experts can rate on a scale of -1, 0, or 1 based on the extent to which each statement is satisfied. The resulting scores are aggregated to provide an overall evaluation of a website's User Experience.

Table 1. Original Checkpoint List Framework with Dimensions and Corresponding Number of Statements (Travis, 2014)

Checkpoint List Dimensions	Number of Statements
Homepage	20
Task Orientation	44
Navigation & Information Architecture	29
Forms & Data Entry	23
Trust & Credibility	13
Page Layout & Visual Design	23
Writing & Content Quality	38
Search	20
Help, Feedback, Error Tolerance	37
Total	247

2.3.2 Adapted UX Audit – Framework

To tailor this tool to the specific context of municipal websites, the statements within each dimension were systematically reviewed and adapted. This adaptation ensured that the evaluation criteria were appropriate for municipal services, content, and user needs, diverging from the original e-commerce orientation. The process resulted in the removal, modification, or retention of specific statements within each dimension, guided by expert input to ensure content validity and maintain the theoretical integrity of the framework. The final adapted UX Audit checklist comprised nine dimensions with 216 total statements, reduced from the original 247, reflecting a more focused application for municipal websites (Table 2).

Table 2. Adapted UX Audit tool with Dimensions and Corresponding Number of Statements

Checkpoint List Dimensions	Number of Statements
Homepage	19
Task Orientation	33
Navigation & Information Architecture	24
Forms & Data Entry	21
Trust & Credibility	10
Page Layout & Visual Design	19
Writing & Content Quality	37
Search	19
Help, Feedback, Error Tolerance	34

Total	216
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The adaptation process ensured that the tool accurately captured the unique challenges and functionalities of municipal websites. For instance, statements originally related to product categories or purchasing workflows were modified to address municipal service categories and public administration processes. Similarly, statements regarding “checkout” and “shopping cart” were replaced with criteria relevant to forms, task completion, and government transparency. This careful adjustment provided a contextually relevant and reliable instrument to evaluate the performance of 138 municipalities out of the 336 total in Greece, making this study the first large-scale UX Audit of Greek municipal websites.

The following examples illustrate the adaptation process across key dimensions:

- **Homepage:** Adaptations included replacing statements like *“Product categories are provided and clearly visible on the homepage”* with *“municipality services’ categories are provided and clearly visible on the homepage.”* Similarly, statements focused on e-commerce value propositions and corporate information were reframed to emphasize municipal information and transparency.
- **Task Orientation:** Several statements were removed due to irrelevance, such as those addressing pricing, shopping carts, or transaction workflows. Adapted examples include reframing *“The critical path (e.g. purchase, subscription) is clear, with no distractions on route”* to *“Critical paths (e.g. locate municipality services) are clear, with no distractions on route.”*
- **Navigation & Information Architecture:** Irrelevant criteria, such as the presence of site maps for product navigation, were removed while maintaining emphasis on effective and intuitive navigation for municipal content.
- **Trust & Credibility:** Statements emphasizing branding and marketing were reframed to address governmental transparency, e.g., *“The site’s privacy policy is easy to find”* was adapted to *“The site’s transparency policy (e.g., financial statements) is easy to find.”*
- **Writing & Content Quality:** Removed e-commerce-specific statements like *“Product pages contain the detail necessary to make a purchase”* and adapted others to emphasize municipal language clarity and accessibility.

- **Help, Feedback, Error Tolerance:** Statements related to e-commerce transactions were replaced with criteria relevant to municipal systems, such as feedback on page loading delays or navigation across multi-page forms.

This rigorous adaptation process preserved the theoretical robustness of the original framework while aligning the criteria with the distinct requirements of municipal websites.

Overall, beyond technical adjustments, the adapted UX Audit departs from the original e-commerce-oriented checklist by shifting the evaluative focus toward citizen-centric tasks, informational transparency, and public-service orientation. The tool emphasizes task discoverability, clarity of municipal services, and trust-related cues, reflecting the distinct goals and constraints of public sector digital platforms.

2.3.3 Methodology for Comparative Analysis of Municipal Website Performance

To assess the performance of municipal websites across regions, the analysis was conducted in three stages: (1) comparison of overall municipality scores by region, (2) identification of strengths and weaknesses across usability dimensions for each region, and (3) ranking of dimensions to highlight key usability issues for all investigated municipalities.

2.3.3.1 Comparison of Overall Municipality Scores by Region

A one-way Analysis of Variance (ANOVA) was conducted to evaluate whether the overall municipality usability scores differed significantly across regions. Since the sample sizes of municipalities varied between regions, Welch’s ANOVA was used to account for potential heterogeneity in variances. Post-hoc tests, specifically Games-Howell, were performed to identify which regions exhibited significant differences in usability scores. The results provided insights into regional disparities in digital performance and guided recommendations for targeted interventions.

2.3.3.2 Regional Analysis of Usability Dimensions

To explore regional strengths and weaknesses, descriptive statistics, including mean, median, and standard deviation, were calculated for each usability dimension (e.g., Home, Navigation & IA, Form & Data Entry) across regions. Dimension scores were ranked within each region to identify key areas of excellence and concern. For example, regions with low scores in “Home” were noted to have challenges with Homepage design and functionality, while regions scoring well in “Trust & Credibility” demonstrated stronger digital reliability and user trust. Visualization tools such as heatmaps and stacked bar charts were employed to communicate findings effectively.

2.3.3.3 Ranking Dimensions Across Greek Municipalities

To identify the most critical usability issues across all municipalities, the mean scores for each dimension were calculated and ranked in ascending order. A repeated-measures ANOVA was used to test whether the differences in mean scores between dimensions were statistically significant, further confirming the areas requiring the most urgent attention. This analysis revealed systemic issues affecting all regions, such as low scores in “Home” and “Page Layout & Visual Design,” highlighting the need for targeted improvements in these areas.

2.4 Sampling and Data Collection

The sampling process for the adapted UX Audit was designed to evaluate a representative subset of Greek municipal websites across different regions. Out of the 332 municipalities in Greece, 138 were randomly selected to ensure geographical and administrative diversity. Nine of these were excluded from the final analysis due to technical inaccessibility (e.g., non-functioning websites, redirection to Facebook pages, or absence of a secure domain). The goal was to maintain a feasible yet comprehensive sample that could offer meaningful insights across various regional contexts.

In terms of regional distribution, the Attica Region accounted for 33 evaluated municipalities out of 66. From the Thessaly and Central Greece Region, 3 out of 49 municipalities were included. Similarly, 3 municipalities were sampled from the Epirus and Western Macedonia Region, which comprises 31 municipalities in total. The Peloponnese, Western Greece, and Ionian Region was represented by 27 evaluated municipalities out of 31, while the Aegean Region contributed 23 out of 45. In the island of Crete, 15 municipalities were assessed out of a total of 24. Lastly, from the Macedonia and Thrace Region, 11 municipalities were included out of 60.

Overall, this resulted in a final analyzed sample of 129 municipalities, which corresponds to approximately 39% of the total municipalities in the country (see Table 3). This sample ensured the inclusion of municipalities from all major Greek administrative regions, allowing for a well-rounded and regionally diverse evaluation of website usability and performance. The adapted UX Audit tool was subsequently applied to these websites to systematically assess their User Experience across standardized criteria.

Table 3. Distribution of Greek Regions with Total Municipalities, Sampled Municipalities, and Corresponding Sampling Percentages.

Administrative Region	Total Municipalities	Sampled Municipalities	Percentage Sampled
Attica	66	33	50%
Thessaly – Central Greece	49	3	6%
Epirus – Western Macedonia	31	3	10%
Peloponnese – Western Greece & Ionian	31	27	87%
Aegean	45	23	51%
Crete	24	15	62%
Macedonia – Thrace	60	11	18%
Total	332	129	39%

The total sample represents approximately **39% of all municipalities** in Greece, providing a substantial subset for evaluation. This sampling approach ensured that municipalities from all major Greek regions were included, allowing for a comprehensive evaluation of website performance across the country. The evaluation of these websites was carried out using the adapted UX Audit tool, providing insights into the User Experience of a significant portion of municipal websites.

RESULTS

3.1 Survey

To better understand citizens’ awareness and perceptions regarding municipal services, a qualitative survey was conducted with 26 participants between 2021 and 2023. Thematic analysis was employed to synthesize responses related to prior interactions with municipalities and evaluate users’ familiarity with and impressions of these services.

3.1.1 Sample Characteristics

The sample consisted of 26 participants, 73% of whom were women and 27% men. The majority were between 30–39 years old (42.3%), followed by 18–29 (26.9%) and 40–49 (19.2%). Participants came from diverse employment backgrounds, with 34.6% working in the private sector, 19.2% being self-employed, and 15.4% unemployed. Regarding their residential history, 34.6% had lived in three different municipalities throughout their lives.

3.2 Citizen Experience with Local Municipalities

3.2.1 User Familiarity & Citizen's Past Experience with Municipal Services

Participants were asked to indicate how familiar they felt with the services provided by their municipality and to evaluate their overall past experience interacting with municipal services. These questions aimed to contextualize their current opinions and emotional responses toward local government services and digital tools.

On a 5-point Likert scale (1 = “Not at all familiar”, 5 = “Very familiar”), participants reported relatively low familiarity ($M = 1.69$, $SD = 0.84$). No one rated their familiarity above 3. When evaluating the quality of their past municipal interactions, the average score was moderate ($M = 2.85$, $SD = 1.16$), suggesting mixed or limited satisfaction with their experiences. These findings are summarized in Table 4.

Table 4. Descriptive statistics of the users' familiarity and overall experience

	Mean	SD	Min	Max
User Familiarity	1.69	0.84	1.0	3.0
Overall Experience	2.85	1.16	1.0	4.0

In addition to rating their experience, participants were invited to describe past forms of engagement with their local municipalities. Thematic content analysis revealed six distinct types of municipal interactions (Table 5). The most frequently mentioned were **Administrative Services & Certificates** (23%), followed by **Infrastructure & Technical Services** (19%). Examples included document requests, road repair submissions, and contact with sanitation services. Notably, 15% of participants reported **no prior engagement** with their municipality.

Table 5. Thematic categorization of the reported reasons for citizens' past engagement with municipal services

Thematic Category	Description	Frequency	Percentage (%)
Administrative Services & Certificates	Requests for certificates, permits, records	6	23
Infrastructure & Technical Services	Road repairs, sanitation, green space maintenance	5	19
Cultural, Social & Athletic Programs	Summer camps, festivals, community events, school award ceremonies	4	15

Requests & Complaints	Appeals, service reports, use of digital platforms like Novoville	4	15
Non-engagement	No previous contact or interaction with municipality	4	15
Political Involvement & Representation	Civic participation, volunteering, local council candidacy	1	4

Finally, participants offered brief open-ended justifications about their past experiences, which were thematically categorized into seven types (Table 6). Most frequently mentioned were Delays & Low Responsiveness (23%) and Bureaucracy & Inefficiency (19%), indicating systemic obstacles in local public service delivery. Other themes reflected both positive and negative perceptions regarding service organization (19%), professionalism of staff (15%), and the ease of digital interaction.

Table 6. Citizens’ evaluations of previous municipal services

Thematic Category	Description	Frequency	Percentage (%)
Delays & Low Responsiveness	Unfulfilled requests, long wait times, lack of follow-up	6	23
Bureaucracy & Inefficiency	Overlapping responsibilities, excessive paperwork	5	19
General Disorganization	Procedural confusion, lack of clarity in communication	5	19
Politeness & Professionalism	Positive or negative behavior from municipal staff	4	15
Timely & Effective Service	Fast, well-organized and efficient response	3	11
Digital Convenience & Accessibility	Reflections on ease or difficulty using online platforms	3	11
Negative Emotional Reactions	Expressions of frustration, fatigue, or disappointment	3	11

3.2.2 Reported Current Pain Points with Municipalities

Participants were invited to share any pressing issues they currently face in their municipality. Thematic content analysis of the open-ended responses revealed nine distinct problem areas (Table 7).

The most frequently reported issue concerned waste management and public cleanliness (23%), including recurring complaints about poor sanitation services, irregular garbage collection, and inadequate recycling practices. A second cluster of concerns related to digital and User Experience barriers (19%), with participants describing outdated municipal websites, overloaded page layouts, and confusing navigation. Another 12% cited inadequate website structure and infrequent updates, while others expressed frustration with bureaucratic inefficiencies and slow administrative processes (12%). Infrastructure-related grievances, such as damaged roads, poor signage, or insufficient maintenance, also accounted for 12% of responses. Less frequent but notable issues included lack of transparency and responsiveness from municipal officials (8%), urban congestion and traffic disruptions (8%), and isolated mentions of safety concerns, public document inaccessibility, and deterioration of public services.

These insights reflect a combination of operational, infrastructural, and digital pain points that affect both the physical and virtual engagement citizens have with their municipalities.

Table 7. Thematic categorization of citizen-reported current pain points regarding their municipality

Thematic Category	Description	Frequency	Percentage (%)
Waste Management & Cleanliness	Irregular garbage collection, lack of recycling, unsanitary streets	6	23
Digital Interface & UX Issues	Outdated websites, confusing layout, poor usability	5	19
Lack of Website Organization & Updates	Messy content structure, infrequent information refresh	3	11
Bureaucratic Inefficiencies & Delays	Slow processes, excessive paperwork, lack of automation	3	11

Infrastructure Problems	Damaged roads, bad signage, insufficient urban maintenance	3	11
Lack of Transparency	Perceived political bias, unclear procedures, missing accountability	2	8
Traffic & Urban Management	Poor traffic planning, disturbances from construction or waste pickup	2	8
Safety & Public Space Maintenance	Unsafe public spaces, lighting or policing issues	1	4
Document Retrieval Limitations	Difficulty retrieving public documents online	1	4

3.3 Citizen Experience with Municipalities’ Digital Portals

3.3.1 Reasons for Visiting Municipalities’ Digital Portals

Participants were asked to reflect on their most recent experiences using their municipality’s digital platforms. The aim was to explore both the types of interactions that took place and the perceived quality of those interactions. Descriptive content analysis of the responses revealed five recurring themes of digital engagement (Table 8).

The most common reason for visiting municipal portals was information retrieval (30.8%), with citizens seeking administrative details, event announcements, or service availability. While some users were able to locate the information they needed, others encountered outdated or incomplete content. Another 26.9% of participants described successful task completion, reporting positive experiences related to form submissions, service applications, or document downloads. At the same time, usability and accessibility barriers (19.2%) were frequently mentioned, including non-intuitive design, visual clutter, and navigation issues. A smaller percentage (15.4%) expressed emotional reactions, ranging from satisfaction and pride to confusion or frustration. Finally, 7.7% of users shared specific use cases such as registering for summer activities, submitting objections, or reviewing municipal council decisions—demonstrating the breadth of user needs beyond administrative basics.

These findings underscore the dual role of municipal websites as both functional tools and experiential touchpoints. Usability, content clarity, and emotional resonance shape how citizens interact with and perceive their municipality’s digital presence.

Table 8: Thematic categorization of citizens' reasons for visiting municipal websites

Thematic Category	Description	Frequency	Percentage (%)
Informational Retrieval	Accessing services, event listings, procedures	8	31
Successful Task Completion	Smooth interaction, form submission, service application	7	27
Usability & Accessibility Issues	Navigation problems, visual overload, layout difficulties	5	19
Emotional Responses	Satisfaction, confusion, frustration, indifference	4	15
Specific Use Cases	Unique actions like objections, council info, or summer registration	2	8

3.3.2 Digital Performance Rating

Participants were invited to justify their ratings by briefly describing their experience with the digital services offered by their municipality. They rated their municipality's digital performance using a 5-point Likert scale (1 = "Very Poor", 5 = "Very Good"). Descriptive statistics revealed a modest overall evaluation ($M = 2.65$, $SD = 1.06$), with ratings ranging from 1 to 5. Most participants provided neutral to moderately positive ratings (3 or 4), while fewer respondents selected extreme values. These results suggest that while some users found municipal websites functional, overall perceptions of quality, usability, and utility remain mixed (Table 9).

Table 9. Descriptive statistics for digital performance rating

	Mean	SD	Min	Max
Digital Performance	2.65	1.06	1	5

Thematic content analysis of participants' open-ended justifications revealed six recurring experience-related themes (Table 10).

The most frequently cited issue (23.1%) concerned outdated or ineffective User Experiences, with participants describing poorly designed websites, overloaded interfaces, and hard-to-navigate structures. Another 19.2% of participants emphasized a lack of core

functionality, such as missing forms, service submission tools, or integration with digital platforms. Approximately 15.4% reported dissatisfaction with information overload or poor structure, citing difficulty locating content or a disorganized layout. In contrast, 15.4% of respondents reported positive experiences, including ease of use, fast service, or access to useful resources. Other themes included disinterest or low engagement with the portal (11.5%), often due to unfamiliarity or perceived irrelevance, and frustration with politicized or promotional content (11.5%) that replaced service information with mayoral campaigns or outdated announcements.

These findings underscore varying levels of satisfaction with municipal digital platforms, highlighting opportunities for structural, functional, and content-level improvements.

Table 10. Thematic categorization of reasons behind citizens’ digital performance ratings

Thematic Category	Description	Frequency	Percentage (%)
Outdated or Ineffective User Experience	Poor usability, old design, difficult navigation	6	23
Lack of Functionality & Digital Integration	Missing tools (e.g., complaints, applications, automation)	5	19
Poor Information Architecture / Overload	Too much information, poor structure, hard to find content	4	15
Positive Digital Experience	Helpful, timely, and efficient interactions	4	15
Limited Use / Low Engagement	Lack of use, irrelevance, uncertainty about services	3	11
Politicized or Promotional Content	Use of website for political communication rather than services	3	11

3.3.3 Emotional Responses during past Interactions with Municipal Websites

Participants described a wide spectrum of emotional responses resulting from their interactions with their municipality’s digital platforms. These emotions provide insight into both the perceived usability and the emotional tone of the digital experience. Thematic content analysis revealed five distinct emotional categories (Table 11).

The most frequently reported cluster was **confusion, doubt, and uncertainty** (29%), associated with disorientation, ambiguous navigation, and unclear service descriptions. **Frustration** (18%) followed closely, often linked to poor interface design, limited interactivity, and perceived misuse of the platform for non-service-related messaging. Another 15% of participants described **mental fatigue**, often due to overloaded pages, outdated content, or the absence of efficient pathways for task completion. On the positive side, **satisfaction, joy, and safety** were cited by 21% of respondents—typically in cases of successful task completion or clear information discovery. Lastly, 12% expressed a sense of **autonomy**, appreciating the ability to independently complete tasks through the website.

These emotional insights underscore the importance of not only functionality and design, but also emotional resonance in shaping user perceptions of public digital services.

Table 11. Reported emotions following past interaction with municipal websites

Thematic Category	Description	Frequency	Percentage (%)
Doubt, Confusion, Uncertainty	Disorientation, unclear pathways, lack of trust or guidance	10	29
Satisfaction, Joy, Safety	Positive outcomes, successful task completion, sense of security	7	21
Frustration	Annoyance, dissatisfaction, or perceived inefficiency	6	18
Fatigue	Cognitive overload, difficulty maintaining focus or navigating	5	15
Autonomy	Ability to self-serve, complete actions independently	4	12

3.3.4 Website Capabilities Preferences

Participants were asked to indicate which features they would ideally like to access through their municipality's digital platform. Thematic categorization of their multiple-choice

responses revealed a clear prioritization of essential services and streamlined access points (Table 12).

The most commonly selected category was **Informational Access** (92.3%), with participants expressing a strong desire for clear, up-to-date information on local services, events, and announcements. This was closely followed by **Online Applications & Document Services** (88.5%) and **Downloadable Forms & Certificate Retrieval** (80.8%), reflecting a growing demand for digitized administrative procedures. Three additional categories—**Issue Reporting** (73.1%), **Financial Transactions** (73.1%), and **Online School Enrollments** (73.1%)—were equally prioritized, indicating that participants seek integrated, transactional capabilities on municipal portals. Lower, yet notable, preferences included **Waste Management Services** (61.5%) and **Direct Communication with Municipality** (57.7%). These responses highlight expectations for both operational clarity and citizen-to-administration feedback loops. Finally, a smaller cluster of responses (each under 4%) indicated interest in less commonly integrated features, such as **Parking Permit Management**, **Mental Health & Cultural Services**, and **Open Data or Civic Forums**.

These findings underscore a strong citizen preference for streamlined, efficient digital services that reduce administrative friction and support autonomous interaction.

Table 12. Preferred digital capabilities that citizens would like to be able to perform via their municipality’s website (N = 26). Participants could select multiple options.

Thematic Category	Description	Frequency	Percentage (%)
Informational Access	Local services, events, updates	24	92
Online Applications & Receipt of official Documents	Digital submission and receipt of certificates	23	88
Downloadable Forms & Document Retrieval	PDF forms, application materials	21	80
Online School Enrollments	Submitting complaints or technical problems	19	73
Financial Transactions (e.g. fine payments)	Payment of fines, taxes, or other financial obligations	19	73

Issue Reporting (e.g. damage declarations)	Enrolling children in schools or municipal educational services	19	73
Waste Management Services	Garbage schedules, recycling, and reporting sanitation issues	16	62
Contact with Municipality	Contact forms, staff directories, direct feedback channels	15	58
Parking Permit Management	Application and renewal of residential parking permits	1	4
Mental Health & Arts Services	Listings for wellbeing support or cultural engagement	1	4
Cultural Association Memberships	Joining or accessing info on community groups	1	4
Open Data & Civic Forum Access	Public data access, participatory forums for dialogue or voting	1	4

3.3.5 Functional Elements Preferences

Participants were asked to identify which functional elements they would ideally like to see integrated into their municipality's website interface. As summarized in Table 13, responses revealed a broad interest in interactive, user-friendly components that support information discovery and citizen autonomy.

The most frequently selected response was "Search Engine" (42.3%), highlighting users' need for quick and intuitive access to content. This was followed by a general preference for comprehensive design solutions, as 38.5% selected "All of the above", signaling a desire for well-rounded, multifunctional portals. Interactive Maps with Points of Interest (34.6%) and Multimedia (30.8%) were also frequently mentioned, indicating the importance of geographic orientation and visual content in enhancing engagement. Online Booking tools were selected by 26.9% of participants, reflecting expectations for transactional features typically found in modern digital services. Less frequently mentioned but still noteworthy were tools such as Contact Information (11.5%), Business Directories (7.7%), and features like Accessibility tools, Contact Forms, Live Chat, and Municipal Apps with Notifications (each at 3.8%).

These responses suggest emerging citizen expectations around inclusivity, real-time communication, and personalized experiences.

Table 13. Preferred functional features for Municipal websites. Participants could select multiple options.

Thematic Category		Frequency	Percentage (%)
Search Engine	Easy-to-use search engines to locate services and content	11	42
All of the above	All options, indicating a multifunctional digital platform	10	39
Interactive Maps	Maps with points of interest and location-based info	9	35
Multimedia Integration	Photos, videos to enhance content presentation	8	31
Online Booking Tools	Tools to schedule appointments or access services	7	27
Contact Information	Email, phone numbers for municipality, local businesses or departments	3	12
Business Directory	Listings of local companies and services	2	8
Accessibility	WCAG compliance, mobile support	1	4
Contact Forms	Online contact or request submission forms (e.g., complaint forms, drop-down service menus)	1	4
Live Chat	Real-time chat functionality for citizen support	1	4
App with Notifications	Dedicated municipal mobile app with real-time personalized notifications	1	4

3.3.6 Traveler-Oriented Information Preferences

Participants were asked to identify the types of information they would like to access when visiting the website of a municipality they are traveling to. Thematic categorization of responses revealed a clear preference for rich, visitor-oriented content (Table 14).

The majority of participants expressed interest in comprehensive coverage of all available categories (38%), including accommodation, local gastronomy, cultural events, transport schedules, and local products. This preference suggests a strong demand for unified, easy-to-navigate digital tourism portals hosted on municipal websites. Accommodation-related information was the second most commonly selected feature (31%), followed by equal interest in local activities (31%) and local products (31%). Other important categories included museums and cultural events (27%), transportation options (27%), and gastronomy (27%). Entertainment and leisure options were mentioned by 12% of respondents.

These insights reflect an opportunity for municipalities to evolve their digital presence not only as administrative service hubs but also as informative and appealing gateways for domestic tourism.

Table 15. Thematic categorization of traveler-oriented information preferences. Participants could select multiple options.

Thematic Category	Description	Frequency	Percentage (%)
All of the above	All options, indicating an all-in-one tourism content	10	39
Accommodation	Hotel info, short-stay options, booking links	8	31
Local Activities	Things to do, guided tours, outdoor and cultural activities	8	31
Local Products	Access to info about local food, crafts, and souvenirs	8	31
Museums & Cultural Events	Exhibitions, events, festivals, historical attractions	7	27

Transportation	Routes, timetables, and accessibility of local transit	7	27
Gastronomy	Local cuisine, dining options, food markets	7	27
Entertainment	Nightlife, live shows, and leisure options	3	11

3.3.7 Perceived Potential of Municipal Websites in Addressing Local Service Challenges

Participants were asked whether they believed municipal websites could assist in resolving ongoing problems they encounter with local government services. Thematic content analysis of their open-ended responses revealed six functional expectations (Table 16).

The most frequently mentioned benefit was improved guidance and navigation (26.9%), with participants emphasizing the need for intuitive website structures that explain available services and assist citizens in finding the correct actions. The second most common theme (23.1%) involved request and complaint management, where users desired tools for digitally submitting issues and receiving updates. A similar proportion of participants (19.2%) envisioned enhanced communication, including more consistent updates and direct contact with departments. Additionally, participants expressed the need for clear and accessible information (19.2%), such as service descriptions, forms, and structured menus. A smaller portion (7.7%) emphasized reduced bureaucracy and fewer physical visits, while 3.8% proposed expanded digital capabilities, including payment integration and multilingual support.

These findings underline citizens’ demand for digital services that prioritize usability, transparency, and functionality.

Table 16. Thematic categorization of how citizens believe municipal websites could help solve local challenges

Thematic Category	Description	Frequency	Percentage (%)
Guidance & Simplicity	Clear navigation, service explanation, user-centered architecture	7	27

Request & Complaint Management	Submit and track complaints/issues	6	23
Communication & Responsiveness	Faster contact, real-time updates, active content maintenance	5	19
Accessible Information & Clarity	Process details, downloadable forms, structured menus	5	19
Bureaucracy Reduction	Minimize physical presence, ease routine tasks	2	8
Advanced Digital Capabilities	Payments, segmented portals, multilingual options	1	4

3.3 Adapted UX Audit

3.3.1 Comparison of Overall Municipality Scores by Region

To explore regional disparities in municipal website User Experience across Greece, the study compared the overall UX scores among the seven administrative regions. A preliminary inspection of normality and homogeneity of variance assumptions indicated violations, warranting the use of non-parametric tests. Thus, a Kruskal–Wallis H test was performed to assess whether the distributions of overall UX scores differed significantly across regions.

Descriptive statistics (Table 17) suggested substantial variation in central tendency and dispersion between regions. For example, municipalities in Epirus–Western Macedonia showed the highest mean UX score ($M = 0.67$, $SD = 0.06$), whereas those in the Peloponnese–Western Greece & Ionian region scored lowest ($M = 0.43$, $SD = 0.14$). The Thessaly–Central Greece region demonstrated relatively high performance with the least variability ($SD = 0.03$).

Table 17. Descriptives statistics of overall UX scores by region

Administrative Region	Mean Overall UX Score	Median	SD	Min	Max
Attica	0.57	0.57	0.17	0.25	0.90
Macedonia-Thrace	0.47	0.44	0.15	0.20	0.81
Thessaly-Central Greece	0.62	0.62	0.03	0.59	0.64

Peloponnese-Western Greece & Ionian	0.43	0.41	0.14	0.22	0.78
Epirus-Western Macedonia	0.67	0.70	0.06	0.59	0.71
Crete	0.46	0.37	0.22	0.28	0.89
Aegean	0.46	0.45	0.15	0.22	0.78

In addition, Table 18 reports the results of the Kruskal–Wallis H test conducted to examine whether overall UX scores differ significantly across administrative regions. The test revealed a statistically significant difference between the groups, $H(6) = 18.77$, $p = .005$, indicating that at least one region's median score differs from the others. The test statistic was adjusted for ties.

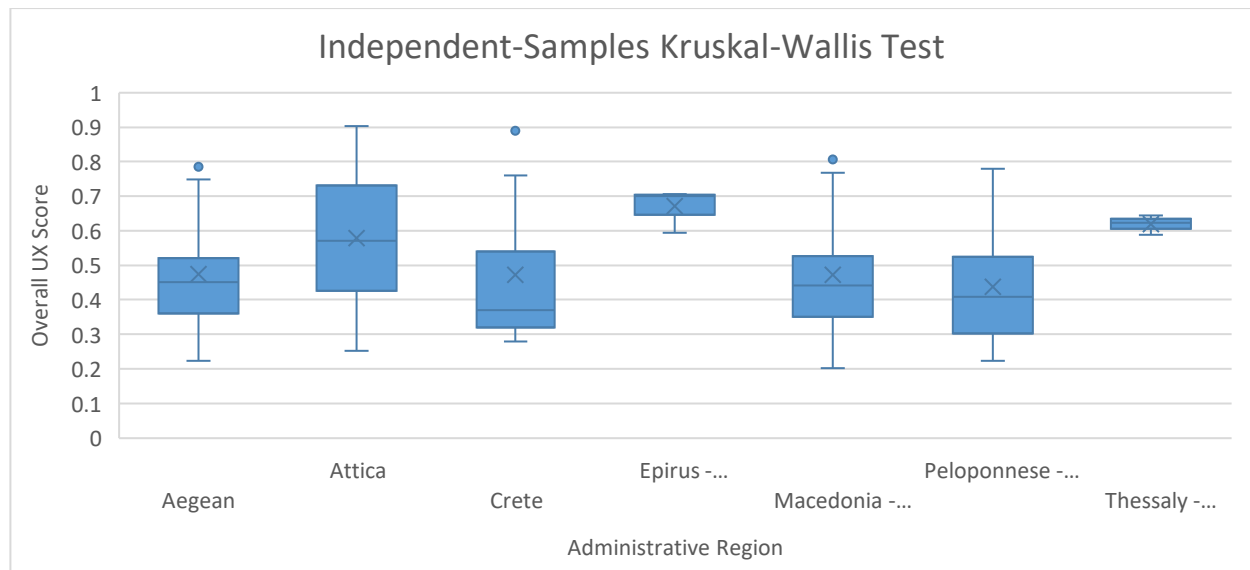
Table 18. Kruskal-Wallis Test Summary

Independent-Samples Kruskal-Wallis Test Summary

Total N	129
Test Statistic	18.774 ^a
Degree Of Freedom	6
Asymptotic Sig.(2-sided test)	.005

a. The test statistic is adjusted for ties.

Further, Figure 2 illustrates the distribution of overall UX scores across the seven administrative regions. Each box represents the interquartile range, the line within the box marks the median, and whiskers indicate the range. Outliers are shown as individual dots. The plot reveals substantial variability among regions, with Epirus–Western Macedonia and Thessaly–Central Greece exhibiting higher and more consistent scores compared to regions such as Crete and the Aegean.

Figure 2. Boxplot of overall UX Scores by administrative region

Pairwise comparisons using Bonferroni-adjusted p-values (Table 19) revealed statistically significant differences in the overall UX scores between several administrative regions. Specifically, municipalities in Attica scored significantly higher than those in both Crete ($p = .017$) and the Aegean ($p = .017$). Additionally, Thessaly–Central Greece significantly outperformed Peloponnese–Western Greece & Ionian ($p = .002$), while Epirus–Western Macedonia also demonstrated significantly higher scores compared to Peloponnese–Western Greece & Ionian ($p = .043$).

Table 19. Pairwise comparisons (Bonferroni Adjusted)

Region Pair	Adjusted p-value
Crete – Attica	.017
Peloponnese – Thessaly	.002
Aegean – Attica	.017
Peloponnese – Epirus	.043

These results indicate that specific administrative regions outperform others in municipal website usability, underscoring regional disparities in digital infrastructure quality.

3.3.2 Regional Analysis of Usability Dimensions

This section examines whether usability dimension scores vary significantly across Greece's administrative regions. For each of the nine dimensions evaluated in the UX Audit, normality checks indicated violations of parametric assumptions. As such, Kruskal–Wallis H tests were performed to detect regional differences. Where significant effects were found, Bonferroni-adjusted pairwise comparisons were conducted to identify specific group differences.

In particular, Table 20 presents the mean usability scores across the nine evaluation dimensions for each administrative region. The region of Epirus – Western Macedonia consistently outperforms others, with particularly high scores in Trust & Credibility (0.80), Writing & Content Quality (0.67), and Page Layout & Visual Design (0.70). In contrast, the Aegean and Peloponnese – Western Greece & Ionian regions exhibit the lowest scores across multiple dimensions, including Homepage, Trust, and Help & Feedback, suggesting significant usability limitations in these areas.

Table 20. Mean usability scores per dimension across administrative regions

Dimension	Aegean	Attica	Crete	Epirus – Western Macedonia	Macedonia – Thrace	Peloponnese – Western Greece & Ionian	Thessaly – Central Greece
Home	0.33	0.53	0.34	0.71	0.39	0.33	0.61
Task Orientation	0.4	0.53	0.4	0.68	0.35	0.36	0.52
Navigation & IA	0.47	0.6	0.48	0.64	0.46	0.42	0.66
Form & Data Entry	0.57	0.58	0.54	0.67	0.56	0.55	0.66
Trust & Credibility	0.51	0.67	0.61	0.8	0.66	0.52	0.75
Writing & Content Quality	0.5	0.61	0.44	0.67	0.43	0.44	0.64
Page Layout & Visual Design	0.45	0.58	0.43	0.7	0.48	0.4	0.69
Search	0.49	0.5	0.49	0.55	0.5	0.48	0.55
Help, Feedback & Error Tolerance	0.39	0.52	0.4	0.58	0.43	0.35	0.49

Overall Score	0.46	0.57	0.46	0.67	0.47	0.43	0.62
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To test whether these observed differences were statistically significant, Kruskal–Wallis H tests were conducted for each dimension.

3

3.3.2.1 Dimension 1. Homepage

Regional differences in Homepage usability were examined using a Kruskal–Wallis H test. As shown in Table 21, the analysis revealed a statistically significant overall effect, $H(6) = 14.13$, $p = .028$. However, Bonferroni-adjusted post hoc comparisons did not identify statistically significant differences between specific regional pairs (all $p > .05$), suggesting that the observed variation reflects subtle and distributed disparities rather than distinct regional contrasts.

Table 21. Kruskal-Wallis Test Summary for the Homepage dimension
Independent-Samples Kruskal-Wallis Test Summary

Total N	129
Test Statistic	14.134 ^a
Degree Of Freedom	6
Asymptotic Sig.(2-sided test)	.028

a. The test statistic is adjusted for ties.

3.3.2.2 Dimension 2. Task Orientation

A statistically significant regional variation was observed in Task Orientation scores (Table 22), $H(6) = 17.39$, $p = .008$. Despite the overall effect, Bonferroni-adjusted pairwise comparisons did not yield statistically significant differences between individual regions (all $p > .05$), indicating a pattern of general variability rather than clearly delineated regional groupings.

Table 22. Kruskal-Wallis Test Summary for the Task & Orientation dimension
Independent-Samples Kruskal-Wallis Test Summary

Total N	129
Test Statistic	17.387 ^a
Degree Of Freedom	6
Asymptotic Sig.(2-sided test)	.008

a. The test statistic is adjusted for ties.

3.3.2.3 Dimension 3: Navigation & Information Architecture

The Kruskal–Wallis test indicated a significant regional effect for Navigation & Information Architecture (Table 23), $H(6) = 19.62$, $p = .003$. Nevertheless, none of the Bonferroni-adjusted pairwise comparisons reached statistical significance (all $p > .05$), suggesting that the overall difference stems from dispersed performance variations across regions rather than specific group disparities.

Table 23. Kruskal-Wallis Test Summary for the Navigation & Information Architecture dimension

Independent-Samples Kruskal-Wallis Test Summary	
Total N	129
Test Statistic	19.624 ^a
Degree Of Freedom	6
Asymptotic Sig.(2-sided test)	.003

a. The test statistic is adjusted for ties.

3.3.2.4 Dimension 4: Forms & Data Entry

No statistically significant regional differences were found for Forms & Data Entry usability (Table 24), $H(6) = 9.29$, $p = .158$. This finding suggests that User Experience related to form completion and data entry remains relatively consistent across the examined administrative regions.

Table 24. Kruskal-Wallis Test Summary for the Forms & Data Entry dimension

Independent-Samples Kruskal-Wallis Test Summary	
Total N	129
Test Statistic	9.287 ^a
Degree Of Freedom	6
Asymptotic Sig.(2-sided test)	.158

a. The test statistic is adjusted for ties.

3.3.2.5 Dimension 5: Trust & Credibility

Analysis of Trust & Credibility scores revealed a statistically significant overall regional effect (Table 25), $H(6) = 13.91$, $p = .031$. However, Bonferroni-adjusted post hoc tests did not identify significant differences between specific regional pairs (all $p > .05$), again pointing to broadly distributed variation rather than localized contrasts.

Table 25. Kruskal-Wallis Test Summary for the Trust & Credibility dimension
Independent-Samples Kruskal-Wallis Test Summary

Total N	129
Test Statistic	13.906 ^a
Degree Of Freedom	6
Asymptotic Sig.(2-sided test)	.031

a. The test statistic is adjusted for ties.

3.3.2.6 Dimension 6: Writing & Content Quality

Significant regional variation was also observed in Writing & Content Quality scores (Table 26), $H(6) = 19.77$, $p = .003$. Despite this overall effect, Bonferroni-adjusted comparisons did not reveal statistically significant differences between individual regions (all $p > .05$), suggesting widespread variability rather than isolated under- or over-performing regions.

Table 26. Kruskal-Wallis Test Summary for the Writing & Content Quality dimension
Independent-Samples Kruskal-Wallis Test Summary

Total N	129
Test Statistic	19.766 ^a
Degree Of Freedom	6
Asymptotic Sig.(2-sided test)	.003

a. The test statistic is adjusted for ties.

3.3.2.7 Dimension 7: Page Layout & Visual Design

The Kruskal–Wallis test for Page Layout & Visual Design yielded a statistically significant result (Table 27), $H(6) = 14.13$, $p = .028$. Nonetheless, Bonferroni-adjusted pairwise comparisons were not statistically significant (all $p > .05$), indicating that the observed regional differences reflect general trends rather than distinct regional contrasts.

Table 27. Kruskal-Wallis Test Summary for the Page Layout & Visual Design dimension
Independent-Samples Kruskal-Wallis Test Summary

Total N	129
Test Statistic	14.127 ^a
Degree Of Freedom	6

Asymptotic Sig.(2-sided test)	.028
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a. The test statistic is adjusted for ties.

3.3.2.8 Dimension 8: Search Functionality

No statistically significant regional differences were identified for Search functionality (Table 28), $H(6) = 5.37$, $p = .497$. This result suggests a relatively uniform level of Search usability across the examined administrative regions.

Table 28. Kruskal-Wallis Test Summary for the Search Functionality dimension
Independent-Samples Kruskal-Wallis Test Summary

Total N	129
Test Statistic	5.373 ^a
Degree Of Freedom	6
Asymptotic Sig.(2-sided test)	.497

a. The test statistic is adjusted for ties.

3.3.2.9 Dimension 9: Help, Feedback & Error Tolerance

The strongest regional effect was observed for Help, Feedback & Error Tolerance (Table 29), with the Kruskal–Wallis test indicating a highly significant difference, $H(6) = 30.16$, $p < .001$. Bonferroni-adjusted post hoc analysis identified one statistically significant pairwise difference between Peloponnese–Western Greece & Ionian and Attica ($p = .000$), highlighting pronounced regional disparities in user support and error-handling features.

Table 29. Kruskal-Wallis Test Summary for the Help, Feedback & Error Tolerance dimension
Independent-Samples Kruskal-Wallis Test Summary

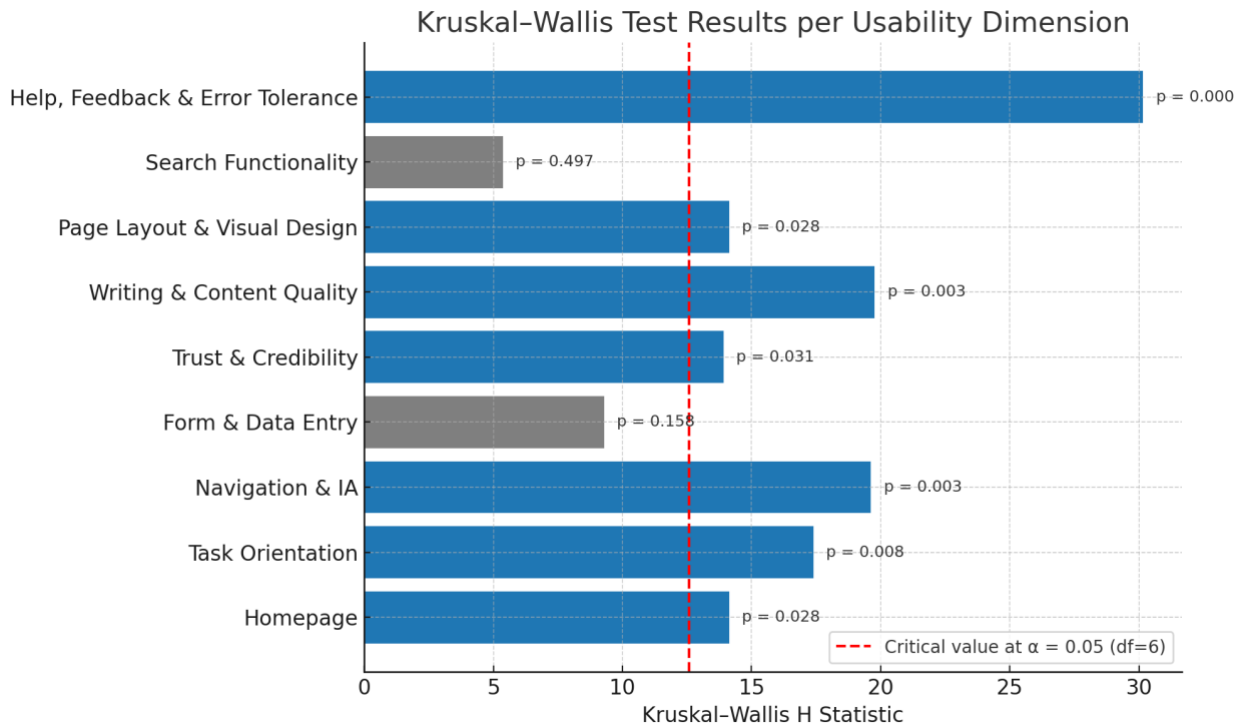
Total N	129
Test Statistic	30.163 ^a
Degree Of Freedom	6
Asymptotic Sig.(2-sided test)	<.001

a. The test statistic is adjusted for ties.

To synthesize the findings across all dimensions, Figure 3 presents a summary of Kruskal–Wallis H test results for each of the nine usability dimensions examined in the UX Audit. The y-axis displays the H statistic, while the dashed red line marks the critical chi-square value for statistical significance ($\chi^2(6) = 12.59$, $p = .05$). Dimensions that exceeded this

threshold are highlighted in blue, indicating statistically significant regional differences. In contrast, grey bars represent dimensions where no significant variation was detected. This overview illustrates that while certain aspects of usability, such as Help & Feedback, Writing & Content, and Navigation, exhibited strong regional disparities, others remained relatively consistent across Greece's administrative regions.

Figure 3. Schematic representation of Kruskal–Wallis H test results across usability dimensions



3.3.3 Rank Dimensions for Overall Greek Regions

To investigate whether certain usability dimensions outperformed others across the national sample of Greek municipalities, a repeated-measures ANOVA was conducted using the nine UX evaluation dimensions as within-subjects factors.

Table 30. Mauchly's Test of Sphericity

Mauchly's Test of Sphericity							
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse – Geisser	Epsilon – Huynh – Feldt	Lower Bound
Dimension	.074	324.977	35	<.001	.513	.532	.125

Mauchly's test indicated a violation of the sphericity assumption, $\chi^2(35) = 324.98$, $p < .001$; therefore, the Greenhouse-Geisser corrections were applied (Table 30). The results showed a statistically significant effect of dimension on usability scores, $F(4.10, 524.92) = 29.72$, $p < .001$, $\eta^2_p = .188$, indicating that certain dimensions were consistently rated higher or lower than others across all administrative regions (Table 31).

Table 31. Repeated-Measures ANOVA Results

Tests of Within-Subjects Effects							
Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Dimension	Sphericity	4.397	8	.550	29.715	<.001	.188
	Assumed						
	Greenhouse – Geisser	4.397	4.101	1.072	29.715	<.001	.188
Error (Dimension)	Sphericity	18.942	1024	.018			
	Assumed						
	Greenhouse – Geisser	18.942	524.921	.036			

As shown in Table 32, the highest-performing dimensions included **Trust & Credibility** ($M = .607$), **Forms & Data Entry** ($M = .568$), and **Writing & Content Quality** ($M = .504$), while **Homepage** ($M = .410$) and **Help, Feedback & Error Tolerance** ($M = .431$) received the lowest usability scores.

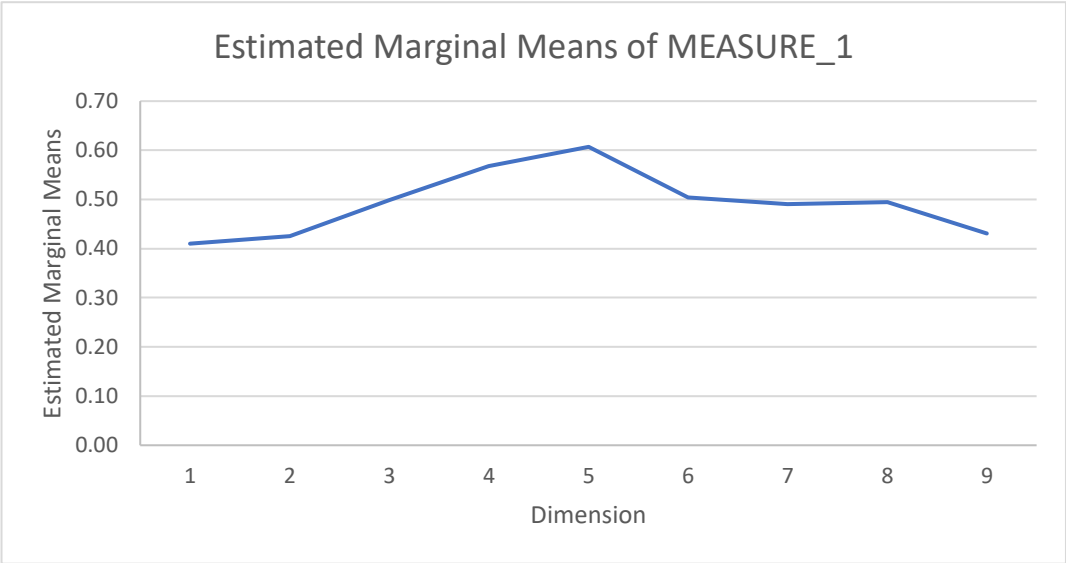
These findings underscore which aspects of municipal website UX are perceived as more functional or satisfactory nationwide, and which are more problematic regardless of regional affiliation.

Table 32. Mean usability scores across dimensions

Descriptive Statistics			
Dimension Scores	Mean	Std. Deviation	N
Homepage	.41	0.30	129
Task Orientation	.43	0.24	129
Navigation & Information Architecture	.50	0.21	129
Forms & Data Entry	.57	0.09	129
Trust & Credibility	.61	0.23	129
Writing & Content Quality	.50	0.21	129
Page Layout & Visual Design	.49	0.25	129
Search Functionality	.49	0.15	129
Help, Feedback & Error Tolerance	.43	0.14	129

Figure 4 presents the estimated marginal means for each UX dimension. The line plot illustrates clear strengths in **Trust & Credibility**, with gradually lower scores across dimensions ending in **Help, Feedback & Error Tolerance**, the lowest-rated category. This visualization highlights systemic usability gaps in areas crucial for supporting user autonomy and satisfaction—particularly among older or less digitally literate populations.

Figure 4. Estimated marginal means of usability dimensions



NB. Profile plot displaying the estimated marginal means for each usability dimension across all municipalities. The x-axis represents the nine dimensions, while the y-axis shows the average usability score. The trend highlights relative strengths and weaknesses in the evaluated categories.

4. DISCUSSION

This study explored the User Experience of Greek municipal websites from two complementary perspectives: the lived experiences and expectations of citizens, and the objective evaluation of website usability across regional governments. By integrating survey responses with a large-scale UX Audit of 138 municipal websites, the findings reveal systemic barriers to usability, functional inconsistency, and a fragmented national digital strategy for local governance.

RQ1. How do citizens perceive the capacity of local municipal websites to meet their service needs and support meaningful e-participation, despite national progress in digital transformation?

H1. Despite national progress in digital transformation, citizens perceive local municipal websites as insufficiently developed to address their service needs or support meaningful e-participation.

4.1 Limited Familiarity and Sporadic Engagement with Municipal Services

In line with H1, the findings of this study reveal a generally low level of citizen familiarity with the services provided by local municipalities. The mean score on a 5-point Likert scale was just **1.69**, with no participant indicating high awareness. This limited

familiarity appears to reflect a broader disconnect between citizens and their local governments (Helling et al., 2005), weakening their ability to navigate administrative processes or engage with available resources. Although a few respondents reported isolated positive interactions, such as successful online form submissions or helpful municipal staff, these were frequently overshadowed by accounts of delays, lack of responsiveness, or procedural opacity. Crucially, a significant portion of participants reported **no prior engagement at all** with their municipality, suggesting that barriers extend beyond usability and into deeper issues of **trust, perceived relevance, and institutional visibility**.

This disengagement is especially striking when considered in the context of rising digital literacy, particularly among younger demographics like Millennials and Gen Z (Stefán et al., 2025; 2024). For these users, shaped by seamless digital experiences in the private sector, basic usability features, such as intuitive navigation, quick feedback, and transparent workflows, are no longer luxuries but expected norms. Municipal websites that fall short are not merely inconvenient; they are perceived as outdated or untrustworthy (Tan et al., 2008; Schuck, 2014). The absence of a citizen-centered digital strategy reinforces this perception and alienates those most likely to engage online. Furthermore, the **failure to proactively include all user groups**, including migrants, elderly citizens, and people with disabilities, raises critical questions of equity and democratic inclusion. Municipal websites must evolve beyond static repositories of information and become participatory infrastructures that foster transparency, reduce access barriers, and support civic empowerment (Alexander, 2025). The current gap is not only technical but **strategic and cultural**, requiring municipalities to reimagine their role as digital service providers in an increasingly participatory governance landscape.

4.2 Citizens' Expectations for Transactional and Interactive Features

Supporting H1, the survey revealed a striking mismatch between citizens' actual experience with municipal websites and their expectations for digital service delivery. While familiarity remains limited, participants articulated a clear and ambitious vision of what local e-Government platforms should offer. Transactional efficiency emerged as a top priority, with 88% of respondents requesting online certificate applications, 80% document retrieval, and 73% issue reporting functionalities. These preferences suggest that citizens increasingly expect routine administrative tasks to be handled seamlessly online, minimizing the need for in-person visits or paper-based procedures. Importantly, this expectation extends beyond mere

convenience: it signals a desire for time-saving, autonomous interactions that reflect the digital service norms already adopted in other sectors (e.g., banking, utilities, gov.gr).

Beyond core transactions, participants also highlighted a need for interactive and user-centric tools. A significant share requested features such as online appointment booking (27%), multimedia content (31%), and interactive mapping tools (35%), while nearly 40% selected “all of the above”, a strong indicator of demand for integrated, multifunctional platforms. Moreover, open-ended responses revealed a latent desire for features like smart search engines, personalized dashboards, and real-time communication (e.g., chat, messaging systems). **These expectations reflect shifting digital norms, particularly among younger users who benchmark municipal sites against platforms like banks, gov.gr, or logistics apps (Lotsis et al., 2024; Kyriakogkonas et al., 2023). Citizens increasingly perceive access to functional, user-friendly digital services as a civic right, not a luxury (Milakovich, 2012). When municipalities fail to meet this standard, the result is not** mere inconvenience but a decline in trust and engagement. In alignment with H1, the findings underscore a missed opportunity for municipalities to embrace user-centered, responsive digital governance that meets modern expectations (Alexander, 2025; Wirtz and Kurtz, 2016).

4.3 Expanding the Role of Municipal Websites: From Utility to Destination

While traditionally viewed as administrative portals, municipal websites are increasingly expected to function as comprehensive civic platforms serving a variety of user types beyond local residents. Survey results highlight citizens’ aspirations for a broader and richer digital offering, including localized content such as accommodation listings, gastronomy guides, transportation updates, and cultural event calendars. These preferences suggest a shift in expectations: users no longer seek municipal sites solely for transactional efficiency but also for informational depth and community relevance. In this context, the digital municipal presence becomes an entry point into the identity and daily life of each locality, a role that is especially critical in municipalities located in touristic, insular, or culturally rich regions. However, most Greek municipal websites fail to deliver on this potential. Participants noted limited or outdated content, poor design, and the absence of tailored information for transient users, such as tourists, students, or recent migrants.

This limited scope points to an underutilization of municipal digital infrastructure and a missed opportunity for strategic value creation. International civic technology trends emphasize the role of municipal platforms in place-branding and local economic development,

yet the Greek context lags behind. Citizens reported a striking lack of multilingual content, accessibility features, and real-time updates, especially in Aegean regions where the audience is diverse and often international. These omissions are not merely usability flaws, they reinforce digital exclusion, reduce institutional visibility, and diminish perceived legitimacy. Furthermore, qualitative responses suggest that citizens associate inactive or minimal web presences with institutional inertia or disinterest. A well-designed and regularly updated municipal site, by contrast, fosters perceptions of reliability, transparency, and civic engagement. Reframing these platforms as destinations, not just utilities, requires both technical upgrades and a cultural shift: municipalities must begin to see themselves as digital hosts with a responsibility to serve diverse publics dynamically, inclusively, and meaningfully.

RQ2. What usability and content features in municipal websites are most strongly associated with citizens' perceptions of trustworthiness and overall satisfaction?

H2. Municipal websites that demonstrate higher usability, reflected in effective navigation, intuitive layout, relevant content, and technical reliability, are more likely to be perceived by citizens as trustworthy and satisfactory.

4.4 Emotional Experiences Reflect Usability Failures and Trust Deficits

Citizens' evaluations of their municipalities' digital platforms revealed widespread dissatisfaction, with an average satisfaction rating of just 2.65 on a 5-point scale, supporting our second hypothesis. This negative perception was primarily linked to usability limitations such as unintuitive navigation, outdated design, and non-functional or broken features. Participants consistently reported issues like overloaded Homepages, disorganized menu structures, and the absence of clear visual hierarchies, which led to confusion and disrupted task completion. Open-ended responses highlighted frustration when basic services, like retrieving a document or submitting a request, could not be completed without obstacles or workarounds. Citizens, especially younger ones, compare public platforms to seamless private-sector experiences (Koya et al., 2021). As a result, poor usability is interpreted as institutional neglect or obsolescence (Sundberg and Gidlung, 2024; van den Broek, 2023). Vulnerable users, including those with low digital literacy or accessibility needs, are particularly affected (Choi and Chang, 2025; Helsper, 2021).

The emotional toll of these encounters was evident across the dataset. Thematic analysis highlighted reactions such as irritation, cognitive fatigue, and disorientation, especially when users struggled to find the information they needed or complete simple tasks. These responses

are symptoms of deeper usability failures that go beyond aesthetics or performance, they reflect a system misaligned with user capabilities and expectations. In some cases, successful experiences, such as completing a task smoothly, generated satisfaction or empowerment, but these instances were rare. Notably, the disappointment expressed was not limited to digital design but extended to perceptions of municipal engagement. Several participants described their municipalities as “absent” or “only responsive during elections,” linking technical inefficiency with political disengagement. These findings suggest that poor digital design does not only hinder service delivery, it actively erodes trust (Tan et al., 2008; Schuck, 2004). Thus, emotional usability becomes central to trust-based, inclusive digital governance (Yenugula, 2024).

4.5 Regional Variation in Overall UX Performance

The analysis uncovered substantial regional disparities in the overall usability of municipal websites across Greece, as confirmed by a Kruskal–Wallis H test [$H(6) = 18.77$, $p = .005$]. Municipalities in Epirus–Western Macedonia and Thessaly–Central Greece achieved the highest average UX scores, paired with low internal variability, suggesting greater coherence in design approaches or shared institutional support mechanisms. In contrast, regions like the Aegean and Peloponnese–Western Greece & Ionian performed significantly worse, with broader score dispersion indicating inconsistent quality and possible gaps in technical capacity or strategic alignment at the local level. Notably, Attica, home to the urban hub of Athens, scored above the national average and showed statistically significant differences from underperforming regions such as Crete and the Aegean, likely due to centralized resources, higher user expectations, or access to skilled digital teams.

These discrepancies extend beyond interface design, they signal underlying inequities in municipal capacity, digital governance, and institutional prioritization, suggesting deeper structural imbalances (Schwoerer, 2025; Tsatsani et al., 2024). In the absence of unified national guidelines or coordinated UX strategies, each municipality is left to navigate digital transformation independently (Patergiannaki, 2023). This results in a fragmented landscape where a citizen’s access to functional, usable, and inclusive digital services depends more on geographical location than actual need or vulnerability. In this light, the UX score emerges as more than a design metric, it becomes a proxy for political will, administrative maturity, and commitment to digital equity. Without targeted interventions to uplift underperforming

regions, existing disparities risk deepening, particularly for rural, island, or economically constrained communities that depend on digital channels for access to essential public services.

4.6 Regional Analysis of Usability Dimensions

3 A closer examination of the individual usability dimensions revealed stark regional discrepancies across Greek municipalities. Homepages were broadly ineffective (Brinck et al., 2022), with the Aegean and Peloponnese–Western Greece & Ionian regions showing the weakest performance. Common issues included visual overload, broken entry points, and absent multilingual access. Task Orientation was similarly limited, with most websites offering static information instead of actionable tools. Only a few municipalities, primarily in Thessaly and Epirus, demonstrated more structured workflows and integrated access to national services. Navigation and Information Architecture suffered from deep menu nesting, redundant categories, and vague labels, undermining usability (Dabrowski et al., 2014), especially in Attica and Macedonia–Thrace. Even though Forms and Data Entry scored comparatively higher, this often reflected the bare minimum, basic contact forms with minimal interactivity rather than robust transactional systems, undermining user trust (Edelmann and Baumann, 2024).

Other dimensions further illustrated the uneven digital landscape. Trust and Credibility appeared stronger in Thessaly, Epirus, and parts of Attica, where municipalities offered transparency tools and a professional tone (Evans et al., 2018; Gritzalis et al., 2014). However, sporadic content updates and political undertones in messaging weakened perceived integrity in several cases. Writing and Content Quality varied significantly, with regions like Peloponnese and the Aegean struggling with outdated language and inaccessible phrasing. Visual Design and Layout problems were nearly universal-marked by clutter, broken UI elements, and poor mobile responsiveness. Critically, Search Functionality was the most underdeveloped area: over half of the websites lacked search tools entirely, and those available often failed to return relevant results. Help and Feedback mechanisms were equally weak, with error messages and contact forms offering little guidance. Overall, while Thessaly and Epirus demonstrated relative strength, many rural and island municipalities showed systemic usability deficits, signaling the need for coordinated national UX standards and localized capacity-building.

4.7 Rank Dimensions for Overall Greek Regions

A comparative ranking of average usability scores across the nine UX Audit dimensions revealed significant regional disparities, offering insight into which administrative areas are investing in coherent digital strategies. Epirus–Western Macedonia and Thessaly–Central Greece emerged as the highest-performing regions, excelling in dimensions such as Task Orientation, Content Quality, or Trust and Credibility. These results suggest a structured, citizen-oriented approach to digital service delivery despite these regions’ limited geographic or infrastructural advantages. In contrast, Attica, despite its metropolitan character and population density, ranked unexpectedly low in several areas, including interactivity, navigation, and form usability, indicating that digital scale does not guarantee service maturity.

Regions like Macedonia–Thrace and the Aegean Islands consistently underperformed across most categories, with critical weaknesses in visual design, search functionality, and error tolerance. High-performing regions shared common traits: consistent design, clear information architecture, and a baseline of user-centered thinking. Poor-performing areas, however, often lacked even essential features like functioning search bars or mobile responsiveness. These discrepancies point to a broader digital inequality across Greece, where access to usable and trustworthy municipal platforms is determined not by citizen need but by local administrative capability. Without national UX benchmarks or centralized digital governance, these regional gaps risk deepening existing inequalities in public service access and digital participation.

RQ3. To what extent do persistent usability issues in navigation, interactivity, and content relevance contribute to regional disparities in citizens’ engagement with local e-Government services?

H3. Despite infrastructure improvements, persistent usability issues in municipal websites, particularly in navigation, interactivity, and content relevance, limit user engagement and reinforce regional disparities in digital service adoption.

4.8 Reassessing Barriers to the Adoption of Local e-Government Services

Despite significant advancements in the digitization of public services at the national level, Greece continues to face challenges in citizen adoption of municipal e-Government platforms. While limited digital skills are often cited as a primary barrier, the present findings suggest that systemic platform shortcomings play a more central role. Across regions, the UX Audit revealed widespread usability deficits, minimal transactional features, and accessibility gaps. At the same time, survey results show that many citizens, particularly younger users, are

digitally competent, familiar with modern web standards, and expect intuitive, efficient, and inclusive digital services.

This disconnect between user expectations and platform delivery points to a structural imbalance: the problem lies less in user readiness and more in inadequate digital design and governance at the municipal level. The limited adoption of local e-Government services appears to reflect this quality gap rather than user reluctance. To address this, national digital policy must shift its focus from generalized assumptions about digital literacy to more targeted interventions that improve platform usability, consistency, and relevance. Without national standards, regional discrepancies in UX may persist, limiting citizens' equitable access to functional public services and reinforcing existing geographic divides (Lnenicka et al., 2024; Kumar et al., 2017). A strategic emphasis on user-centered design could significantly boost both adoption rates and public trust in local digital governance.

4.9 Implications for Local Digital Governance

The findings of this study carry important implications for both municipal practice and national digital strategy. First, they highlight the necessity of adopting a user-centered approach in the design, development, and maintenance of municipal websites. Current systems often fall short of citizens' expectations, particularly in terms of usability, interactivity, and task completion capabilities. This suggests that local authorities must go beyond basic information provision and instead invest in platforms that enable seamless, secure, and intuitive digital interactions.

Second, the results point to the importance of standardization and strategic oversight. While certain municipalities perform notably better than others, the lack of consistent design principles, accessibility features, and service depth across regions undermines citizens' ability to rely on digital services nationwide. National-level frameworks or guidelines for local e-Government UX design, similar to those used in centralized platforms like gov.gr, could help ensure a baseline of quality and functionality across municipalities.

Third, the study challenges the assumption that low adoption is primarily due to citizens' limited digital skills. Instead, the data support the view that a digitally literate public is met with underperforming digital infrastructures. This disconnect suggests that boosting engagement will require improvements in system quality rather than solely investing in user education.

Finally, from a governance and civic participation perspective, improved municipal platforms could serve as gateways to more inclusive e-democracy. When well-designed, these

platforms have the potential to enhance trust, transparency, and civic involvement—especially when they incorporate participatory tools such as feedback forms, consultative processes, or real-time service tracking.

In sum, advancing local e-Government in Greece requires not only technical upgrades but also a paradigm shift toward citizen-centric digital service delivery. This involves aligning technological development with users’ needs, habits, and expectations—an approach that is foundational for meaningful and sustainable digital transformation at the municipal level.

4.10 Study Limitations & Future Research Recommendations

This study presents certain limitations that should be acknowledged. First, the citizen survey involved a relatively small sample size ($N = 26$), which limits the statistical generalizability of the findings across the broader Greek population. However, the survey was intentionally designed as an exploratory qualitative component, providing rich insights that contextualize and complement the results of the large-scale UX Audit. Future research could build on these results by employing larger, more demographically diverse samples to validate and expand upon the themes identified here. Second, the UX Audit, although methodologically rigorous, covered 138 out of 332 municipalities. An expanded evaluation encompassing all municipal websites would allow for more comprehensive regional comparisons and Benchmarking. Additionally, future studies could incorporate user testing and physiological methods (e.g., eye tracking, EEG) to further validate usability issues from an experiential perspective. Finally, longitudinal research would be valuable to track whether improvements in municipal platforms lead to increased adoption and civic engagement over time.

APPENDIX

6.1 Benchmarking International Best Practices: What Greek Municipalities Can Learn

The challenges identified in the present study—ranging from low usability to missed opportunities for inclusive and transactional design—stand in sharp contrast to international best practices. Countries such as **Estonia**, **Denmark**, **Finland**, **Canada**, and the **Netherlands** have established citizen-centered municipal web platforms that exemplify both functionality and inclusion.

For example, **Estonia’s municipal portals** are integrated within the broader “e-Estonia” ecosystem, allowing seamless transactions via eID authentication, with services ranging from tax payments to school enrollment. **Denmark’s municipal websites**, such as that of Copenhagen, provide multilingual content, live chat assistance, and interactive tools that

resemble best-in-class private-sector platforms. **Finland** and **Canada** further stand out for embedding accessibility standards (e.g., WCAG, AODA compliance) and for incorporating participatory features such as feedback forms and consultation hubs. Meanwhile, **Amsterdam’s municipal portal** demonstrates exemplary personalization, with services dynamically adapting based on the user’s profile (e.g., family status, age, business ownership).

What these municipalities share is not just technical excellence, but **a cultural and strategic commitment to digital governance**. Their success is underpinned by:

- **Centralized digital strategies** that mandate standards across all municipalities.
- **Unified design systems** ensuring visual consistency and usability.
- **Real-time interaction** features (e.g., status tracking, live response).
- **Multilingual, mobile-friendly, and accessible-by-default platforms**.
- **Digital inclusion policies**, targeting youth, elderly, migrants, and people with disabilities.

By comparison, the Greek municipal ecosystem appears fragmented and reactive. The absence of a national UX or digital performance framework contributes to wide disparities across regions and often results in websites that fall short of basic expectations—even for digitally literate citizens.

For Greece to close this gap, lessons from these countries suggest the need for:

- A **national digital design system** applied across municipalities.
- **Central UX standards**, enforced through policy and training.
- **Participatory service models** enabling feedback and local democratic involvement.
- A **commitment to multilingualism, accessibility, and personalization**, especially for regions with tourism or diverse populations.

In short, municipal websites should evolve from static repositories to dynamic civic platforms—equipped not only to deliver services but to **empower, include, and engage citizens** at every level of digital readiness.

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Chapter 4

How Do Users Neurophysiologically Experience Greek Municipal Websites?

4

Beyond Traditional UX Evaluation: Investigating User Experience in Greek Municipal Platforms Using EEG and Eye Tracking

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Abstract

4 Despite growing investment in e-government infrastructure, the adoption of local municipal digital services remains limited, raising questions about how user experience (UX) is currently evaluated. Traditional approaches, based on expert audits and self-reported measures, capture mainly the conscious and observable layers of interaction, overlooking the underlying cognitive and emotional processes that shape actual user behavior. This study introduces a multimodal, neuroscience-informed framework for UX evaluation. A pilot experiment was conducted on three Greek municipal websites (bad, medium, good UX), combining electroencephalography (EEG), eye-tracking tasks, an Implicit Memory Test (IMT), and self-reported measures. Based on these data, the study proposes the Neurocognitive Engagement (NCE) Index, a composite metric integrating neurophysiological, behavioral, cognitive, and subjective indicators. Findings show that while self-reports differentiated UX conditions, the NCE Index revealed near-identical engagement between medium and good UX (5.20 vs 5.07), despite substantial differences in audit scores. This divergence indicates that perceived quality does not necessarily reflect actual engagement, and that multimodal, neuroscience-informed methods are required to capture the full user experience. Overall, the study provides a proof-of-concept for scalable, real-time UX evaluation, supporting more accurate and evidence-based design decisions.

Keywords: user experience, e-government, EEG, eye-tracking, implicit memory, multimodal evaluation, NCE Index

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INTRODUCTION

In the broader context of public sector digitization, the development of effective e-government services has become a strategic priority for both the European Commission and national governments, including Greece (EC, 2010). A central goal of this transition has been the creation of transparent, efficient, and citizen-oriented digital interfaces that strengthen democratic participation and reconnect citizens with public administration. This need became even more urgent during and after the COVID-19 period, when digital access to public services was no longer optional but essential.

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At the same time, the expansion of e-government infrastructure has not automatically translated into sustained citizen use. Despite substantial public investment in digital governance, the adoption of e-government services remains limited (Perez-Morote et al., 2020). Prior studies indicate that satisfaction, trust, and perceived service quality are strongly associated with citizens' willingness to use digital government platforms (Perez-Morote et al., 2020; Zheng & Schachter, 2017; Nam, 2014; Reddick, 2011). This positions user experience (UX) as a central factor in the success of digital public services.

In the context of e-democracy, municipal websites play a critical role as the primary digital interface between citizens and local governments, supporting access to services, information, and participation (Rodríguez Bolívar, 2016; Ali, 2023). However, in Greece, despite progress in centralized e-government platforms such as gov.gr (Dimitreloy and Fouskas, 2023; Spinellis et al., 2022), local municipal websites often remain outdated, fragmented, and poorly maintained (Patergiannaki and Pollalis, 2022; Georgios and Nikolaos, 2021). These limitations are frequently linked to structural constraints, including limited budgets, decentralized governance, and a lack of specialized digital expertise (Anastasopoulou et al., 2025; Chairistanidis and Rusu, 2024; Chourmouziadis, 2024; Choudrie et al., 2018; Katsikas and Gritzalis, 2017).

Beyond structural issues, practical constraints in UX research further exacerbate the problem. In real-world professional environments, UX practitioners often operate under severe time and resource limitations, leading to design decisions that are not systematically validated. Business practice has shown that traditional UX methods—such as usability testing, interviews, and surveys—are frequently perceived by stakeholders as time-consuming, costly, or overly subjective. As a result, they are often underutilized or entirely omitted, increasing the likelihood of arbitrary design decisions and digital products that require costly revisions after implementation.

At the same time, user expectations toward digital services have significantly evolved. Digitally experienced users, particularly younger generations such as Millennials and Generation Z, expect fast, intuitive, and seamless interactions, while older users increasingly depend on digital platforms for accessing essential services and require clarity and accessibility (Fernandes et al., 2013). This growing diversity of expectations further amplifies the importance of designing municipal platforms that are not only functional but also cognitively and emotionally aligned with user needs.

Building on this context, our previous large-scale study examined 138 Greek municipal websites through an adapted UX Audit framework, combined with citizen-oriented evidence on expectations and frustrations (Tsatsani and Pollalis, 2025; 2024). The findings revealed widespread weaknesses in navigation, task orientation, multilingual accessibility, content relevance, search functionality, and interactive support, alongside significant regional disparities and a broader mismatch between citizen expectations and platform performance. Overall, municipal websites were found to operate primarily as static information repositories rather than as intuitive and participatory digital environments.

While such audit-based and survey-based approaches are valuable for identifying structural usability issues, they also present inherent limitations. Traditional UX methods rely heavily on self-reported data and expert judgment, which may fail to capture users' real-time cognitive and emotional responses during interaction. Consequently, critical experiential dimensions—such as cognitive load, attentional processes, emotional engagement, and implicit memory—remain insufficiently explored.

Prior research has emphasized that trust, transparency, and perceived system quality are essential for the adoption of digital public services (i.e. Nulhusna et al., 2017; Alzahrani et al., 2017; Zuiderwijk et al., 2015). At the same time, studies have shown that even digitally skilled users may struggle to locate information or complete tasks when usability is poor (Fernandes et al., 2013), reinforcing the importance of experience-driven evaluation approaches.

Despite these insights, the application of neurophysiological and behavioral methods in e-government UX research remains limited. One of the few relevant studies is that of Albayrak and Çağıltay (2013), who combined eye-tracking with qualitative methods to examine user interaction with governmental websites, identifying fixation patterns associated with system visual complexity and reduced task efficiency. However, such approaches remain only recent and rare, particularly in municipal contexts (i.e. Zhang et al., 2021; Yildiz et al., 2020; Bataineh and Mourad, 2017; Demir et al., 2017), and the integration of neurocognitive data into UX evaluation frameworks is still underexplored.

Responding to this gap, the present study extends previous UX Audit findings by moving from structural evaluation to neurophysiological and behavioral investigation. It adopts a multimodal approach combining electroencephalography (EEG), eye-tracking, an implicit memory test, and self-reported measures to examine whether municipal websites previously classified as good, medium, or bad in UX quality also produce different cognitive and experiential responses. In doing so, the study explores the potential of neuroscience-informed methods as a more objective and efficient complement to traditional UX evaluation, with reduced reliance on large samples and time-intensive procedures.

The theoretical background that follows is organized around three core issues. First, it examines the importance of UX in public sector platforms, focusing on local e-government effectiveness and age-related expectations in digital behavior. Second, it discusses the limitations of traditional UX research methods, particularly self-reporting bias and the absence of unconscious data. Third, it explores how cognitive psychology and neuroscience contribute to advancing UX evaluation in governmental contexts.

1. LITERATURE REVIEW

1.1 User Experience and the Effectiveness of Local e-Government

User experience (UX) in public sector websites is not merely a matter of convenience; it is closely tied to digital accessibility, equity, trust, and democratic participation. Municipal websites, in particular, function as the primary digital interface between citizens and local governments, supporting access to information, administrative procedures, and civic engagement opportunities (OECD, 2020; Rodríguez Bolívar, 2016; Ali, 2023). In this sense, local e-democracy depends not only on the existence of digital platforms, but also on the quality of the interaction they enable.

Previous literature (i.e. Camilleri, 2020; Carter and Bélanger, 2005; Welch et al., 2005) has consistently shown that the effectiveness of e-government services cannot be reduced to technical availability alone. The extent to which citizens use and trust digital public services is strongly influenced by how usable, transparent, and relevant these services are perceived to be (Perez-Morote et al., 2020; Nulhusna et al., 2017; Alzahrani et al., 2018; Zuiderwijk et al., 2015). When public websites are difficult to navigate, poorly structured, or lacking in interactivity, citizens may experience confusion, frustration, and disengagement, which in turn weakens both service adoption and institutional trust (Galvez and Youngblood, 2016; Jun et al., 2014; Voutinioti, 2013; Scott, 2006). Conversely, well-designed municipal websites can

streamline bureaucracy, improve transparency, and enhance the inclusiveness of local governance.

This issue is particularly relevant in the Greek context. Although Greece has made visible progress in centralized e-government systems such as gov.gr, local municipal websites often remain fragmented in quality, uneven in digital maturity, and weak in service depth (Dimitreloy and Fouskas, 2023; Spinellis et al., 2022; Patergiannaki and Pollalis, 2024; Georgios and Nikolaos, 2021). Earlier studies have highlighted problems related to outdated infrastructures, limited interactivity, poor content relevance, and inconsistent alignment with citizen needs (Anastasopoulou et al., 2025; Chairistanidis and Rusu, 2024; Chourmouziadis, 2024; Choudrie et al., 2018; Katsikas and Gritzalis, 2017). Technical and heuristic evaluations of Greek municipal websites have also pointed to recurring weaknesses in navigation, accessibility, and trust-related design elements (Patergiannaki et al., 2020; Panayiotou and Stavrou, 2019; Chatzopoulos, 2009;).

These concerns were further reinforced by our previous large-scale UX Audit of 138 Greek municipal websites, which revealed widespread deficits across core usability dimensions (Tsatsani and Pollalis, 2024). Taken together, this evidence suggests that many municipal websites still operate as static repositories of information rather than as user-centered and participatory public service platforms.

These findings inform the development of the following hypothesis:

H1. Municipal websites with higher UX quality will be associated with more positive user experience outcomes, reflected in both behavioral and perceptual responses.

1.2 Age Expectations and Digital Behavior in UX Contexts

The importance of UX in public platforms is further amplified by changing user expectations across age groups. Contemporary digital users, especially Millennials and Generation Z, have developed high standards for speed, clarity, responsiveness, and ease of use through repeated exposure to mature private-sector digital ecosystems (Süleymanov, 2025; Zaelani et al., 2025). As a result, they are quick to detect friction in online environments and are less tolerant of confusing structures, delays, or inefficient navigation. When a system fails to meet these expectations, abandonment may occur almost immediately, often accompanied by negative judgments about the service provider itself.

At the same time, older adults are increasingly engaged with digital platforms in their everyday lives, especially when accessing essential services such as banking, health, or public administration (Xie et al., 2021; Hodge et al., 2017). Although they may display somewhat

greater patience than younger users, they also require clear information structures, predictable workflows, and accessible interfaces. In governmental contexts, where the stakes of use are often higher than in commercial environments, poor UX may affect not only convenience but also the ability to complete necessary tasks or access public support.

This means that municipal websites must address a broad spectrum of digital behaviors and expectations. Designing only for digitally fluent users risks excluding older or less confident citizens, while designing only for simplicity without considering contemporary standards risks alienating younger users who expect efficient and intuitive experiences. Research has shown that even highly educated and digitally experienced users may struggle with poorly designed governmental systems, suggesting that usability barriers are not merely a matter of user skill, but of interface quality and system logic (Fernandes et al., 2013). Therefore, effective public-sector UX requires balancing inclusiveness, clarity, efficiency, and relevance across diverse user groups.

These observations lead to the following hypothesis:

H2. Differences in UX quality will be reflected in users' interaction patterns and engagement levels across diverse user groups, regardless of digital familiarity.

1.3 Limitations of Traditional UX Research Methods

Traditional UX research has made an important contribution to the evaluation of digital systems through methods such as surveys, interviews, usability tests, and expert reviews (i.e. Ardito et al., 2014; Duman and Salzman, 2006). However, these methods are also characterized by significant limitations, especially when the goal is to understand how users actually experience a digital interface in real time (i.e. Albert and Tullis, 2022; Allam and Dahlan, 2013; Schwarz, 2012). Most traditional approaches rely heavily on self-reported perceptions or retrospective accounts, which are shaped by memory bias, social desirability, interpretation errors, and users' limited ability to articulate unconscious emotional or cognitive states (Tsatsani and Pollalis, 2025).

This limitation is especially important in public-sector environments, where usability failures often occur under conditions of time pressure, confusion, or cognitive overload. A citizen may report that a website was "acceptable" overall while still experiencing frustration, attentional disruption, or mental fatigue during specific tasks. As a result, self-reported satisfaction does not always reflect the actual moment-to-moment experience of interacting with a platform. This creates a methodological gap between what users say and what they cognitively and behaviorally undergo (Hekler et al., 2013; Schwarz, 2012).

The problem is further intensified in professional practice. In applied UX environments, especially in public or resource-constrained settings, research teams often face limited budgets, short timelines, and low stakeholder tolerance for complex or repeated testing (Ardito et al., 2014; Kuniavsky, 2003). Traditional UX methods are therefore frequently perceived as too slow, too costly, or too subjective to support rapid decision-making. In many cases, this leads to minimal validation, small convenience samples, or design decisions based primarily on assumptions. Ironically, the avoidance of research for reasons of efficiency may ultimately result in ineffective implementations, costly redesigns, and lower user adoption after launch.

In the case of municipal websites, these constraints are particularly problematic. Such platforms serve heterogeneous populations, support essential tasks, and carry strong implications for trust in public administration (Feeney and Brown, 2017). Yet their evaluation is often reduced to technical compliance or superficial usability review, leaving deeper experiential dimensions underexplored. Thus, while traditional UX methods remain useful for identifying structural problems, they are often insufficient for capturing the full cognitive and emotional complexity of digital public service interaction (Yang, 2025).

These insights suggest the following hypothesis:

H3. Traditional self-reported UX measures will not fully capture users' real-time cognitive and behavioral responses during interaction with municipal websites.

1.4 The Role of Neurocognitive Methods

Addressing this limitation requires moving beyond conscious evaluation and examining the underlying cognitive processes that shape user experience. From a cognitive psychology perspective, user experience is not solely a conscious process. Digital interactions generate implicit cognitive and emotional responses that shape perception, trust, and future behavior. These responses are often encoded in implicit memory, defined as the unconscious retention of experiences that influence judgments and decisions without deliberate awareness (Tucker et al., 2022; Tobias et al., 2014). Importantly, users may not be able to explicitly recall or verbalize these experiences, even though they significantly impact their interaction with a system.

To address these limitations, UX research has increasingly incorporated neuroscientific and behavioral methods that capture real-time user responses. Electroencephalography (EEG), for example, enables the monitoring of brain activity with high temporal resolution, allowing researchers to assess cognitive load, attentional engagement, and emotional activation as they occur (Dan and Reiner, 2017; Antonenko et al., 2010). Specific frequency bands, such as theta,

alpha, and beta, provide measurable indicators of mental effort, attentional states, and task engagement. Crucially, EEG captures rapid, unconscious processes that remain inaccessible through self-report methods, offering a more direct reflection of the user's internal state during interaction (Bell et al., 2018).

In parallel, eye-tracking technology provides detailed insights into users' visual behavior. By recording gaze patterns, fixation durations, and scan paths, eye-tracking reveals how users allocate attention, process information, and navigate digital environments. It allows researchers to identify whether key elements are easily discoverable, whether users experience confusion or hesitation, and how efficiently they complete tasks. Unlike verbal feedback, which is retrospective and subjective, eye-tracking captures observable behavioral evidence of interaction in real time (Macdonald and Tatler, 2018).

Beyond neural and visual attention measures, implicit memory testing offers an additional layer of insight into how digital content is encoded and retained. By assessing whether users unconsciously recognize or recall elements encountered during interaction, implicit memory measures reveal the extent to which information has been meaningfully processed (Greenwald and Banaji, 2017; Ellis, 2005). This is particularly relevant in public-sector contexts, where the perceived relevance and memorability of content influence trust, usability, and continued engagement.

While some studies have raised concerns regarding the reliability of implicit measures and their comparative advantage over self-reported methods (Corneille and Gawronski, 2024), in the present study implicit memory is employed as a complementary metric alongside neurophysiological, behavioral, and subjective measures, contributing to a more comprehensive assessment of user experience.

When combined, these methods provide a multidimensional understanding of user experience that goes beyond the limitations of traditional approaches. EEG captures internal cognitive and emotional processes, eye-tracking reflects external behavioral interaction, and implicit memory reveals downstream cognitive encoding. Together, they enable the triangulation of user experience across complementary levels of analysis, reducing reliance on subjective reporting and increasing the robustness of findings.

This multimodal approach is especially valuable in the evaluation of public-sector digital platforms, such as municipal websites, where usability directly affects access to services, citizen participation, and institutional trust. Previous research in e-government contexts remains limited in its use of such methods. As such, the integration of

neurophysiological, behavioral, and cognitive measures in a **unified e-governmental framework** remains largely underexplored.

Addressing this gap, the present study adopts a multimodal, neuroscience-informed approach to UX evaluation, combining EEG, eye-tracking, implicit memory testing, and self-reported measures. By doing so, it seeks to capture both conscious and unconscious dimensions of user experience, providing a more comprehensive and objective understanding of how users interact with municipal digital platforms.

Accordingly, the following hypotheses are proposed:

H4. Neurophysiological measures through EEG will capture variations in users' cognitive and emotional responses associated with differences in UX quality.

H5. Behavioral efficiency measures through eye-tracking tool will reflect differences in attention allocation and navigation efficiency across websites of varying UX quality.

H6. Implicit memory performance and cognitive encoding of the website's content will vary according to the quality and structure of the overall user experience score.

H7. A multimodal approach combining neurophysiological, behavioral, and self-reported measures will provide a more comprehensive assessment of user experience than any single method alone.

1.5 Study Objectives

Building on the limitations of traditional UX research and the emerging role of neurocognitive methods, the present study aims to investigate how differences in the UX quality of municipal websites are reflected in users' cognitive, behavioral, and experiential responses. Specifically, the study seeks to examine whether websites previously classified as having good, medium, or bad UX produce distinct patterns of interaction, attention, and information processing. To achieve this, a multimodal research framework is employed, integrating electroencephalography (EEG), eye-tracking, implicit memory testing, and self-reported measures. This approach allows for the simultaneous examination of both conscious and unconscious dimensions of user experience, moving beyond the limitations of single-method evaluations. Ultimately, the study aims to contribute to the development of a more objective, scalable, and comprehensive approach to UX evaluation in public-sector digital platforms, particularly within the context of local e-government services.

Within this context, this study also **introduces for the first time, on a pilot basis**, the **Neuro-Cognitive Engagement (NCE) Index**, a composite metric that integrates neurophysiological, behavioral and cognitive indicators (EEG, eye-tracking, memory

performance, and self-reports) into a unified evaluative framework. The NCE Index is proposed as a step toward a more holistic and evidence-based assessment of user interaction, supporting more informed design and decision-making in digital public services.

2. METHODS

2.1 Study Design

This study adopts a mixed experimental design to evaluate the user experience (UX) of Greek municipal websites through a combination of neuroscientific, behavioral, cognitive, and self-reported measures. The research consists of two distinct but complementary data collection phases, each targeting different dimensions of user experience.

In the first phase (EEG session), a within-subjects design was employed. All participants were exposed to static images from three municipal websites representing distinct levels of UX quality, namely good, medium, and bad, as determined by a prior large-scale UX Audit (Tsatsani & Pollalis, 2024; 2025). EEG data were recorded continuously while participants observed the stimuli across three experimental blocks, each corresponding to a different cognitive context (free exploration, goal-oriented search, and emergency scenario). This design enables within-subject comparisons of neurophysiological responses across UX quality conditions and contextual framings.

In the second phase (eye-tracking session), a between-subjects design was applied. Each participant was randomly assigned to interact with one of the three municipal websites and completed a standardized set of tasks simulating realistic citizen interactions. During task execution, visual behavior was recorded using eye-tracking technology. Following task completion, participants completed an Implicit Memory Test (IMT) and a self-reported questionnaire, capturing both cognitive and subjective evaluations of the experience. This between-subjects structure allows for comparison of behavioral and perceptual responses across participants interacting with websites of differing UX quality, while minimizing learning effects.

Together, the two phases enable the triangulation of conscious and unconscious dimensions of user experience. The multimodal and mixed-design approach supports both within-subject comparisons (in the EEG phase) and between-condition comparisons (in the eye-tracking phase), providing a comprehensive and ecologically valid evaluation of UX in local e-government platforms.

2.2 Participants

The sample consisted of **N = 10 adult male participants**, recruited through convenience sampling. The decision to include only male participants was made to control for potential gender-related variability in neurophysiological responses, which has been documented in the EEG literature (reference). Participants were distributed across three generational cohorts: Generation Z (18–27 years), Millennials (28–43 years), and older adults (44–55+ years), ensuring coverage of a range of digital experience levels and interaction patterns. All participants provided written informed consent prior to participation.

2.3 Stimuli and Materials

The experimental stimuli consisted of three Greek municipal websites, each representing a distinct level of UX quality, as classified through a prior UX Audit of over 138 municipal websites using a nine-dimension evaluation framework (Tsatsani & Pollalis, 2024; 2025). UX categories were defined based on composite scores (0–100%), with thresholds set at: **good UX (>71%)**, **medium UX (50–70%)**, and **bad UX (<50%)**. The three selected municipalities were: the **Municipality of Alexandroupolis** (good UX, score: 84%), the **Municipality of Mytilene** (medium UX, score: 59%), and the **Municipality of Didymoteicho** (bad UX, score: 28%).

For the EEG session, standardized full-page images of each website's homepage were prepared as static visual stimuli. For the eye-tracking session, participants interacted with the live website assigned to their condition via a standardized browser interface.

2.4 Procedure

The study was conducted in a quiet, controlled environment to minimize external interference and ensure data quality. Each session lasted approximately 45 minutes per participant and was organized into two sequential phases.

2.4.1 Phase 1: EEG Session

EEG data were recorded using the **Emotiv Insight headset** (5 channels: AF3, T7, Pz, T8, AF4; sampling rate: 128 Hz), a portable, non-invasive device suitable for field-based research. Prior to stimulus presentation, a calibration phase was conducted, comprising a standard eyes-open fixation period (15 seconds) and an eyes-closed resting period (15 seconds) to establish individual baseline neurophysiological activity.

The experimental stimuli were presented using the Emotiv Pro Builder platform. Each participant was exposed to all nine images (three per UX condition) across three experimental blocks, each preceded by a brief instruction designed to prime a specific cognitive orientation:

- **Block 1 (Free Exploration):** Participants observed each image freely, focusing on general visual impression.
- **Block 2 (Goal-Oriented Task):** Participants imagined completing a specific administrative task (e.g., submitting an application or locating a municipal service).
- **Block 3 (Emergency Scenario):** Participants imagined a time-sensitive situation (e.g., water outage) and attempted to locate relevant information rapidly.

Each trial followed a standardized sequence: a **fixation cross (+)** presented at the centre of the screen for baseline stabilization, followed by **stimulus presentation for 8 seconds**, and a **2-second inter-stimulus interval** before the next trial. The order of stimuli within each block was fixed and consistent across participants to ensure comparability.

Following the EEG recording, participants completed a **Self-Assessment Manikin (SAM)-based questionnaire**, rating each of the nine stimuli on two dimensions: *Emotional Valence* (pleasant–unpleasant) and *Arousal* (low–high activation), using a 7-point Likert scale. These self-reported ratings were subsequently used as input for the Emotional Intensity (EI) component of the NCE Index.

2.4.2 Phase 2: Eye-Tracking Session

In the second phase, participants were randomly assigned to interact with one of the three municipal websites. Eye-tracking data were recorded using a portable eye-tracking device, capturing participants' visual behavior during task execution. Participants completed **four standardized tasks** designed to simulate realistic citizen interactions and elicit different cognitive and behavioral responses. Task instructions were identical across all three website conditions to ensure comparability of findings:

- **Task 1 — Exploratory Browsing:** Participants were asked to freely navigate the homepage and form an initial overall impression of the website, without a specific goal.
- **Task 2 — Information Retrieval:** Participants were instructed to locate content related to municipal cleaning and recycling services, assessing the discoverability and clarity of service-related information.
- **Task 3 — Online Request Submission:** Participants were asked to identify how to submit an online request or application, reflecting one of the most common citizen

interaction needs in the context of local e-government services (Tsatsani & Pollalis, 2025).

- **Task 4 — Language Accessibility:** Participants were required to locate and activate an English-language version of the website, evaluating the accessibility and discoverability of multilingual support features.

Eye-tracking recordings were captured as video files and were subsequently subjected to manual coding for the identification of Areas of Interest (AOIs), fixation counts, fixation durations, and time-to-first-fixation metrics.

NB. These behavioral indicators were used to derive the **Relevance (R) component** of the **NCE Index**.

2.4.3 Post-Session Measures

Following the eye-tracking session, participants completed two additional measures administered via the Emotiv Pro Builder platform:

- **Implicit Memory Test (IMT):** A recognition task consisting of 29 terms — 15 targets (content appearing on the assigned website) and 14 distractors (content-unrelated terms). Participants indicated whether they recognized each term. Accuracy and response patterns were recorded and used to calculate a Memory Retention (MR) score based on Signal Detection Theory (Hit Rate – False Alarm Rate), scaled to a 0–10 range (Wixted, 2020; Macmillan, 2002; Macmillan and Kaplan, 1985).
- **Self-Reported Questionnaire (SRQ):** A 7-item questionnaire assessing subjective experience of the assigned website on a 7-point Likert scale (1 = strongly disagree / very low, 7 = strongly agree / very high). Items covered: ease of use, information findability, content clarity, emotional engagement, content relevance, reuse intention, and perceived cognitive fatigue. Item 7 (cognitive fatigue) was reverse-scored, and all items were scaled to a 0–10 range for inclusion in the NCE Index.

2.5 EEG Data Processing and Analysis

Raw EEG data were exported from the Emotiv Pro platform in CSV format, retaining continuous time-series recordings alongside event markers corresponding to stimulus onset and offset timestamps. Data processing and analysis were conducted using custom Python scripts (pandas, NumPy, SciPy).

2.5.1 Stimulus Window Extraction

Individual stimulus windows were extracted using the event markers recorded in each participant's *intervalMarker.csv* file, which contained precise latency and duration timestamps for each stimulus element. Absolute timestamps were computed by adding stimulus latency values to each participant's session start timestamp. EEG data rows falling within each stimulus window (onset to offset) were selected for analysis, yielding **27 stimulus windows per participant** (9 images $\times$ 3 blocks), and 270 windows in total across the sample.

2.5.2 Band Power Extraction

For each stimulus window, mean spectral power values were extracted across five frequency bands, namely *Theta* (4–8 Hz), *Alpha* (8–13 Hz), *Beta-Low* (13–20 Hz), *Beta-High* (20–30 Hz), and *Gamma* (30–45 Hz), across all five EEG channels (AF3, T7, Pz, T8, AF4), using Emotiv's pre-computed band power output (POW columns). These values represent the mean oscillatory power within each frequency band during each stimulus exposure. Oscillatory power in these frequency bands is widely used in cognitive neuroscience as **an indirect indicator** of underlying mental processes, such as **attention allocation**, **cognitive effort**, and **emotional engagement**, enabling the interpretation of neurophysiological responses in relation to user experience.

2.5.3 Derived EEG Metrics

Three composite metrics were derived from the band power data to serve as neurophysiological indicators within the NCE Index:

- **Frontal Theta Power (Cognitive Load indicator):** Computed as the mean of AF3.Theta and AF4.Theta across stimulus windows. Frontal Theta activity is associated with increased cognitive effort and working memory engagement (i.e. Yu et al., 2022).
- **Parietal Alpha Power (Relaxation/Disengagement indicator):** Derived from Pz.Alpha. Alpha oscillations in parietal regions are inversely related to attentional engagement and reflect cognitive relaxation states (i.e. Bonnefond and Jensen, 2025; Chen et al., 2020).
- **Frontal Beta-Low Power (Engagement proxy):** Computed as the mean of AF3.BetaL and AF4.BetaL. Beta-Low activity in frontal regions is associated with active cognitive processing and task engagement (i.e. Halderman et al., 2021; Nuamah and Seong, 2018).

- **Theta/Alpha Ratio (Cognitive Engagement Index):** Computed as Frontal Theta / (Parietal Alpha + 0.001) to avoid division by zero. This ratio provides a composite indicator of cognitive load relative to attentional state, with higher values indicating greater mental effort (i.e. Kamzanova et al., 2015).

All derived metrics were normalized to a 0–10 scale across the full sample prior to inclusion in the NCE Index. The Cognitive Load metric was additionally inverted ($CL_inverted = 10 - CL_scaled$), so that higher values consistently indicate a more positive user experience (i.e., lower cognitive effort).

2.5.4 Statistical Analysis of EEG Data

Given the small sample size ($N = 10$) and the non-normal distribution of EEG band power values, non-parametric statistical tests were employed. Differences in EEG metrics across UX conditions (Bad, Medium, Good) were assessed using the Friedman test for repeated measures. Post-hoc pairwise comparisons were conducted using Wilcoxon signed-rank tests with appropriate correction for multiple comparisons.

All analyses were performed in Python (SciPy). Results are reported with test statistics, p-values, and effect size estimates where applicable. Given the exploratory and pilot nature of the study, a significance threshold of $\alpha = .05$ was applied, while non-significant trends are reported descriptively.

2.6 The Neurocognitive Engagement (NCE) Index

This study introduces the **Neurocognitive Engagement (NCE) Index**, a novel composite metric developed by the authors to integrate neurophysiological, behavioral, cognitive, and self-reported indicators of user experience into a single, unified evaluative score. The NCE Index is proposed as a more objective and comprehensive complement to traditional single-method UX evaluation approaches, specifically designed to capture both conscious and unconscious dimensions of user experience. The NCE Index is structured around six core dimensions, each targeting a distinct layer of user experience:

Table 1. NCE Index Components, Definitions and Data Sources

Component	Full Name	Description	Data Source
EI	Emotional Intensity	Captures the emotional quality and intensity of the user's response to the interface	SAM questionnaire (post-EEG)

ENG	Engagement	Reflects the degree of active cognitive and neural engagement during interface exposure	EEG neurophysiological data
CL	Cognitive Load	Assesses the mental effort required to process and navigate the interface	EEG neurophysiological data
R	Relevance	Evaluates the perceived meaningfulness and utility of the interface content, based on implicit behavioral indicators	EEG + IMT + Eye-tracking
MR	Memory Retention	Measures the implicit encoding and retention of content encountered during interaction	Implicit Memory Test (IMT)
SRQ	Self-Reported Questionnaire	Captures the participant's subjective evaluation of the overall interaction experience	Post-session questionnaire

NB. The NCE Index integrates all five components into a single composite score. Full technical specifications regarding component derivation and aggregation are **subject to intellectual property protection** (see note below).

The resulting NCE score ranges from 0 to 10, with higher values indicating more positive and cognitively engaged user experiences. For interpretive purposes, the following qualitative thresholds are applied: **Low Engagement (0–4)**, namely the digital environment fails to elicit meaningful interest or cognitive involvement; **Moderate Engagement (4–6)**, namely the interface partially meets user needs but presents barriers to full engagement; **Good Engagement (6–8)**, namely the system responds effectively to user needs with room for improvement; **High Engagement (8–10)**, the interface is highly comprehensible, relevant, and cognitively engaging.

Note on Intellectual Property: The detailed computational methodology of the NCE Index, including component weighting, normalization procedures, and sub-component derivation formulas, constitutes proprietary intellectual property and is subject to formal copyright registration. Full technical specifications are retained by the authors and will be made available upon request following intellectual property protection procedures.

2.7 Ethical Considerations

This study was conducted in accordance with established ethical guidelines for research involving human participants. All participants were fully informed about the study procedures, data collection methods, and their rights, including voluntary participation and the ability to withdraw at any point without any negative consequences. Written informed consent was obtained prior to data collection.

All data were anonymized and participants were identified using numerical codes (P1–P10). No personally identifiable information was retained. Data handling and storage complied

with the General Data Protection Regulation (GDPR; EU Regulation 2016/679), ensuring confidentiality and data security.

The eye-tracking component of this study was conducted with the technical support of **Optotech**, whose collaboration enabled access to the necessary equipment and expertise. Colleagues from Optotech contributed to the data collection process and supported the development of appropriate experimental materials (e.g., video analysis and task-related assets).

The findings of this study are intended solely for academic dissemination, including publication in a peer-reviewed journal and incorporation into a doctoral dissertation at the University of Piraeus. No data will be shared with third parties beyond the scope of academic reporting, and all disseminated results are presented in aggregated and anonymized form.

4

3. RESULTS

The following section presents the findings of the pilot study across multiple complementary measurement domains, including electroencephalography (EEG), self-reported emotional ratings (SAM), implicit memory performance (IMT), eye-tracking behavioral data, and the composite Neurocognitive Engagement (NCE) Index. Results are first organized by measurement instrument and subsequently integrated through the NCE framework.

Given the exploratory nature of this pilot study ($N = 10$), findings are primarily reported descriptively, supported by non-parametric statistical tests to assess differences across UX conditions where appropriate.

3.1 EEG Band Power Analysis

EEG band power data were extracted across **270 stimulus windows** (27 per participant $\times$ 10 participants) and analysed across three UX conditions (Bad, Medium, Good). Analysis focused on key neurophysiological indicators, including Frontal Theta Power (cognitive load), Parietal Alpha Power (relaxation), Frontal Beta-Low Power (engagement proxy), and the Theta/Alpha ratio.

As shown in Figure 1, descriptive patterns indicate variation in oscillatory activity across UX conditions. Frontal Theta Power showed comparable mean values across conditions (Bad: $M = 22.39$, Medium: $M = 22.26$, Good: $M = 22.85$), with slightly higher values in the Good UX condition. The Theta/Alpha ratio was also higher for Good UX ($M = 9.05$) compared to Bad ($M = 7.59$) and Medium UX ($M = 7.54$). Parietal Alpha Power remained low across

conditions (Bad: $M = 4.92$, Medium: $M = 3.69$, Good: $M = 6.97$), while Frontal Beta-Low Power showed minimal variation (Bad: $M = 2.76$, Medium: $M = 2.01$, Good: $M = 2.29$). No statistically significant differences were observed across conditions (Friedman test, all $p > .05$).

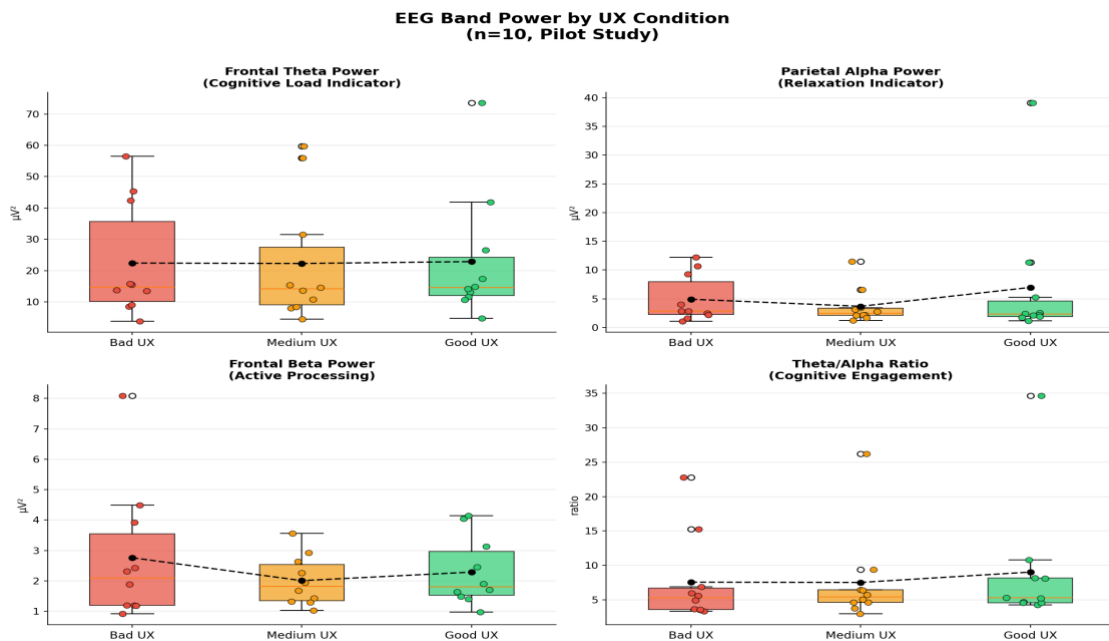


Figure 1. Distribution of EEG-derived metrics across UX conditions (Poor, Medium, Good), including Frontal Theta Power (cognitive load), Parietal Alpha Power (relaxation), Frontal Beta-Low Power (engagement proxy), and Theta/Alpha ratio (attentional engagement). Boxplots represent participant-level distributions ($N = 10$), with median values and interquartile ranges, while dashed lines indicate group means. Although no statistically significant differences were observed (Friedman test, all $p > .05$), **descriptive trends suggest increased cognitive load for Bad UX stimuli and higher engagement-related patterns for Good UX stimuli.**

3.1.1 Frontal Theta Power

Frontal Theta Power, associated with cognitive load and attentional processing, showed comparable mean values across UX conditions: Bad UX ($M = 22.39$, $SD = 37.44$), Medium UX ($M = 22.26$, $SD = 45.02$), and Good UX ($M = 22.85$, $SD = 26.61$). The Friedman test indicated no statistically significant differences across conditions, $\chi^2(2) = 0.163$, $p = .922$. As illustrated in **Figure 1**, a slight descriptive increase in frontal Theta power was observed for Good UX stimuli. Although not statistically significant, this pattern may suggest marginally increased attentional engagement or deeper cognitive processing when interacting with higher-quality interfaces.

3.1.2 Parietal Alpha Power

Parietal Alpha Power, derived from the Pz channel and commonly associated with cognitive relaxation and reduced task engagement, showed mean values of: Bad UX ($M = 4.92$, $SD = 10.64$), Medium UX ($M = 3.69$, $SD = 6.45$), and Good UX ($M = 6.97$, $SD = 27.61$). No statistically significant differences were observed across conditions (Friedman test, $\chi^2(2) = 0.403$, $p = .818$). As shown in **Figure 1**, Alpha power remained relatively low across all conditions, with a slight increase in the Good UX condition. The relatively large variability observed, particularly in the Good UX condition, suggests substantial inter-individual differences, potentially reflecting heterogeneous cognitive strategies across participants.

3.1.3 Frontal Beta-Low Power

Frontal Beta-Low Power, derived from AF3 and AF4 channels, is considered a proxy for active cognitive processing and engagement. Mean values were: Bad UX ($M = 2.76$, $SD = 6.77$), Medium UX ($M = 2.01$, $SD = 1.17$), and Good UX ($M = 2.29$, $SD = 2.11$). The Friedman test revealed no statistically significant differences across conditions, $\chi^2(2) = 0.209$, $p = .901$. As depicted in **Figure 1**, a slight increase in Beta-Low activity was observed for Bad UX stimuli. Although non-significant, this trend may reflect increased cognitive effort or compensatory processing when users interact with less intuitive or more demanding interfaces.

3.1.4 Theta/Alpha Ratio

The Theta/Alpha Ratio was computed as a composite index reflecting the balance between cognitive effort (Theta activity) and attentional regulation (Alpha activity), and is widely interpreted as an indicator of cognitive engagement. Mean values were: Bad UX ($M = 7.59$, $SD = 8.33$), Medium UX ($M = 7.54$, $SD = 8.17$), and Good UX ($M = 9.05$, $SD = 11.03$). The Friedman test did not reveal statistically significant differences across conditions, $\chi^2(2) = 0.581$, $p = .748$.

As shown in **Figure 2**, a consistent increase in the Theta/Alpha ratio was observed for Good UX stimuli compared to both Medium and Bad conditions. This pattern suggests a tendency toward higher cognitive engagement and more effective allocation of attentional resources when participants were exposed to higher-quality interfaces. While variability across participants remains considerable, the observed directional trend highlights the potential sensitivity of ratio-based EEG metrics in capturing subtle differences in user experience.

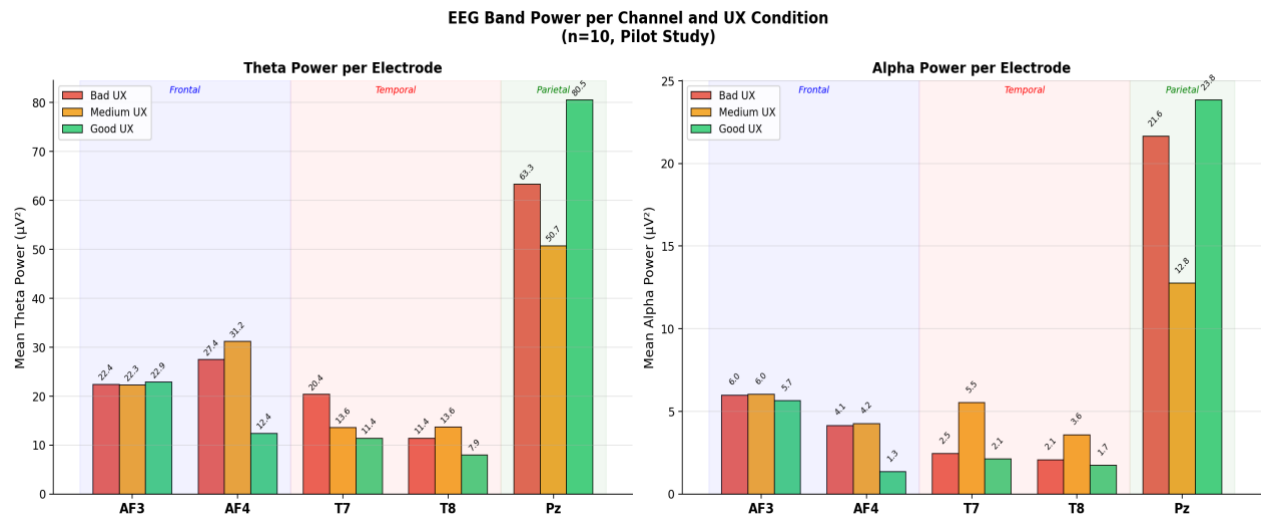


Figure 2. Mean Theta and Alpha power values are presented across five electrodes (AF3, AF4 = frontal; T7, T8 = temporal; Pz = parietal) for each UX condition (Bad, Medium, Good). Parietal activity (Pz) consistently exhibits the highest power values across conditions, particularly for Alpha in the Good UX condition. This pattern indicates increased attentional stability and reduced cognitive strain during exposure to higher-quality interfaces, **supporting the interpretation of improved user experience at the neurophysiological level.**

3.1.5 EEG by Experimental Block and UX Condition

Band power metrics were further examined across the three experimental blocks (Free Exploration, Goal-Oriented, Emergency Scenario), revealing context-dependent modulation of neurophysiological responses. As shown in **Figure 3**, Frontal Theta Power exhibited distinct patterns across blocks and UX conditions.

- In **Block 1 (Free Exploration)**, greater variability was observed, particularly in the Bad UX condition, with values ranging approximately from ~ 10 to $>100 \mu V^2$, while Good UX showed slightly higher central tendencies (medians around $\sim 20\text{--}30 \mu V^2$) compared to Medium and Bad UX. This pattern may reflect increased attentional engagement or exploratory processing when participants freely observe higher-quality interfaces without specific task constraints.
- In **Block 2 (Goal-Oriented Task)**, Theta activity appeared more evenly distributed across conditions, generally ranging between ~ 5 and $40 \mu V^2$, with overlapping distributions across all UX groups, suggesting that task demands may reduce the relative impact of UX quality, as participants allocate cognitive resources toward task completion rather than interface evaluation.

- In **Block 3 (Emergency Scenario)**, a shift in response patterns was observed, with Good UX stimuli showing relatively higher Theta values compared to other conditions. Good UX showed relatively higher Theta values (medians approximately $\sim 25\text{--}35 \mu\text{V}^2$) compared to Bad and Medium UX (typically $\sim 10\text{--}25 \mu\text{V}^2$), along with increased dispersion. This trend indicates increased cognitive engagement or more efficient allocation of attentional resources when users interact with more usable interfaces under time-pressure conditions.

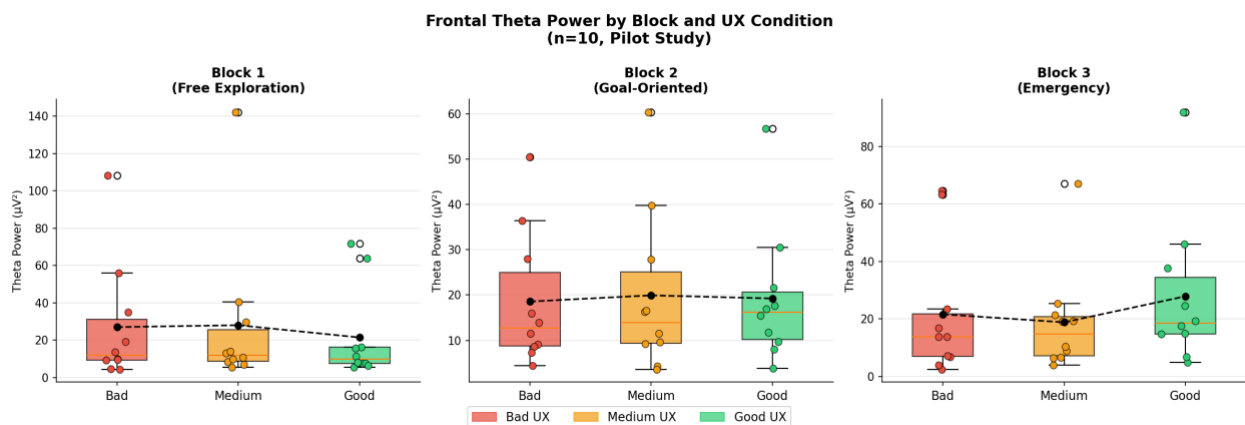


Figure 3. Boxplots illustrate the distribution of Frontal Theta Power across three experimental blocks (Free Exploration, Goal-Oriented, Emergency Scenario) and UX conditions (Bad, Medium, Good). Greater variability is observed in the Free Exploration condition, while more uniform patterns emerge in the Goal-Oriented task. In the Emergency Scenario, Good UX stimuli show relatively higher Theta values, suggesting increased cognitive engagement under time-pressure conditions. These patterns are descriptive and should be interpreted cautiously given the pilot sample size ($N = 10$).

Overall, these patterns indicate variation in Theta activity across task contexts and UX conditions, with the largest variability observed during free exploration and more comparable distributions during goal-oriented tasks. No statistically significant differences were observed ($p > .05$).

3.1.6 Topographic Distribution of EEG Activity

Topographic maps of Frontal Theta and Parietal Alpha power are presented in **Figure 4**. Despite the limited spatial resolution, these maps provide a qualitative view of regional activity across UX conditions. Theta activity (top row) appears broadly distributed across frontal regions (AF3, AF4), with similar intensity patterns across conditions (approximately

$\sim 20\text{--}30 \mu\text{V}^2$), indicating limited spatial differentiation. In contrast, Alpha activity (bottom row) shows a clear parietal dominance (Pz), with higher values in the Good UX condition (approximately $\sim 18\text{--}23 \mu\text{V}^2$) compared to Medium ($\sim 10\text{--}15 \mu\text{V}^2$) and Bad UX ($\sim 8\text{--}12 \mu\text{V}^2$). These patterns are descriptive and should be interpreted cautiously given the limited number of electrodes and the use of interpolation.

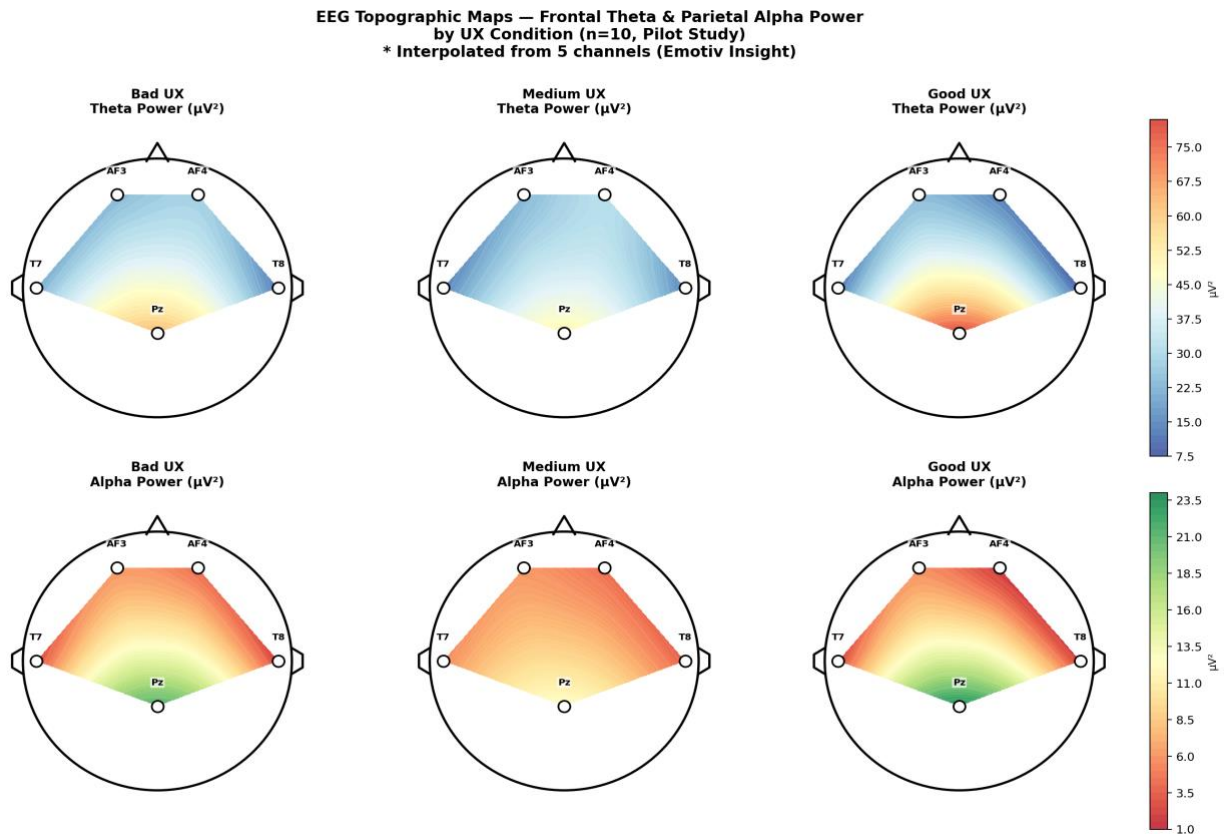


Figure 4. Topographic maps illustrate the spatial distribution of Frontal Theta (top row) and Parietal Alpha (bottom row) across UX conditions (Bad, Medium, Good), based on interpolation from five electrodes (AF3, AF4, T7, T8, Pz). Theta activity appears broadly distributed across frontal regions with minimal differentiation between conditions, whereas Alpha activity shows stronger parietal concentration (Pz), particularly in the Good UX condition. Maps are qualitative due to limited spatial resolution.

Descriptive statistics for all EEG band power metrics across UX conditions are summarized in **Table 2**. Mean values were comparable across conditions for Frontal Theta (Bad: $M = 22.39$, Medium: $M = 22.26$, Good: $M = 22.85$) and Beta-Low Power ($M \approx 2.0\text{--}2.8$). Parietal Alpha showed slightly higher mean values in Good UX ($M = 6.97$) compared to Bad ($M = 4.92$) and Medium UX ($M = 3.69$), while the Theta/Alpha ratio was also highest in Good UX ($M = 9.05$).

Table 2. EEG Band Power Metrics by UX Condition (N = 10)

EEG Metric	Bad UX		Medium UX		Good UX		χ^2 / p-value
	M	SD	M	SD	M	SD	
Frontal Theta Power	22.39	37.44	22.26	45.02	22.85	26.61	0.17/.922
Parietal Alpha Power	4.92	10.64	3.69	6.45	6.97	27.61	0.40/.818
Frontal Beta-Low Power	2.76	6.77	2.01	1.17	2.29	2.11	0.21/.901
Theta/Alpha Ratio	7.59	8.33	7.54	8.17	9.05	11.03	0.58/.748

NB. χ^2 = Friedman test statistic; p = asymptotic significance (two-sided). No comparisons reached statistical significance ($\alpha = .05$), consistent with the pilot nature of the study (N = 10).

3.2 Self-Reported Emotional Ratings (SAM)

Following the EEG session, participants evaluated each of the nine stimuli using the Self-Assessment Manikin (SAM), rating Emotional Valence (pleasant–unpleasant) and Arousal (low–high activation) on a 7-point Likert scale. Ratings were aggregated per UX condition across all participants. As shown in **Figure 5**, Emotional Valence demonstrates a clear and consistent gradient across UX conditions. Bad UX stimuli were associated with negative affect (M = 2.97), falling below the midpoint of the scale, while Medium UX received moderately positive evaluations, and Good UX elicited the highest valence ratings (M = 5.73). This pattern indicates that perceived usability is strongly associated with users' affective appraisal, even during brief visual exposure.

In contrast, Arousal levels remained relatively stable across conditions (M $\approx$ 5.8), with only minor variation between UX categories. This suggests that while UX quality influences the emotional tone of the experience (valence), it does not substantially affect the level of physiological or emotional activation under short exposure conditions.

Together, these findings indicate that UX quality primarily shapes **how users feel (valence)** rather than **how strongly they feel (arousal)**, highlighting a dissociation between affective evaluation and activation in early-stage interaction.

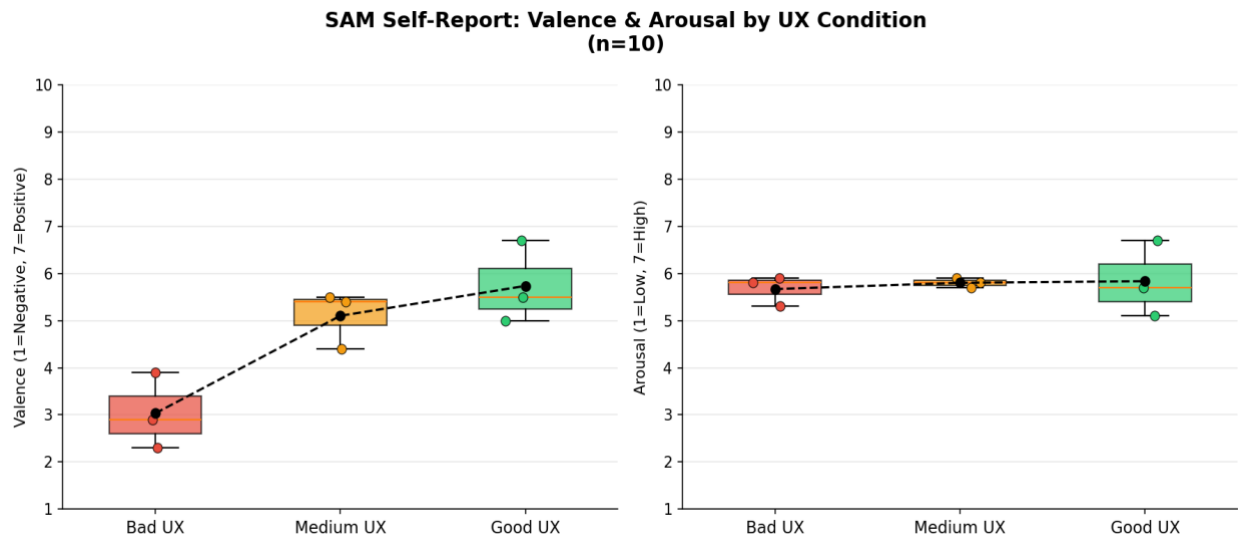


Figure 5. Boxplots illustrate participants' self-reported Emotional Valence (left) and Arousal (right) ratings across UX conditions (Bad, Medium, Good). Valence shows a clear positive gradient aligned with UX quality, with Bad UX associated with negative evaluations and Good UX with more positive affective responses. In contrast, Arousal levels remain relatively stable across conditions, indicating that emotional activation is not substantially modulated by UX quality during brief stimulus exposure.

3.2.1 Emotional Valence

Valence ratings exhibited a clear gradient across UX conditions, consistent with perceived interface quality (see **Table 3**). Bad UX stimuli received the lowest mean Valence rating ($M = 2.97$, $SD = 1.52$), falling below the midpoint of the scale, while Medium UX ($M = 4.97$, $SD = 1.78$) and Good UX stimuli ($M = 5.73$, $SD = 1.62$) were associated with increasingly positive affective evaluations. This pattern aligns with **Hypothesis (H1)**, suggesting that **websites previously classified as higher quality in the UX Audit elicited more positive emotional responses**. The fact that Bad UX is the only condition rated below the neutral midpoint further indicates a **clearly negative affective appraisal** of lower-quality interfaces.

3.2.2 Emotional Arousal

Arousal ratings, as presented in **Table 3**, remained relatively stable across UX conditions, with mean values of Poor UX ($M = 5.77$, $SD = 1.85$), Medium UX ($M = 5.93$, $SD = 1.41$), and Good UX ($M = 5.87$, $SD = 1.54$). No meaningful variation in Arousal was observed between conditions. This finding suggests that while UX quality influences the **direction of emotional experience (valence)**, it does not substantially affect the **intensity of emotional activation (arousal)** during brief visual exposure. Instead, arousal levels may be driven by

more general factors such as stimulus novelty or task context, rather than interface quality per se.

Table 3. SAM Emotional Ratings by UX Condition (N=10)

SAM Dimension	Poor UX		Medium UX		Good UX	
	M	SD	M	SD	M	SD
Emotional Valence (1-7)	2.97	1.52	4.97	1.78	5.73	1.62
Emotional Arousal (1-7)	5.77	1.85	5.93	1.41	5.87	1.54

NB. Scale: 1 = very negative / very low; 7 = very positive / very high. Values represent mean ratings across all nine stimuli per UX condition, averaged across all 10 participants.

3.3 Implicit Memory Test (IMT)

The Implicit Memory Test (IMT) assessed unconscious content retention through a recognition task comprising 29 terms (15 targets, 14 distractors). Results are reported at the individual level (Table 4), as the IMT was administered once per participant, capturing overall encoding during the experimental session. Mean recognition accuracy across participants was **M = 80.7% (SD = 6.6%)**, ranging from **69.0% (P7)** to **89.7% (P1, P4)**. The Memory Retention (MR) score averaged **M = 0.610 (SD = 0.139)**, with values ranging from **0.337 (P7)** to **0.798 (P1)**. Descriptively, MR scores were highest for **Good UX (M = 0.664)**, followed by **Medium UX (M = 0.647)**, and lowest for **Bad UX (M = 0.428)**.

Table 4. Implicit Memory Test Results per Participant

N	UX Group	Memory Retention (MR)	Accuracy (%)
P1	Website with Medium UX	0.798	89.7%
P2	Website with Medium UX	0.457	72.4%
P3	Website with Good UX	0.721	86.2%
P4	Website with Good UX	0.784	89.7%
P5	Website with Medium UX	0.673	82.8%

P6	Website with Bad UX	0.519	75.9%
P7	Website with Bad UX	0.337	69.0%
P8	Website with Good UX	0.582	79.3%
P9	Website with Medium UX	0.659	82.8%
P10	Website with Good UX	0.567	79.3%
Mean		0.610	80.7%

NB. MR = Memory Retention Score (Hit Rate – FA Rate); Accuracy (%) = proportion of correct responses (hits + correct rejections) out of 29 items.

3.4 Eye-Tracking Behavioral Data

Eye-tracking data were recorded during the second phase and manually coded to extract fixation counts, time to first fixation (TTFF), time on task, and task completion outcomes across four standardized tasks. Areas of Interest (AOIs) were defined per website based on task-relevant elements. Results are reported descriptively by task and UX condition.

3.4.1 Task 1 — Free Exploration

During Task 1, participants were invited to freely navigate the assigned website homepage and form an initial impression. Mean fixation counts were highest for Poor UX ($M = 36.50$, $SD = 2.12$), reflecting greater visual search effort during unconstrained exploration, compared to Medium UX ($M = 28.75$, $SD = 1.71$) and Good UX ($M = 22.50$, $SD = 1.29$). Gaze paths for Bad UX participants were notably more erratic, with frequent back-and-forth movements across unstructured content areas. Medium and Good UX participants demonstrated more directed gaze patterns, consistent with clearer visual hierarchies in those interfaces.

3.4.2 Task 2 — Cleaning & Recycling Information

Task 2 revealed clear differences in task performance across UX conditions (see Table 5). Participants in the Bad UX condition failed to complete the task (0% completion), with high fixation counts ($M = 74.0$) and prolonged task duration ($M = 110$ sec). In contrast, both Medium UX (100% completion; $M = 41.0$ fixations; $M = 64$ sec) and Good UX (100% completion; $M = 33.0$ fixations; $M = 52$ sec) enabled successful and more efficient task completion. These results indicate substantially higher search effort and task failure in the Bad UX condition.

Table 5. Eye-Tracking Metrics (Task 2: Cleaning & Recycling Information)

UX Condition	Mean Fixations	Mean TTFF (sec)	Mean Time on Task (sec)	Completion Rate	Completion Status
Bad UX	74.0	9	110	0%	Failed
Medium UX	41.0	3.6	64	100%	Efficient
Good UX	33.0	2.4	52	100%	Efficient

NB. Time thresholds: ≤60s = Efficient; 60–90s = Effortful; >90s or not found = Failed.

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3.4.3 Task 3 — Online Request Submission

In Task 3 (see **Table 6**), **Bad UX participants again failed to complete the task (0% completion)**, with elevated fixation counts (**M = 81.0**) and longer task duration (**M = 98 sec**). Both **Medium UX (100% completion; M = 37.0 fixations; M = 60 sec)** and **Good UX (100% completion; M = 45.6 fixations; M = 71 sec)** supported successful task completion, although Good UX required slightly higher effort. **Overall, Bad UX was consistently associated with task failure and increased visual search effort.**

Table 6. Eye-Tracking Metrics — Task 3: Online Request Submission

UX Condition	Mean Fixations	Mean TTFF (sec)	Mean Time on Task (sec)	Completion Rate	Completion Status
Bad UX	81.0	11.4	98	0%	Failed
Medium UX	37.0	4.5	60	100%	Efficient
Good UX	45.6	5.7	71	100%	Efficient

NB. Time thresholds: ≤60s = Efficient; 60–90s = Effortful; >90s or not found = Failed.

3.4.4 Task 4 — Language Accessibility (English Version)

Task 4 showed a reversed pattern (see **Table 7**). Participants in the **Bad UX condition successfully completed the task (100% completion; M = 21.0 fixations; M = 17 sec)**, while both **Medium UX and Good UX conditions failed (0% completion)**, as the feature was not available. Despite this, participants in Medium and Good UX conditions exhibited extended search behavior (**M = 68 and 54 fixations; M = 88 and 76 sec**, respectively). **This finding**

highlights that the presence or absence of a specific functionality, such as the Language Accessibility, can outweigh overall UX quality in task performance.

Table 7. Eye-Tracking Metrics — Task 4: English Language Accessibility

UX Condition	Mean Fixations	Mean TTFF (sec)	Mean Time on Task (sec)	Completion Rate	Completion Status
Bad UX	21.0	1.8	17	100%	Efficient
Medium UX	68.0	N/A	88	0%	Failed
Good UX	54.0	N/A	76	0%	Failed

NB. Time thresholds: ≤60s = Efficient; 60–90s = Effortful; >90s or not found = Failed.

3.5 Self-Reported Questionnaire (SRQ) - Post Eye-Tracking

Following the eye-tracking session, participants completed a 7-item self-reported questionnaire (SRQ) evaluating their experience on a 7-point Likert scale. Scores are reported per UX condition. Item Q7 (cognitive fatigue) was reverse-scored so that higher values indicate more positive experience.

- Participants in the **Bad UX condition** reported the lowest composite SRQ score (**M = 3.10, SD = 0.00**), indicating consistently negative evaluations. Low scores were observed across key items, including Ease of Use (**M = 2.00**) and Reuse Intention (**M = 2.50**), along with relatively low reversed fatigue scores (**M = 3.50**).
- The **Medium UX group** reported the highest composite SRQ score (**M = 6.13, SD = 0.88**), with consistently positive evaluations across items. Notably, this group showed high Ease of Use (**M = 5.00**). Reuse Intention (**M = 4.75**), and low cognitive fatigue (**M = 5.75**), with relatively low variability across responses.
- The **Good UX group** reported a moderate composite score (**M = 5.00, SD = 2.78**), accompanied by substantial inter-individual variability. Scores ranged from **2.38 to 7.86**, reflecting divergent user experiences within the same condition.

Table 8. Self-Reported Questionnaire (SRQ) Scores per UX Condition (Post Eye-Tracking)

UX Condition	Assigned Website	M	SD	Min	Max	Dominant Pattern
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Bad UX	Didymoteicho	3.10	0.00	3.10	3.10	Low ease of use; high fatigue
Medium UX	Mytilene	6.13	0.88	5.00	7.14	High ease & reuse; low fatigue
Good UX	Alexandroupolis	5.00	2.78	2.38	7.86	Mixed User Experience; P3 & P8 notably low

NB. SRQ: Higher scores indicate more positive subjective experience. Bad UX SD = 0.00 reflects identical scores for both participants (P6 = P7 = 3.10). Good UX shows high SD (2.78) driven by marked divergence between P3/P8 (low scorers) and P4/P10 (high scorers).

Table 9 presents item-level SRQ responses across UX conditions. Medium UX consistently received higher ratings across most dimensions, including Ease of Use (M = 5.00, SD = 0.82), Content Clarity (M = 4.50, SD = 0.58), Reuse Intention (M = 4.75, SD = 0.50), and low cognitive fatigue (Q7 reversed: M = 5.75, SD = 0.96). In contrast, Bad UX showed uniformly low scores across items (e.g., Ease of Use: M = 2.00, SD = 0.00; Reuse Intention: M = 2.50, SD = 0.71). The Good UX condition demonstrated more uneven responses, with relatively strong ratings in Content Relevance (M = 4.50, SD = 2.38) and Emotional Engagement (M = 4.00, SD = 1.41), but lower scores in Information Findability (M = 3.75, SD = 2.22) and Reuse Intention (M = 3.75, SD = 2.63), alongside higher variability across participants.

Medium UX yielded the highest and most consistent subjective experience scores, exceeding Good UX and indicating that higher audit-based UX quality does not necessarily correspond to more positive or stable user evaluations.

Table 9. Self-Reported Questionnaire (SRQ) Scores per Item (Post Eye-Tracking)

Item	Label	Bad UX			Medium UX			Good UX		
		M	SD	Min-Max	M	SD	Min-Max	M	SD	Min-Max
Q1	Ease of use	2.00	0.00	2-2	5.00	0.82	4-6	4.25	2.06	2-6

Q2	Information Findability	4.00	0.00	4-4	4.50	1.29	3-6	3.75	2.22	1-6
Q3	Content Clarity	3.00	1.41	2-4	4.50	0.58	4-5	3.75	1.50	2-5
Q4	Emotional Engagement	2.00	1.41	1-3	3.75	0.96	3-5	4.00	1.41	3-6
Q5	Content Relevance	3.00	1.41	2-4	4.50	1.00	3-5	4.50	2.38	2-7
Q6	Reuse Intention	2.50	0.71	2-3	4.75	0.50	4-5	3.75	2.63	1-6
Q7	Cognitive Fatigue (reverse score)	3.50	0.71	3-4	5.75	0.96	5-7	4.00	1.83	2-6
SQR Score		3.10	0.00	3.10-3.10	6.13	0.88	5.00-7.14	5.00	2.78	2.38-7.86

NB. SQ7 (cognitive fatigue) was reverse-scored prior to computation. All items rated on a 7-point Likert scale (1 = strongly disagree / very low; 7 = strongly agree / very high). Notable items reflect individual response patterns of interest.

3.6 Neurocognitive Engagement (NCE) Index

The NCE Index was computed for each participant by integrating six dimensions described in Section 2.6: Emotional Intensity (EI), Engagement (ENG), Cognitive Load (CL), Relevance derived from eye-tracking (R), Memory Retention (MR), and Self-Reported Quality (SRQ). Results are reported at both the individual and group level and compared to UX Audit scores from prior research (Tsatsani & Pollalis, 2025).

3.6.1 NCE Index per Participant

NCE scores ranged from **2.83 to 5.75**, with a sample mean of **M = 4.88 (SD = 0.73)** (see **Table 10**). All participants fell within either the **Low Engagement (NCE < 4.0)** or **Moderate Engagement (4.0–6.0)** categories, with no participant reaching higher engagement thresholds. Participants in the **Bad UX condition (P6, P7)** consistently exhibited the lowest NCE scores ($M \approx 3.52$), while Medium and Good UX participants clustered within the Moderate Engagement range.

Table 10. NCE Index Composite Score per Participant

N	UX Condition	EI	ENG	CL	R	MR	SRQ	NCE	ENG Category	UX Audit (%)
P1	Medium UX	4.93	0.16	8.76	6.46	7.98	6.19	5.75	Moderate Engagement	59%
P2	Medium UX	6.67	1.44	0.73	6.17	4.57	7.14	4.45	Moderate Engagement	59%
P3	Good UX	5.28	1.11	6.15	6.67	7.21	2.86	4.88	Moderate Engagement	84%
P4	Good UX	5.35	0.68	4.99	6.88	7.84	7.86	5.60	Moderate Engagement	84%
P5	Medium UX	5.90	2.80	2.92	6.35	6.73	5.00	4.95	Moderate Engagement	59%
P6	Bad UX	3.75	4.18	2.18	3.56	5.19	3.10	3.66	Low Engagement	28%
P7	Bad UX	4.79	0.38	4.47	4.10	3.37	3.10	3.37	Low Engagement	28%
P8	Good UX	4.24	3.09	3.98	6.49	5.82	2.38	4.33	Moderate Engagement	84%
P9	Medium UX	5.69	0.53	8.34	6.54	6.59	6.19	5.65	Moderate Engagement	59%
P10	Good UX	5.83	2.15	5.46	6.83	5.67	6.90	5.47	Moderate Engagement	84%

3.6.2 NCE Index by UX Group

Group-level analysis revealed a clear separation for the Bad UX condition, with **Bad UX** ($M = 3.52$, $SD = 0.21$) scoring substantially lower than both **Medium UX** ($M = 5.20$, $SD = 0.61$) and **Good UX** ($M = 5.07$, $SD = 0.58$). Importantly, the difference between Medium

and Good UX was minimal ($\Delta = 0.13$), despite a **25-percentage-point difference in UX Audit scores (59% vs 84%)**. **This convergence represents the central finding of the study.**

Table 11. Comparative Analysis: UX Audit Scores vs NCE Index

UX Condition	UX Audit (%)	NCE (M)	NCE (SD)	SQR (M)	SQR (SD)
Bad UX	28%	3.52	0.21	3.10	0.00
Medium UX	59%	5.20	0.61	6.13	0.88
Good UX	84%	5.07	0.58	5.00	2.78

3.6.3 Comparison with UX Audit Scores

As shown in **Table 12**, the relationship between UX Audit scores and NCE Index values is not linear. While **Bad UX (28%) aligns with low NCE (3.52)**, both **Medium UX (59%) and Good UX (84%) fall within the same Moderate Engagement range**, with comparable NCE values. Notably, self-reported results follow a similar pattern, with Medium UX scoring higher than Good UX in SRQ, further reinforcing the observed divergence between audit-based evaluations and user experience outcomes. **These results suggest that higher UX Audit scores do not necessarily translate into higher neurocognitive engagement.**

Table 12. Comparative Analysis: UX Audit Scores vs NCE Index

Municipality	UX Audit (%)	UX Category	NCE Index (0-10)	NCE Category	Interpretation
Didymoteicho	28%	Bad UX	3.52	Low Engagement	Consistent with Audit
Mytilene	59%	Medium UX	5.20	Moderate Engagement	NCE lower than Audit
Alexandroupolis	84%	Good UX	5.07	Moderate Engagement	NCE $\approx$ Medium UX

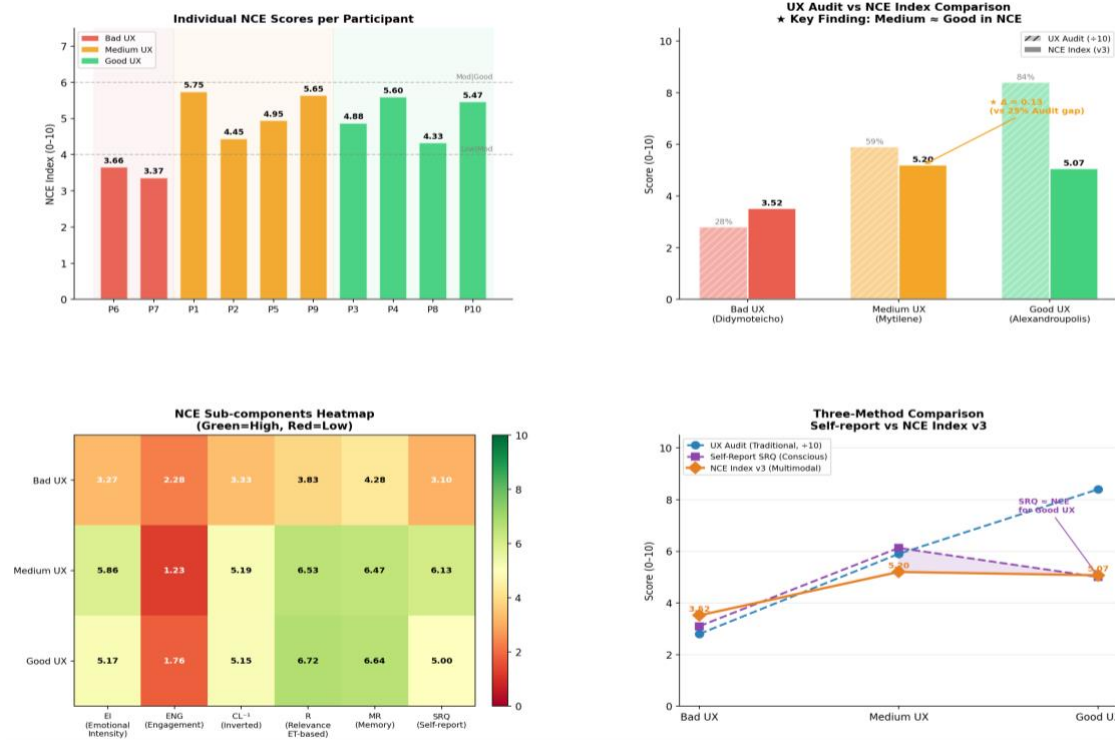


Figure 6. Top-left: Individual NCE scores by UX group. Top-right: Comparison between UX Audit scores and NCE group means, highlighting the minimal difference between Medium and Good UX despite a 25-point Audit gap. Bottom-left: Heatmap of NCE component contributions (EI, ENG, CL, R, MR, SRQ) across conditions. Bottom-right: Cross-method comparison illustrating the relationship between NCE, UX Audit, and SRQ scores.

4. DISCUSSION

This pilot study set out to examine whether differences in the UX quality of Greek municipal websites, as classified by a prior large-scale UX Audit, produce distinct patterns of cognitive, emotional, and behavioral engagement, as captured through a multimodal neuroscientific framework. The following discussion interprets the findings in relation to the study's research hypotheses, situates them within the existing literature, and reflects on their implications for UX evaluation methodology and local e-government design.

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Given the exploratory nature of the study and the small sample size ($N = 10$), results do not permit generalization. Instead, the discussion focuses on the plausibility and theoretical significance of the observed patterns, with particular attention to the divergence between neurocognitive indicators and traditional self-reported or expert-based evaluations.

4.1 UX Quality and User Experience Outcomes

H1 proposed that municipal websites with higher UX quality would be associated with more positive user experience outcomes, reflected in both behavioral and perceptual responses. The findings provide **partial but meaningful support** for this hypothesis.

The strongest support for H1 comes from the SAM self-reported ratings, where Emotional Valence followed a clear gradient consistent with UX quality. Bad UX stimuli received the lowest mean Valence rating ($M = 2.97$), Medium UX received a moderate rating ($M = 4.97$), and Good UX elicited the most positive evaluations ($M = 5.73$). This pattern suggests that participants were able to consciously detect and respond to differences in visual quality and overall interface coherence across the three websites. In this respect, the findings align with prior literature showing that interface quality shapes affective appraisals during digital interaction (Hassenzahl & Tractinsky, 2006; Galvez & Youngblood, 2016).

At the multimodal level, the NCE Index also differentiated the Bad UX condition clearly from the other two, with Bad UX showing substantially lower engagement ($M = 3.52$, $SD = 0.21$) than both Medium UX ($M = 5.20$, $SD = 0.61$) and Good UX ($M = 5.07$, $SD = 0.58$). This indicates that the overall framework was sensitive to meaningful differences in experience quality.

At the same time, the near-equivalence between Medium and Good UX on the NCE Index ($\Delta = 0.13$) suggests that improvements in audit-based UX quality may not always translate into proportionally stronger neurocognitive engagement once a certain usability

threshold has been reached. Rather than contradicting H1, this finding indicates that the most substantial experiential difference lies between clearly poor interfaces and those that achieve at least a moderate level of usability. In other words, users appear to benefit strongly from moving away from poor UX, while differences between medium and high-performing websites may become more subtle at the cognitive and emotional level.

Overall, these findings support H1 while challenging the assumption that improvements in audit-based UX quality lead to proportional gains in user experience. Although higher UX quality is associated with more positive outcomes (i.e. Sonderegger et al., 2019), particularly in conscious affective evaluation and in distinguishing poor from usable interfaces, the results suggest that these gains are not strictly linear across all UX levels (Kujala et al., 2011).

4.2 Age-Related Differences in Interaction Patterns

H2 proposed that differences in UX quality would be reflected in users' interaction patterns and engagement levels across diverse user groups, regardless of digital familiarity. While the present pilot study was not designed to formally test between-group differences, the findings offer preliminary insights **consistent** with this hypothesis at the **descriptive level**.

Substantial inter-individual variability was observed across EEG band power metrics, with some participants exhibiting higher absolute values (e.g., P5, P6) compared to others (e.g., P1, P3). This pattern is consistent with established findings in the EEG literature where baseline neural activity and responsivity vary across individuals due to cognitive, demographic, and physiological factors (Moore and Depue, 2016; Cohen, 2010; Fontanini and Katz, 2008). Rather than limiting interpretation, this variability highlights the sensitivity of neurophysiological measures in capturing individual differences in how users process and respond to digital environments.

Importantly, despite this variability, convergent patterns emerged across multiple measures. For example, the participant with the lowest overall engagement (P7, Bad UX) consistently showed lower performance across all modalities, including NCE (3.37), IMT accuracy (69.0%), and SRQ (3.10). This alignment suggests that the multimodal framework is capable of detecting coherent user experience patterns even at the individual level.

At the group level, no clear association was observed between SRQ scores and potential generational differences; however, responses were generally consistent within UX conditions, particularly in the Medium UX group, which showed both higher and more stable subjective ratings.

Overall, while the current data do not allow for definitive conclusions regarding the role of demographic factors such as age or digital familiarity, the findings suggest that UX-related effects can be detected across users despite individual variability, supporting the conceptual premise of H2. Future research with larger and more balanced samples will be necessary to further examine how user characteristics interact with UX quality in shaping engagement.

4.3 Limitations of Self-Reported Measures

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H3 proposed that self-reported measures would not fully capture real-time cognitive and behavioral responses. The findings provide **direct and compelling support** for this hypothesis, and represent the most practically significant contribution of the study.

A divergence was observed between subjective evaluations and multimodal engagement indicators. Participants in the Good UX condition reported positive experiences, reflected in SRQ scores ($M = 5.00$), while Medium UX yielded even higher subjective ratings ($M = 6.13$). However, at the neurocognitive level, the NCE Index showed near-identical engagement between Medium and Good UX ($M = 5.20$ vs $M = 5.07$, $\Delta = 0.13$). This suggests that differences captured through conscious evaluation were not mirrored in underlying cognitive and behavioral responses (Baumeister et al., 2011; Chartrand, 2005).

Rather than indicating inconsistency, this pattern reflects the complementary nature of self-reported and implicit measures. Self-reports primarily capture conscious appraisal and perceived quality, whereas neurophysiological and behavioral metrics reflect real-time processing, cognitive effort, and engagement dynamics during interaction (Wiedbusch et al., 2023).

In the context of **e-democracy and public-sector digital services**, this means that municipalities may invest heavily in refining a website that citizens consciously rate as good, without realizing that the actual cognitive experience is no different from a mediocre one. Citizens may say they are satisfied, but the neurocognitive data suggest they are not meaningfully more engaged, cognitively or emotionally. As a result, users are unlikely to engage with these platforms more frequently or more effectively, thereby undermining the core goals of digital governance, namely participation, transparency, and service delivery, consistent with findings from previous studies (i.e. Tsatsani and Pollalis, 2025; 2024).

For **businesses and organizations** investing in digital product development, the implications are equally serious. If design decisions are based solely on self-reported user

satisfaction, which is susceptible to halo effects, social desirability bias, and the inability to articulate unconscious experience, organizations may invest significant financial and human resources in optimizing products that users already perceive as adequate at the conscious level, while the underlying cognitive experience remains flat. The NCE Index, by contrast, captures what users cannot or do not report: the real depth of their engagement, cognitive load, and emotional investment. These are the implicit drivers of adoption, loyalty, and behavioral use, and they are systematically underestimated by traditional evaluation tools. **In simple terms, a user who says a product is good may not actually use it more. A user whose brain shows genuine engagement will** (Lalmas and Yom-Tom, 2022).

Overall, the results support H3 by demonstrating that **self-reported experience and real-time engagement represent related but distinct dimensions of UX**, both of which are necessary for a complete assessment.

4.4 EEG as a Measure of Cognitive and Emotional Variation

H4 proposed that neurophysiological measures through EEG would capture variations in users' cognitive and emotional responses associated with differences in UX quality. The findings provide **clear directional support** for this hypothesis, demonstrating that EEG is capable of **capturing subtle variations in user experience that are not fully reflected in traditional evaluation metrics** (i.e. Bellos et al., 2025; Frey et al., 2016).

Across conditions, consistent patterns emerged in key EEG indicators. The Theta/Alpha Ratio, associated with cognitive engagement (i.e. Kamzanova et al., 2015), was highest in the Good UX condition ($M = 9.05$) compared to Bad ($M = 7.59$) and Medium UX ($M = 7.54$), suggesting relatively enhanced engagement during interaction with higher-quality interfaces. Similarly, Parietal Alpha Power showed higher values in the Good UX condition ($M = 6.97$) compared to Bad ($M = 4.92$) and Medium UX ($M = 3.69$), indicating a tendency toward reduced cognitive strain and more efficient processing (i.e. Bonnefond and Jensen, 2025; Chen et al., 2020).

Importantly, EEG measures revealed patterns that were not apparent in self-reported or audit-based evaluations. While subjective ratings differentiated UX conditions primarily at the perceptual level, EEG data captured continuous variation in cognitive engagement and effort, even between conditions that appeared similar in traditional metrics. This highlights the added sensitivity of neurophysiological measures in detecting differences in how users process and experience digital interfaces in real time.

Block-level analyses further demonstrated that EEG responses are context-sensitive. During free exploration, higher-quality interfaces were associated with patterns indicative of more efficient cognitive processing, whereas under time-pressure conditions, neural activity shifted across all UX levels, suggesting that task demands dynamically interact with interface quality.

The observed topographic patterns further suggest that UX quality influences not only the intensity but also the spatial distribution of neural activity, with higher-quality interfaces associated with more localized and stable attentional processing, implying that users are able to focus their attention more effectively and process information with less effort during interaction.

Overall, these findings position EEG as a sensitive tool for capturing cognitive and emotional dynamics that remain partially inaccessible through conventional UX measures. Rather than replacing traditional metrics, it provides a complementary layer of insight into how users experience digital systems. Importantly, the results indicate that the neurocognitive impact of UX is context-dependent, with interface quality playing a more prominent role under high-demand, time-constrained conditions.

4.5 Eye-Tracking and Attention Allocation

H5 proposed that eye-tracking measures would reflect differences in attention allocation and navigation efficiency. The findings provide strong support for this hypothesis, demonstrating that behavioral metrics capture clear and actionable differences in user interaction across UX conditions.

Distinct patterns emerged in task performance, fixation behavior, and time on task. The Bad UX condition was consistently associated with unsuccessful task completion, elevated fixation counts (e.g., $M \approx 74\text{--}81$), and prolonged interaction times (up to ~ 110 seconds), indicating increased cognitive effort and inefficient navigation. These patterns reflect disorientation and difficulty in locating task-relevant information.

In contrast, both Medium and Good UX conditions demonstrated high completion rates (100%), reduced fixation counts (e.g., $\sim 33\text{--}41$), and shorter task durations (approximately 50–65 seconds), suggesting more efficient information processing and clearer navigation structures. Gaze patterns in these conditions were also more directed, indicating improved information architecture and reduced search effort.

Importantly, differences between Medium and Good UX were more nuanced. While Good UX facilitated faster access in some cases (e.g., visible entry points), it did not consistently outperform Medium UX across all tasks. In more complex navigation scenarios, additional steps or structural depth introduced measurable friction, reflected in increased fixations and longer completion times (e.g., ~71 seconds in Task 3).

These findings suggest that eye-tracking measures are particularly effective in capturing behavioral efficiency and interaction friction, offering direct insight into how users navigate and process interface structures (Wegner et al., 2020; Macdonald and Tatler, 2018). While poor UX clearly disrupts usability, improvements beyond a functional level appear to yield more incremental gains, highlighting the importance of optimizing not only structure but also task-specific pathways and content accessibility.

4.6 Implicit Memory and Cognitive

H6 proposed that implicit memory performance and cognitive encoding of website content would vary according to UX quality. The findings provide consistent directional support for this hypothesis, indicating that interface quality influences how effectively content is encoded and retained.

Overall, participants demonstrated relatively high recognition accuracy ($M = 80.7\%$, $SD = 6.6\%$) and moderate Memory Retention scores (MR: $M = 0.610$, $SD = 0.139$), suggesting that the IMT paradigm was effective in capturing implicit encoding during the experimental session (Gehrke et al., 2018).

At the group level, a clear pattern emerged: participants in the Good UX condition showed the highest mean MR scores ($M = 0.664$), followed closely by Medium UX ($M = 0.647$), while Bad UX showed substantially lower retention ($M = 0.428$). This trend suggests that more usable and structured interfaces support more efficient cognitive encoding by reducing the cognitive effort required for navigation and interpretation (Grunwald and Corsbie-Massay, 2006).

Importantly, this pattern aligns with findings from behavioral and neurophysiological measures, reinforcing the consistency of the multimodal framework. While differences between Medium and Good UX were relatively small, both conditions outperformed Bad UX, indicating that the most substantial gains in memory performance occur when usability reaches at least a functional threshold (Punchoojit and Hongwarittorn, 2017).

At the individual level, the lowest memory performance was observed in a participant assigned to the Poor UX condition (P7: $MR = 0.337$; accuracy = 69.0%), consistent with increased cognitive load and reduced processing efficiency. Although individual variability is expected, the convergence of lower memory performance with lower engagement across other measures further supports the relationship between UX quality and encoding.

Taken together, these findings suggest that UX quality influences not only how users interact with content, but also how effectively that content is retained. Implicit memory measures therefore provide a valuable complementary perspective in UX evaluation, particularly in contexts such as e-government, where successful interaction depends on users' ability to locate, understand, and remember information (Jia et al., 2026; Zhang et al., 2025; Aldrees and Gračanin, 2023).

4.7 The Value of a Multimodal Approach

H7 proposed that a multimodal approach combining neurophysiological, behavioral, and self-reported measures would provide a more comprehensive assessment of user experience than any single method alone. The present findings offer strong empirical support for this hypothesis and represent one of the central contributions of the study.

The value of multimodality becomes particularly evident when comparing how individual methods capture UX quality. When considered in isolation, each measurement approach provides a partial and method-specific perspective:

The UX Audit clearly differentiated all three websites (28%, 59%, 84%), but as an expert-based evaluation, it reflects structural quality rather than actual user experience during interaction.

Self-reported measures (SRQ) successfully identified Poor UX as the lowest-performing condition but suggested a different ranking between Medium and Good UX (Medium: $M = 6.13$, Good: $M = 5.00$), highlighting that perceived experience does not always align with expert evaluations.

EEG measures captured continuous variation in cognitive engagement and effort, revealing subtle differences across conditions, but without a single standalone metric fully distinguishing between UX levels.

The Implicit Memory Test (IMT) provided evidence of differential content encoding (Good: $M = 0.664$, Medium: $M = 0.647$, Bad: $M = 0.428$), yet as a global measure, it cannot independently resolve UX quality differences across conditions.

When these measures are integrated through the NCE Index, a more coherent and informative pattern emerges. The composite results clearly differentiate the Bad UX condition ($M = 3.52$) from the other two, while revealing near-identical engagement levels between Medium and Good UX ($M = 5.20$ vs $M = 5.07$; $\Delta = 0.13$). This pattern is not visible in any single method alone.

This convergence is critical: it demonstrates that user experience is not a single-layer construct, but the outcome of interacting perceptual, behavioral, and neurocognitive processes. Methods such as self-reports capture conscious evaluation, eye-tracking reflects observable behavior, EEG reveals underlying cognitive dynamics, and memory measures capture encoding outcomes. Only through their integration can these layers be meaningfully aligned.

Importantly, the multimodal approach does not simply aggregate data; it resolves contradictions between methods. For example, while audit scores and subjective ratings suggest a clear superiority of Good UX, the integrated neurocognitive profile indicates that Medium and Good UX produce comparable levels of engagement. This finding challenges the assumption that improvements in structural UX quality necessarily translate into proportionally improved user experience.

This divergence between self-reported evaluations and neurocognitive measures can be interpreted through the lens of dual-process theories of cognition. Self-reported ratings primarily reflect **System 2 processing**, involving conscious, reflective judgment, whereas EEG, eye-tracking, and implicit memory measures capture aspects of **System 1 processing**, which operates automatically and often outside conscious awareness (i.e. Da Silva, 2023; Wickens and Carswell, 2021; Simon, 1981). The present findings suggest that while users are able to consciously evaluate interface quality, their underlying cognitive and emotional engagement may remain unaffected. This reinforces the idea that UX is not solely a reflective judgment, but a multi-layered process shaped by both conscious and unconscious mechanisms.

Taken together, the findings support the growing view in UX and Neuroimaging research that methodological triangulation is essential for capturing the full complexity of human–computer interaction. In applied contexts such as e-government, where user experience

directly impacts accessibility, trust, and service effectiveness, multimodal frameworks offer a more accurate and actionable basis for evaluation than any single method alone.

4.8 The NCE Index as a Novel Evaluative Contribution

Beyond the specific hypotheses addressed in the preceding sections, this study introduces the Neurocognitive Engagement (NCE) Index as its primary methodological contribution to UX evaluation. The NCE Index represents a novel attempt to operationalize user experience as a multidimensional construct, integrating both implicit and explicit indicators within a unified evaluative framework.

The index combines five complementary dimensions, namely the Emotional Intensity (EI), Engagement (ENG), Cognitive Load (CL), Relevance (R), and Self-Reported Quality (SRQ), each corresponding to a distinct layer of human–computer interaction. By integrating neurophysiological (EEG), behavioral (eye-tracking), cognitive (IMT), and subjective (SAM, SRQ) measures, the NCE Index captures aspects of experience that remain inaccessible when these methods are used in isolation.

The pilot findings demonstrate both the theoretical coherence and practical applicability of this approach. The NCE Index clearly differentiates the Bad UX condition ($M = 3.52$), placing it within a lower engagement range, while Medium and Good UX cluster closely within a higher engagement band ($M = 5.20$ vs 5.07 ; $\Delta = 0.13$). Importantly, this pattern diverges from the UX Audit ranking (28%, 59%, 84%), indicating that improvements in structural UX quality do not necessarily translate into proportionally enhanced neurocognitive engagement.

This divergence is not a methodological artifact but a meaningful empirical insight. It suggests the presence of a functional engagement threshold, beyond which further improvements in interface quality yield limited gains in cognitive and emotional response. In this context, Medium UX appears to achieve a level of usability sufficient to support efficient interaction, while additional refinements associated with Good UX do not produce a commensurate increase in underlying engagement.

The implications of this finding are particularly relevant for public-sector digital systems. Municipalities investing in incremental UX improvements — for example, moving from moderate to high audit scores — may not achieve proportional gains in how citizens cognitively process, retain, or engage with information. Instead, greater value may lie in optimizing specific experience dimensions, such as reducing cognitive load, improving content relevance, and supporting goal-directed navigation.

More broadly, the NCE Index contributes to UX methodology by demonstrating that user experience is inherently multi-layered and cannot be reliably inferred from any single measurement domain. While self-reports reflect conscious evaluation, behavioral metrics capture observable interaction, and EEG reveals underlying cognitive dynamics, it is their integration that provides a more ecologically valid representation of experience.

The modular structure of the NCE Index allows for adaptability across research and applied contexts. Individual components can be adjusted or extended depending on available tools and evaluation goals, making the framework suitable for both public-sector platforms and commercial digital products. As demonstrated in this pilot study, the index provides a scalable approach for translating complex multimodal data into a single interpretable metric without sacrificing conceptual depth.

Finally, the NCE Index establishes a foundation for future research in neuroadaptive UX evaluation, where design decisions can be informed not only by what users report or do, but by how they cognitively and emotionally process digital environments in real time.

Note on Intellectual Property. The detailed computational architecture of the NCE Index, including weighting schemes, normalization procedures, and sub-component derivations, constitutes proprietary intellectual property and is subject to formal protection. Full technical specifications will be made available through appropriate channels following registration.

4.9 Implications for UX Evaluation in Local e-Government

The findings of this study carry important implications for the evaluation and design of municipal digital platforms, both in Greece and in broader e-government contexts.

First, the results demonstrate that structural UX audits, while valuable, are insufficient as standalone evaluation tools. The observed divergence between UX Audit scores (28%, 59%, 84%) and neurocognitive engagement (NCE: 3.52 vs 5.20 vs 5.07) indicates that expert-based assessments do not necessarily reflect how users cognitively and emotionally experience a system. This suggests that public-sector evaluation frameworks should move beyond purely structural criteria and incorporate measures that capture real-time user responses.

Second, the study highlights the need to expand the definition of UX quality beyond task success and self-reported satisfaction. Metrics such as cognitive load, emotional intensity, and implicit memory performance provide critical insight into how users process and retain information, dimensions that are particularly relevant in e-government environments, where interactions are often goal-oriented, time-sensitive, and information-heavy. The observed

patterns across EEG and memory measures reinforce the importance of capturing these deeper layers of experience.

Third, the findings demonstrate the practical feasibility of applying neuroscientific methods in applied UX contexts. The use of portable, consumer-grade EEG equipment (Emotiv Insight) was sufficient to detect meaningful variations in neurocognitive responses across UX conditions. This supports the scalability of neuro-UX approaches and suggests that such methods can be integrated into real-world evaluation settings without requiring highly controlled laboratory environments.

4

Finally, the study introduces the NCE Index as a scalable and adaptable evaluation framework for digital systems. By integrating neurophysiological, behavioral, cognitive, and self-reported data, the index enables a more comprehensive assessment of user experience that aligns more closely with actual user engagement than traditional methods alone. Its modular structure allows for flexible implementation across different contexts, making it applicable not only to municipal platforms but also to a wide range of public and commercial digital services.

Overall, these implications point toward a shift from single-method evaluation to integrated, multimodal UX assessment, offering a more accurate and actionable foundation for design decisions in digital governance.

4.10 Limitations and Future Research Directions

This study represents a pilot implementation, and certain limitations should be considered. The small and homogeneous sample ($N = 10$) limits generalizability, while some measures (e.g., manual eye-tracking coding and global IMT administration) constrained the granularity of condition-specific analysis.

At the same time, the study deliberately employed a portable EEG system (Emotiv Insight) to prioritize real-time, non-invasive data collection in an applied setting. While lower in spatial resolution compared to laboratory-grade systems, the device proved effective in capturing meaningful variations in cognitive and emotional engagement, supporting its suitability for scalable UX evaluation.

The current version of the NCE Index is based on equal component weighting, serving as a theoretically grounded starting point. Future research can further refine this structure and validate its components across larger and more diverse samples.

Overall, the study provides a strong proof-of-concept for multimodal, neuroscience-informed UX evaluation. Future work should expand this approach with larger samples and enhanced measurement precision, while preserving the key advantage demonstrated here: the ability to capture real-time, ecologically valid user experience using portable technologies.

5

Chapter 5

5

How Can Municipal Platforms Be Redesigned to Better Serve Citizens?

Translating UX and Neurophysiological Insights into Design

This chapter has been submitted for publication under the title:

Tsatsani, O. and Pollalis, Y., 2026. From Neural Evidence to Design Practice: A Neurocognitive-informed Framework for Greek Municipal Websites

Abstract

The design of local e-government services in Greece continues to rely primarily on expert-based usability audits and self-reported satisfaction measures. However, emerging evidence from neuroscience suggests that such approaches may systematically overestimate users' actual cognitive and emotional experience. This paper proposes a Neurocognitive-Informed Design Framework for Greek municipal websites, grounded in empirical findings from a multimodal pilot study combining EEG, eye-tracking, implicit memory testing, and self-reported measures across three websites of varying UX quality. Building on the Neurocognitive Engagement (NCE) Index, namely a composite metric integrating neurophysiological, behavioral, and subjective indicators of User Experience (UX) the proposed framework comprises: (a) a Multimodal Cognitive and Affective Brain Map, (b) six Neurocognitive Design Principles derived from observed user responses, and (c) a conceptual prototype of an ideal municipal website, supported by annotated wireframes and a Three-Level Implementation Model. The framework is positioned as an evidence-based foundation for neurocognitive-informed digital transformation in local governance, with implications for public-sector design practices, digital investment strategies, and the advancement of citizen-centered e-government services promoting e-democracy. Computational details of the NCE Index are subject to intellectual property protection.

Keywords: neurodesign, e-government, municipal websites, UX evaluation, cognitive load, NCE Index, digital transformation, brain-informed design, citizen experience, local governance

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INTRODUCTION

Greek municipal websites constitute the primary digital interface between local governments and citizens. However, a large-scale UX audit of 138 municipalities (Tsatsani & Pollalis, 2024) revealed that the majority fail to meet even basic usability standards, with fewer than 20% achieving scores above 70% across a nine-dimension evaluation framework.

More critically, a subsequent neuroscientific pilot study (Tsatsani & Pollalis, 2025) demonstrated that websites classified as “high-quality” based on expert evaluations do not produce significantly higher levels of neurocognitive engagement compared to “medium-quality” websites. This finding suggests that prevailing UX evaluation approaches may systematically misrepresent actual user experience and, consequently, lead to suboptimal allocation of design and digital investment resources.

In response, this paper introduces a neurocognitive-informed design framework that translates brain-level evidence into actionable guidance for designers, product owners, and digital governance stakeholders responsible for municipal digital services in Greece. Rather than prescribing a single optimal design solution, the framework proposes a set of evidence-based design principles, grounded in the neural correlates of user experience, which can be flexibly applied across municipalities with varying levels of digital maturity and resource availability.

The paper makes three interrelated contributions. First, it presents a Multimodal Cognitive and Affective Brain Map, offering a visual synthesis of the neural mechanisms underlying interaction with digital interfaces, informed by the study’s empirical findings. Second, it derives six Neurocognitive Design Principles, each aligned with a component of the NCE Index, translating neurophysiological evidence into actionable design guidance. Third, it proposes a Conceptual Model of an Ideal Municipal Website, illustrated through annotated wireframes and supported by a three-level implementation model.

The proposed framework is positioned as a pilot-evidence-based starting point, rather than a validated design standard, and is developed in alignment with the conceptual and prescriptive tradition of design science research (Gregor & Hevner, 2013; Hevner et al., 2004).

1. LITERATURE REVIEW

1.1 Neurodesign and Human–Computer Interaction

The application of neuroscientific methods to design research, variously termed *neurodesign*, *neuroaesthetics*, or *neuroergonomics*, has expanded significantly over the past two decades (Orashi et al., 2022). This growth has been driven both by advances in portable

neuroimaging technologies and by increasing recognition that human decision-making and aesthetic judgment operate largely below the threshold of conscious awareness (Cherubino et al., 2019; Vecchiato et al., 2014).

Within the context of Human–Computer Interaction (HCI) and UX research, EEG-based metrics such as cognitive load (e.g., frontal theta activity), attentional engagement (e.g., parietal alpha modulation), and affective arousal have been widely applied to the evaluation of digital interfaces, including websites and mobile applications (Mühl et al., 2014; Fairclough, 2009). Eye-tracking methodologies complement these measures by capturing behavioral indicators of attention allocation, with metrics such as fixation count, time to first fixation (TTFF), and gaze duration providing objective proxies for visual search effort and information discoverability (Holmqvist et al., 2011; Rayner, 1998).

In parallel, implicit memory testing, often operationalized through Signal Detection Theory and quantified via Memory Retention (MR) scores (Hit Rate minus False Alarm Rate), offers a measure of unconscious content encoding that remains inaccessible to self-reported data (Schacter, 1987). Collectively, these approaches form a multimodal evaluation toolkit capable of capturing dimensions of user experience that extend beyond conscious perception (Roto et al., 2011).

These findings support the formulation of the following hypothesis:

H1. Differences in UX quality will be reflected in distinct neurocognitive, behavioral, and affective response patterns during interaction with municipal websites.

1.2 UX in Local e-Government

Research on the usability and citizen experience of e-government services has consistently identified structural deficiencies across diverse national contexts (Alrawabdeh, 2014; Shareef et al., 2011; Verdegem & Verleye, 2009). In Greece, the adoption and effective use of municipal digital services remain below European averages, despite continued investment in digital infrastructure. Prior audit-based research has highlighted persistent usability issues, particularly in navigation complexity, information architecture, and accessibility, as key barriers to citizen engagement (Tsatsani and Pollalis, 2024).

However, existing e-government UX research has relied predominantly on self-reported satisfaction measures and expert heuristic evaluations. As suggested by emerging neuroscientific evidence and further supported by the present study, such methods may not adequately capture the implicit cognitive and emotional dimensions of user experience. The application of neurophysiological methods in the evaluation of public-sector digital services

remains limited, with only a small number of studies exploring this intersection (Alrawabdeh, 2014).

Against this backdrop, the present study seeks to bridge this gap by integrating neuroscientific evidence into the evaluation and design of municipal digital services.

These observations lead to the following hypothesis:

H2. Multimodal measures of user experience (e.g., EEG, eye-tracking, and implicit memory) will reveal patterns of interaction and engagement not captured by traditional self-reported and audit-based evaluations.

1.3 Design Science and Conceptual Frameworks

The methodological positioning of this study is grounded in the design science research tradition (Hevner et al., 2004; Gregor and Hevner, 2013), which recognizes the development of design artifacts, such as frameworks, models, methods, and instantiations, as a valid and impactful form of scholarly contribution. Within this paradigm, conceptual frameworks derived from empirical evidence and proposed for future validation are classified as Level 2 contributions (“Improvement”), representing novel artifacts that extend existing knowledge to address identified problems (Gregor and Hevner, 2013).

The framework proposed in this study is explicitly situated within this tradition. It is grounded in pilot empirical findings, intended as a foundation for future validation, and designed to function as a practical resource for stakeholders involved in digital governance and public-sector service design.

These insights motivate the following hypothesis:

H3. Neurocognitive and behavioral response patterns can be systematically translated into actionable design principles for digital interfaces.

1.4 Study Objectives

Building on the limitations of traditional UX research and the emerging role of neurocognitive methods, the present study aims to investigate how differences in the UX quality of municipal websites are reflected in users’ cognitive, behavioral, and experiential responses. In particular, the study examines whether websites previously classified as having good, medium, or poor UX produce distinct patterns of interaction, attention allocation, and information processing.

To address this objective, a multimodal research framework is employed, integrating electroencephalography (EEG), eye-tracking, implicit memory testing, and self-reported measures. This approach enables the simultaneous examination of both conscious and

unconscious dimensions of user experience, moving beyond the limitations of single-method evaluation techniques.

Within this context, the study introduces, on a pilot basis, the Neurocognitive Engagement (NCE) Index, a composite metric that integrates neurophysiological, behavioral, and subjective indicators (EEG, eye-tracking, memory performance, and self-reports) into a unified evaluative framework. The NCE Index is proposed as a step toward a more holistic and evidence-based assessment of user interaction, supporting more informed design and decision-making in digital public services.

Beyond evaluation, the study aims to translate multimodal empirical findings into design-relevant insights, contributing to the development of a neurocognitive-informed design framework for municipal websites. This framework is intended to provide structured and scalable guidance for improving usability across varying levels of digital maturity within local e-government systems.

These objectives lead to the formulation of the following hypothesis:

H4. A neurocognitive-informed design framework derived from multimodal user data can provide structured guidance for improving municipal website usability across varying levels of UX quality.

METHODS

2.1 Study Design

The design framework presented in this paper is derived from the empirical findings of a multimodal neuroscientific pilot study, reported in full in a companion publication “*Beyond Self-Report: A Neurocognitive Approach to UX Evaluation of Greek Municipal Websites — A Pilot Study*” (Tsatsani and Pollalis, 2025)

The study employed a **multimodal UX evaluation approach**, integrating electroencephalography (EEG), eye-tracking, implicit memory testing, and self-reported measures, in order to capture both conscious and non-conscious dimensions of user experience. The present section provides a concise methodological overview; full technical details are available in the companion paper.

2.2 Participants

The sample consisted of $N = 10$ adult male participants, recruited through convenience sampling. The inclusion of male participants only was intended to control for

potential gender-related variability in neurophysiological responses, as documented in prior EEG research (reference).

Participants were distributed across three generational cohorts Generation Z (18–27 years), Millennials (28–43 years), and older adults (44–55+ years) in order to capture a range of digital experience levels and interaction patterns.

All participants provided written informed consent prior to participation.

2.3 Procedure

The study was conducted in two sequential phases.

2.3.1 Phase 1: EEG Session

Participants were exposed to static screenshots of three Greek municipal websites, selected based on a prior large-scale UX audit and classified as:

- **Low UX quality** (Didymoteicho, 28%)
- **Medium UX quality** (Mytilene, 59%)
- **High UX quality** (Alexandroupolis, 84%)

During exposure, EEG data were recorded using the **Emotiv Insight 5-channel headset** (AF3, T7, Pz, T8, AF4) at a sampling rate of 128 Hz. Following the EEG session, participants completed a **Self-Assessment Manikin (SAM)** questionnaire to capture subjective affective responses.

2.3.2 Phase 2: Eye-Tracking Session

In the second phase, each participant was assigned to one of the three websites and asked to complete four standardized tasks:

1. Free exploration
2. Locating cleaning and recycling information
3. Identifying how to submit an online request
4. Locating an English-language version of the website

Following task completion, participants completed:

- an **Implicit Memory Test (IMT)**
- a **7-item Self-Reported Questionnaire (SRQ)**

2.4 Measures

The study employed a multimodal set of measures capturing cognitive, behavioral, and subjective dimensions of user experience:

- **EEG-based measures:**
 - Emotional Intensity (EI)

- Engagement (ENG)
 - Cognitive Load (CL)
- **Eye-tracking measures:**
 - Behavioral indicators of relevance (R), derived from interaction patterns and visual attention metrics
- **Implicit Memory Test (IMT):**
 - Memory Retention (MR), calculated using Signal Detection Theory (Hit Rate – False Alarm Rate)
- **Self-reported measures:**
 - Self-Assessment Manikin (SAM)
 - Self-Reported Questionnaire (SRQ)

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2.5 Neurocognitive Engagement (NCE) Index

The **Neurocognitive Engagement (NCE) Index** integrates six components—Emotional Intensity (EI), Engagement (ENG), Cognitive Load (CL), Relevance (R), Memory Retention (MR), and Self-Reported Quality (SRQ)—into a composite score ranging from 0 to 10.

The index is designed to provide a unified representation of user experience by combining neurophysiological, behavioral, and subjective indicators.

Table 1. NCE Index Components, Definitions and Data Sources

Component	Full Name	Description	Data Source
EI	Emotional Intensity	Captures the emotional quality and intensity of the user's response to the interface	SAM questionnaire (post-EEG)
ENG	Engagement	Reflects the degree of active cognitive and neural engagement during interface exposure	EEG neurophysiological data
CL	Cognitive Load	Assesses the mental effort required to process and navigate the interface	EEG neurophysiological data
R	Relevance	Evaluates the perceived meaningfulness and utility of the interface content, based on implicit behavioral indicators	EEG + IMT + Eye-tracking

MR	Memory Retention	Measures the implicit encoding and retention of content encountered during interaction	Implicit Memory Test (IMT)
SRQ	Self-Reported Questionnaire	Captures the participant's subjective evaluation of the overall interaction experience	Post-session questionnaire

NB. The NCE Index integrates all five components into a single composite score. Full technical specifications regarding component derivation and aggregation are **subject to intellectual property protection** (see note below).

Note on Intellectual Property: *The NCE Index computational methodology, Neurocognitive Design Principles framework, and associated wireframe specifications presented in this paper constitute proprietary intellectual property subject to formal copyright registration. The wireframes are conceptual prototypes only; full design specifications are retained by the authors.*

2.6 Neurocognitive Engagement (NCE) Index

The computational methodology of the NCE Index, the Neurocognitive Design Principles framework, and the associated wireframe specifications presented in this paper constitute proprietary intellectual property and are subject to formal copyright protection.

The wireframes included in this study are conceptual prototypes; full design specifications are retained by the authors.

2.7 Data Analysis and Design Synthesis

The development of the proposed design framework followed a structured, multi-stage analytical and synthesis process, integrating neurophysiological, behavioral, and self-reported data.

First, all collected data streams (EEG, eye-tracking, implicit memory, and self-reported measures) were processed and aggregated into the **Neurocognitive Engagement (NCE) Index**, enabling comparative evaluation across the three website conditions (low, medium, high UX quality).

Second, patterns across NCE components were analyzed to identify consistent relationships between interface characteristics and user responses. Particular emphasis was placed on:

- variations in cognitive load and attentional engagement,
- discrepancies between self-reported and implicit measures,
- and task-specific behavioral patterns derived from eye-tracking data.

Third, these patterns were synthesized into a **Multimodal Cognitive and Affective Brain Map**, representing the functional relationships between neural processes and interaction outcomes observed during the study.

Fourth, the identified neurocognitive patterns were translated into six **Neurocognitive Design Principles**, each corresponding to a core component of the NCE Index (e.g., cognitive load, engagement, memory retention). These principles were formulated through an iterative abstraction process, linking empirical observations to actionable design implications.

Finally, the design principles were operationalized into a **conceptual prototype of an ideal municipal website**, supported by annotated wireframes and a **three-level implementation model**. This step involved translating abstract principles into concrete interface elements, interaction flows, and feature specifications, while ensuring adaptability across municipalities with varying levels of digital maturity.

This process follows the logic of design science research, moving from empirical observation to artifact creation through iterative abstraction and synthesis (Hevner et al., 2004; Gregor & Hevner, 2013).

3. RESULTS

3.1 Summary of Key Findings

Table 1 summarizes the key findings of the pilot study across the three website conditions (bad, medium, and good UX quality), as defined by the prior UX audit.

Table 2. Summary of Key Pilot Study Findings by UX Condition

Measure	Bad UX	Medium UX	Good UX
UX Audit Score	28%	59%	84%
NCE Index	3.52 (Low Usability)	5.20 (Moderate Usability)	5.07 (Moderate Usability)
SAM Valence (1/7)	2.97	4.97	5.73
SQR Score (1/10)	3.10	6.13	5.00
Eye tracking – Task 2 (Cleaning Services - Completion)	0% (Failed)	100% (Efficient)	100% (Efficient)

Eye tracking – Task 4 (English Language - Completion)	100% (only site with EN)	0% (Absent Language)	0% (Absent Language)
IMT Memory Retention (MR) Score	M = 0.428	M = 0.647	M = 0.664

NB. Despite a 25-point Audit gap, Medium and Good UX produced near-identical NCE engagement ($\Delta=0.13$). The SRQ ranking reversal (Medium > Good) and Task 4 finding (Bad UX = only accessible English site) demonstrate that no single evaluation method captures the full complexity of citizen digital experience.

Overall, the results indicate substantial variation across UX conditions in both neurocognitive and behavioral measures. However, these differences are not consistently aligned with UX audit scores.

Despite a **25-point difference in UX audit scores** between the Medium (59%) and Good (84%) conditions, the corresponding **NCE Index scores were nearly identical** ($\Delta = 0.13$), both falling within the moderate usability range.

Similarly, discrepancies were observed between **self-reported evaluations and behavioral performance**. The SRQ results showed a **ranking reversal**, with the Medium UX condition (6.13) outperforming the Good UX condition (5.00), despite its lower audit score.

Task-based performance further highlighted inconsistencies across evaluation methods. In Task 2 (Cleaning Services), participants in the Medium and Good UX conditions achieved **100% completion**, while participants in the Bad UX condition failed entirely (0%). In contrast, Task 4 (English Language access) revealed an inverse pattern: only the Bad UX website provided an English-language version, resulting in **100% task completion**, whereas both Medium and Good UX conditions recorded **0% completion** due to the absence of the feature.

Memory retention results followed a consistent directional trend, with higher scores observed in better-structured interfaces (Good UX: $M = 0.664$; Medium UX: $M = 0.647$; Bad UX: $M = 0.428$), indicating improved implicit encoding under more organized interface conditions.

3.2 Neurocognitive and Behavioral Differences Across UX Dimensions

3.2.1 Cognitive Load and Visual Search Effort

Eye-tracking data revealed substantial differences in visual search effort across conditions. Participants interacting with the Bad UX website required **74–81 fixations** to

complete information-retrieval tasks, compared to **33–47 fixations** in the Medium and Good UX conditions. These findings indicate a markedly higher level of search effort in poorly structured interfaces.

Table 3. Eye-Tracking Performance Across Tasks and UX Conditions (N = 10)

Task	UX Condition	Mean Fixations	Mean Time on Task (sec)	Completion Rate	Performance
Task 2. Cleaning & Recycling	Bad UX	74.0	110	0%	Failed
	Medium UX	41.0	64	100%	Efficient
	Good UX	33.0	52	100%	Efficient
Task 3. Online Request Submission	Bad UX	81.0	98	0%	Failed
	Medium UX	37.0	60	100%	Efficient
	Good UX	45.6	71	100%	Efficient
Task 4. English Language Access	Bad UX	21.0	17	100%	Efficient
	Medium UX	68.0	88	0%	Failed
	Good UX	54.0	76	0%	Failed

NB. Performance classification: ≤60s = Efficient; 60–90s = Effortful; >90s or unsuccessful = Failed.

3.2.2 Attentional Engagement

EEG data from the parietal region (Pz) showed higher levels of attentional efficiency during interaction with the Good UX condition. In the free exploration task (Block 1), Good UX stimuli elicited higher parietal alpha values (M = 13.49), suggesting more stable and less effortful attentional allocation compared to other conditions.

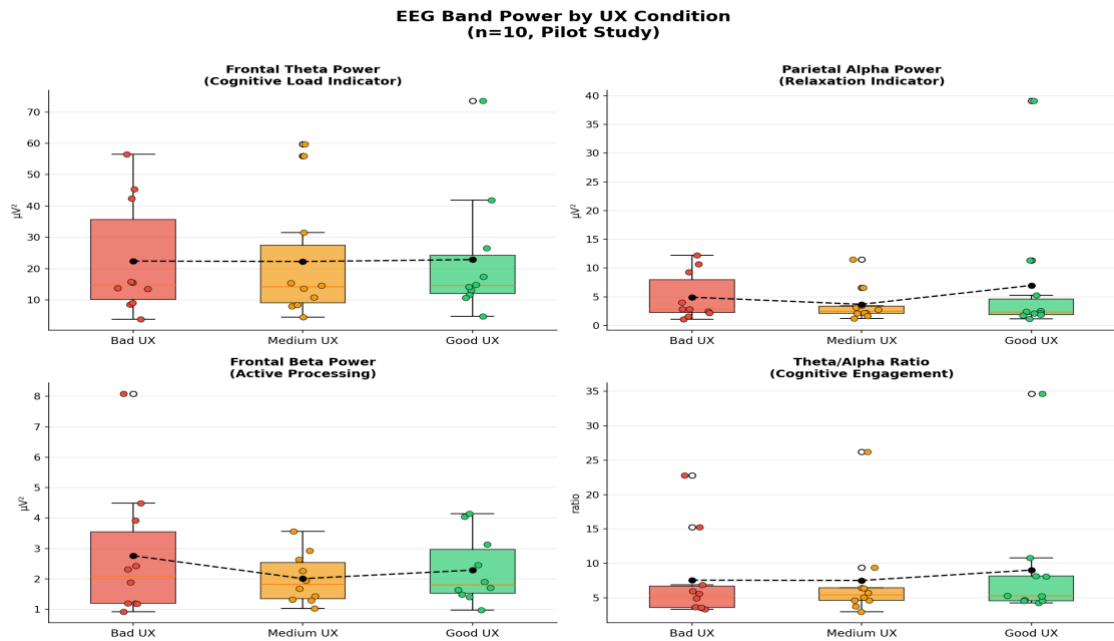


Figure 1. Distribution of EEG-derived metrics across UX conditions (Poor, Medium, Good), including Frontal Theta Power (cognitive load), Parietal Alpha Power (relaxation), Frontal Beta-Low Power (engagement proxy), and Theta/Alpha ratio (attentional engagement). Boxplots represent participant-level distributions (N = 10), with median values and interquartile ranges, while dashed lines indicate group means. Although no statistically significant differences were observed (Friedman test, all $p > .05$), **descriptive trends suggest increased cognitive load for Bad UX stimuli and higher engagement-related patterns for Good UX stimuli.**

3.2.3 Emotional Response

Self-reported affective responses, measured using SAM valence scores, showed a clear gradient across UX conditions:

- Bad UX: 2.97
- Medium UX: 4.97
- Good UX: 5.73

These results indicate progressively more positive emotional responses as interface quality increases.

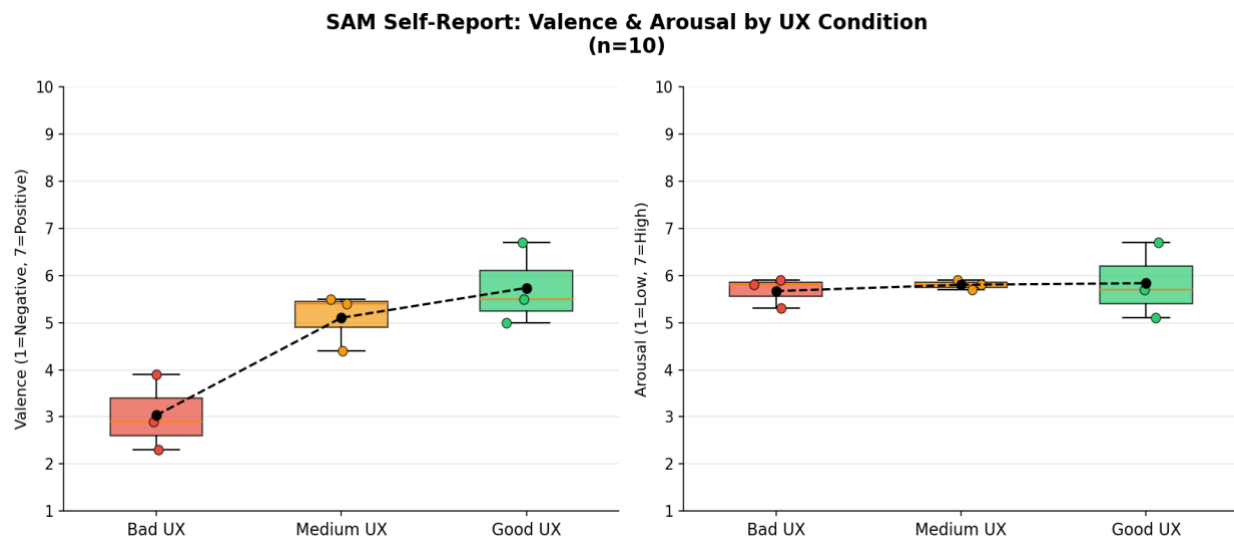


Figure 2. Boxplots illustrate participants' self-reported Emotional Valence (left) and Arousal (right) ratings across UX conditions (Bad, Medium, Good). Valence shows a clear positive gradient aligned with UX quality, with Bad UX associated with negative evaluations and Good UX with more positive affective responses. In contrast, Arousal levels remain relatively stable across conditions, indicating that emotional activation is not substantially modulated by UX quality during brief stimulus exposure.

3.2.4 Memory Retention

Implicit memory performance, as measured by the Memory Retention (MR) score, showed a consistent increase across UX conditions. Participants exposed to the Good UX condition demonstrated the highest memory retention ($M = 0.664$), followed closely by the Medium UX condition ($M = 0.647$), while the Bad UX condition exhibited substantially lower retention ($M = 0.428$).

These results indicate that more structured and navigable interfaces are associated with improved implicit encoding of content, even in the absence of conscious recall.

3.2.5 Neurocognitive Engagement (NCE) Index

The Neurocognitive Engagement (NCE) Index was computed by integrating six dimensions: Emotional Intensity (EI), Engagement (ENG), Cognitive Load (CL), Relevance (R), Memory Retention (MR), and Self-Reported Quality (SRQ), into a composite score ranging from 0 to 10. As shown in Table 4, the Bad UX condition yielded the lowest NCE score ($M = 3.52$, $SD = 0.21$), corresponding to low engagement. In contrast, both the Medium UX ($M = 5.20$, $SD = 0.61$) and Good UX ($M = 5.07$, $SD = 0.58$) conditions fell within the moderate engagement range. Notably, the difference between Medium and Good UX

conditions was minimal ($\Delta = 0.13$), despite a 25-percentage-point difference in UX Audit scores (59% vs 84%).

Figure 3 illustrates the distribution of NCE scores across UX conditions, highlighting the minimal difference between Medium and Good UX despite substantial variation in UX Audit scores.

Table 4. Comparative Analysis: UX Audit Scores vs NCE Index

UX Condition	UX Audit (%)	NCE (M)	NCE (SD)	SQR (M)	SQR (SD)
Bad UX	28%	3.52	0.21	3.10	0.00
Medium UX	59%	5.20	0.61	6.13	0.88
Good UX	84%	5.07	0.58	5.00	2.78

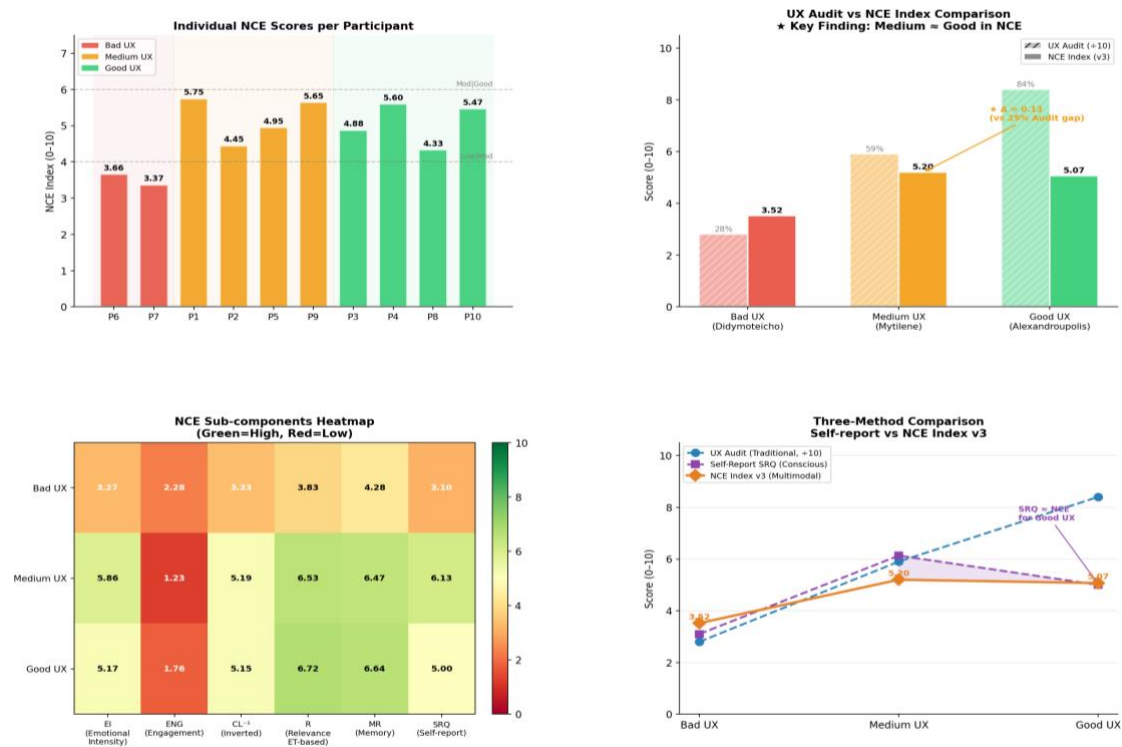


Figure 3. Top-left: Individual NCE scores by UX group. Top-right: Comparison between UX Audit scores and NCE group means, highlighting the minimal difference between Medium and Good UX despite a 25-point Audit gap. Bottom-left: Heatmap of NCE component contributions (EI, ENG, CL, R, MR, SRQ) across conditions. Bottom-right: Cross-method comparison illustrating the relationship between NCE, UX Audit, and SRQ scores.

These results indicate a **lack of alignment between audit-based usability scores and neurocognitive engagement outcomes across conditions.**

4. DISCUSSION

The present study set out to investigate how differences in UX quality are reflected in users' cognitive, behavioral, and experiential responses, and to examine whether such patterns can inform the development of a neurocognitive-informed design framework for municipal websites.

Consistent with H1, the results revealed distinct patterns across UX conditions in neurocognitive, behavioral, and affective measures. Differences were observed in visual search effort, attentional allocation, emotional response, and memory retention, indicating that UX quality is associated with measurable variations in how users process and interact with digital interfaces.

At the same time, supporting H2, these patterns were not fully captured by traditional evaluation methods. The convergence of NCE scores between Medium and Good UX conditions, alongside discrepancies in self-reported and behavioral outcomes, highlights the limitations of audit-based and self-reported measures in capturing the full complexity of user experience.

Building on these findings, the study further demonstrates, in line with H3, that multimodal response patterns can be systematically translated into design-relevant insights. The Multimodal Cognitive and Affective Brain Map and the six Neurocognitive Design Principles represent this translation, linking empirical evidence to actionable design guidance.

Finally, consistent with H4, these elements are integrated into a conceptual design framework, including annotated wireframes and a three-level implementation model, providing structured guidance for improving municipal website usability across varying levels of digital maturity.

4.1 The Multimodal Cognitive and Affective Brain Map

Building on the observed neurocognitive and behavioral differences across UX conditions, the Multimodal Cognitive and Affective Brain Map provides a structured synthesis of how distinct neural systems are engaged during digital interaction.

Figure 1 presents the Multimodal Cognitive and Affective Brain Map, a visual synthesis of the neural architecture underlying digital user experience, derived from the pilot study's multimodal dataset and the broader neuroscientific literature on human–computer interaction.

The map organizes the evidence around six key neural systems, each linked to a specific NCE Index component and a set of concrete design implications.



Figure 4. Multimodal Cognitive and Affective Brain Map. Neural correlates of digital interface interaction, with design implications derived from NCE Index pilot study findings (EEG: AF3, AF4, T7, T8, Pz; SAM; IMT; Eye-Tracking, n=10). Bottom panel: NCE sub-component scores by UX condition. Each region is linked to a corresponding NCE component and practitioner design recommendations.

The Prefrontal Cortex (PFC), the locus of executive function and working memory, is directly implicated in the cognitive load experienced during interface navigation. Elevated Frontal Theta Power (recorded at AF3 and AF4) is a well-established EEG indicator of increased mental effort (Klimesch, 1999). The study's finding that Bad UX participants required 74–81 fixations on information-retrieval tasks, compared to 33–47 for Good/Medium UX participants, reflects the PFC-mediated cognitive cost of navigating poorly organized

interfaces. Design interventions targeting the PFC dimension should **focus on reducing navigational complexity, chunking information, and employing progressive disclosure.**

The Parietal Cortex, recorded via Pz channel, serves attentional integration and spatial processing. Elevated Parietal Alpha Power reflects cognitive relaxation and effortless attention allocation. In Block 1 (Free Exploration), Good UX stimuli elicited notably higher Parietal Alpha ($M = 13.49$) compared to other conditions, suggesting that visually **coherent interfaces reduce attentional strain.** This finding directly supports the use of **clear visual hierarchies, consistent layout grids, and strategic whitespace.**

The Temporal Cortex and Amygdala, implicated in emotional processing and language comprehension, are reflected in the SAM Valence gradient (Bad UX: 2.97; Medium UX: 4.97; Good UX: 5.73). **First impressions, processed within milliseconds by the Amygdala, are emotionally valenced and shape subsequent interaction.** Interface tone, visual aesthetics, and language register all carry affective weight that influences citizen trust and willingness to engage.

The Hippocampus, the primary structure for memory encoding, is implicated in the implicit retention of interface content, as measured by the IMT. The directional MR trend (Good UX: 0.664 > Medium UX: 0.647 > Bad UX: 0.428) suggests that more structured interfaces facilitate deeper implicit encoding, with direct consequences for citizens' ability to locate, retain, and act upon municipal service information.

The Frontal Eye Fields (FEF), reflected in the eye-tracking fixation data, control voluntary gaze during visual search. The dramatic fixation count difference between Bad UX (74–81) and Good/Medium UX (33–47) on Tasks 2–3 illustrates that poorly organized interfaces force citizens into extended, effortful visual search. Prominent, clearly labelled, and visually distinct interface elements minimize FEF-mediated search effort. Critically, Task 4's finding that Medium and Good UX participants spent 76–88 seconds searching for an absent English-language feature, demonstrates that functional gaps generate extensive, frustration-laden FEF activation even on high-scoring sites.

4.2 Six Neurocognitive Design Principles

The Six Neurocognitive Design Principles extend the brain map by translating these neurocognitive patterns into actionable design strategies (Table 5). Each principle corresponds to one component of the NCE Index, is supported by specific pilot study evidence, and is accompanied by concrete design recommendations applicable across interface contexts. The

principles are intended as a minimum baseline, not an exhaustive specification, for neurocognitive-informed municipal website design.

Table 5. Six Neurocognitive Design Principles for Municipal Websites

NCE Component	Principle	Neural basis	Pilot Evidence	Design Recommendation
CL	Reduce Cognitive Load	Prefrontal Cortex (AF3, AF4 — Theta)	Bad UX: 74–81 fixations T2–T3; Task 3 Good UX required multiple clicks despite Audit=84%.	Max 2-level nav; progressive disclosure; chunked content; contextual help
ENG	Sustain Neural Engagement	Frontal Eye Fields (Eye-Tracking)	Bad UX: 0% completion T2–T3; erratic gaze patterns; M=36.5 fixations T1 vs Good=22.5.	Prominent CTAs above fold; task-oriented tiles; minimal dead zones; interactive elements
EI	Positive Emotional Intensity	Amygdala / Temporal (SAM Valence)	SAM Valence: Bad=2.97 (below midpoint) vs Medium=4.97 vs Good=5.73.	Plain language; warm micro-copy; consistent visual identity; emotionally resonant imagery
R	Maximize Relevance	Hippocampus + Frontal Eye Fields	Task 4: Medium & Good UX — 0% completion (EN absent). Only Bad UX (28%) had EN: TTFF=1.9s.	Multilingual access mandatory; geo-aware services; task-based navigation labels
MR	Encode Memory	Hippocampus (IMT)	IMT: Good MR=0.664 vs Bad=0.428. Structured interfaces facilitate implicit content encoding.	Consistent labelling; visual anchors; breadcrumbs; confirmation messages; repetition of key info
SQR	Align Conscious Experience	Prefrontal (Conscious) + SRQ	SRQ: Medium=6.13 > Good=5.00 — reversal of Audit ranking. Conscious evaluation ≠ structural quality.	Transparent processes; real-time status updates; inline validation; post-submission confirmation

NB. Evidence figures are group-level means from the pilot study (N=10). NCE Comp. = NCE Index component. Design recommendations represent minimum standards; full technical specifications are subject to IP protection.

4.2.1 The Primacy of Language Accessibility

Among the six principles, the Relevance (R) principle, and specifically the requirement for multilingual interface support, warrants particular emphasis given the study's most counterintuitive finding. Both the Medium UX (Audit = 59%) and Good UX (Audit = 84%) websites achieved 0% completion on Task 4, as neither provided an English-language version. The Bad UX website (Audit = 28%), typically the poorest performer on all other metrics, was the only site with multilingual support, achieving 100% completion with a mean TTFF of 1.9 seconds.

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This finding provides particularly strong support for H2, demonstrating that critical usability barriers may remain underrepresented when relying solely on audit-based or self-reported evaluation methods. Although such issues may be technically identifiable within an expert audit, they are less likely to be prioritized or interpreted in relation to the needs of non-native users. As a result, barriers affecting linguistically diverse populations, including tourists, migrants, and refugees, may be systematically overlooked.

In the context of municipal digital services, this limitation has direct implications for accessibility, bureaucratic efficiency, and ultimately for inclusive e-democracy. These findings highlight the need for municipal websites to function as multidimensional platforms, capable of simultaneously serving diverse user groups with varying linguistic and informational needs, rather than being optimized for a single, assumed “default” user profile.

Importantly, this establishes a clear policy implication: multilingual accessibility should not be treated as an advanced feature, but as a baseline functional requirement. Traditional evaluation approaches, including expert audits and self-reported measures, do not consistently surface this gap, as users assigned to non-English interfaces are often unable to detect the absence of a feature they cannot access. In contrast, behavioral methods, and particularly task-based eye-tracking, make such failures visible by capturing prolonged search effort and task breakdowns.

While regulatory frameworks such as the EU Web Accessibility Directive (2016/2102) and WCAG 2.1 provide a formal mandate for accessibility, the present findings offer complementary empirical evidence, grounded in neurocognitive and behavioral data, that underscores the necessity of multilingual and inclusive design in municipal digital platforms.

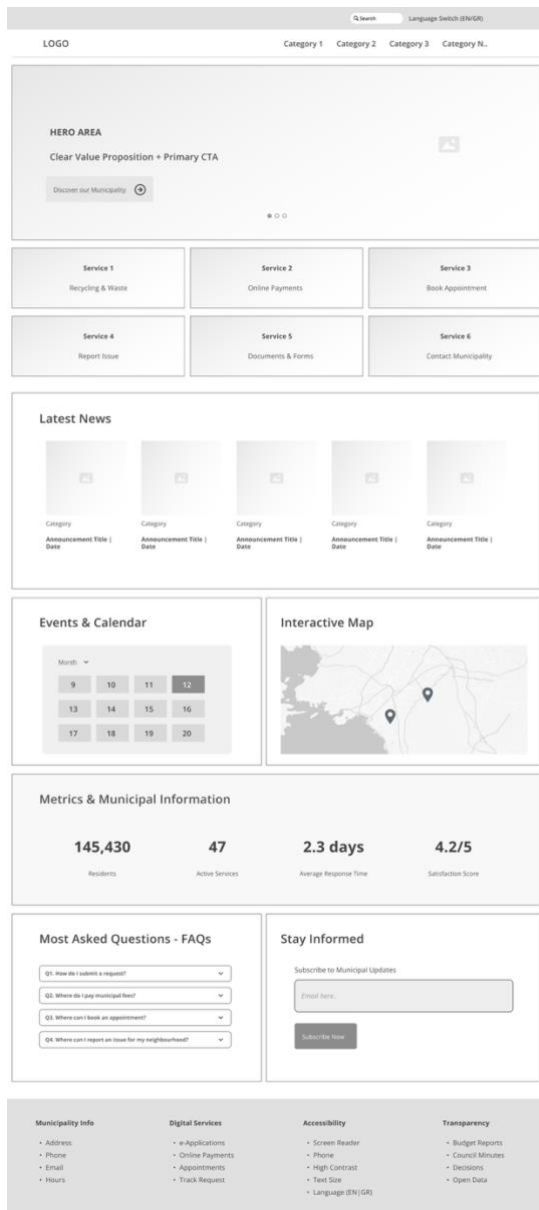
4.3 Conceptual Framework: The Ideal Municipal Website

The six principles above inform the structure of a conceptual design framework for an ideal Greek municipal website, illustrated through annotated wireframes for four key interface types. The wireframes are conceptual prototypes, they communicate structural and functional principles, not final visual design specifications. Implementation details are left to individual municipalities and their design teams, subject to the baseline requirements established by the six principles.

Note on Intellectual Property: *The NCE Index computational methodology, Neurocognitive Design Principles framework, and associated wireframe specifications presented in this paper constitute proprietary intellectual property subject to formal copyright registration. The wireframes are conceptual prototypes only; full design specifications are retained by the authors.*

4.3.1 Homepage: Zone-Based Neurocognitive Organization

The homepage must simultaneously communicate institutional identity, provide immediate access to high-frequency services, and minimize the cognitive effort required for initial orientation. The proposed wireframe (Figure 2) organizes the page into five neurocognitive zones, each serving a distinct function in the citizen's neural processing journey, from initial visual capture (Zone A, Amygdala/FEF) through information retrieval (Zone C, Hippocampus/PFC) to engagement reinforcement (Zone D, ENG/MR) and inclusive access (Zone E, SRQ/CL) (for more see Appendix 1).



-> **Zone A:** Header & Primary Navigation

-> **Zone B:** Hero message & Key Services

-> **Zone C:** Content & Municipal Information

-> **Zone D:** Engagement & Memory Zone

-> **Zone E:** Footer & Accessibility

Figure 5. Homepage Wireframe with Neurocognitive Zone Structure. Five zones (A–E) correspond to distinct neural processing stages. [N] annotations reference specific pilot study findings. **Zone A:** Navigation & Language Access (FEF, language systems). **Zone B:** Hero & Quick Services (Amygdala, attention capture). **Zone C:** Content & Information (Hippocampus, PFC). **Zone D:** Engagement & Memory (ENG, MR). **Zone E:** Footer & Accessibility (SRQ, CL). ***IP Protected — conceptual prototype only.***

The language switcher (**Zone A**) must be persistently visible in the top-right header on every page, not buried in a footer or settings menu. This design decision is directly motivated by the Task 4 finding: Medium and Good UX participants searched an average of 76–88 seconds for a feature that did not exist on their assigned sites, generating erratic gaze patterns

and moderate frustration indicators. A persistent, prominently placed language switcher would have reduced this FEF-mediated search effort to zero.

The Quick Service Tiles (Zone B) directly address the Task 2 and Task 3 findings by placing the six most frequently requested services in the primary attentional capture zone, using emotionally warm colours and task-oriented labels. The CTA for online request submission is positioned above the fold, eliminating the multi-step navigation required by the study's websites (e.g., Medium UX: e-YIIHPEΣIEΣ → e-AITHMATA, a pathway that still required 4.5 seconds to first fixation despite being the best-performing site on this task).

Zones C through E address the hippocampal encoding, engagement, and cognitive fatigue dimensions respectively. The consistently structured content area (Zone C) supports implicit memory encoding through visual anchors and pattern consistency. The engagement zone (Zone D) maintains neural activation through dynamic, data-rich elements. The accessible, well-organized footer (Zone E) reduces cognitive fatigue for citizens who have not found their target in the main content zones, directly addressing the Q7 fatigue finding (Bad UX reversed score: 3.50 vs Medium: 5.75).

3.3.2 Key Interface Pages

Following the same logic, Figure 6 presents conceptual wireframes for three additional high-priority interface pages, each directly motivated by the study's task-based findings, alongside a proposed NCE Monitoring Dashboard.

The Services Page (Figure 6, left) is organized around the Task 2 finding. Bad UX participants failed entirely to locate cleaning and recycling information (0% completion, $M = 111.5$ sec). The proposed page places task-relevant content in the primary viewport with a heading that matches citizen search language, four prominent quick-action tiles, and an inline request form that eliminates multi-page navigation. The information architecture follows the citizen's mental model (by service type) rather than the municipality's internal organizational structure, a distinction that directly reduces PFC-mediated cognitive effort.

The e-Services Portal (Figure 6, middle) responds to the Task 3 finding. A five-step progress indicator reduces cognitive uncertainty during form completion, a design element with direct PFC implications, as clear procedural structure reduces working memory load by externalizing the task schema. An AI-powered natural language search function allows citizens to describe their need in plain language, bypassing the terminology barriers that contributed to Task 3 failures in the Bad UX condition.

The Language and Accessibility Settings page (Figure 6, right) is the most directly motivated by the study's evidence. Its existence as a dedicated, navigable page, rather than a hidden settings menu, is itself a primary design recommendation. The page provides language selection (Greek, English, Italian, German as minimum), a comprehensive accessibility suite (text size, contrast, screen reader compatibility, dyslexia font, motion reduction), explicit WCAG 2.1 AA compliance certification, and translation quality standards acknowledging the ongoing human oversight required for meaningful multilingual support.

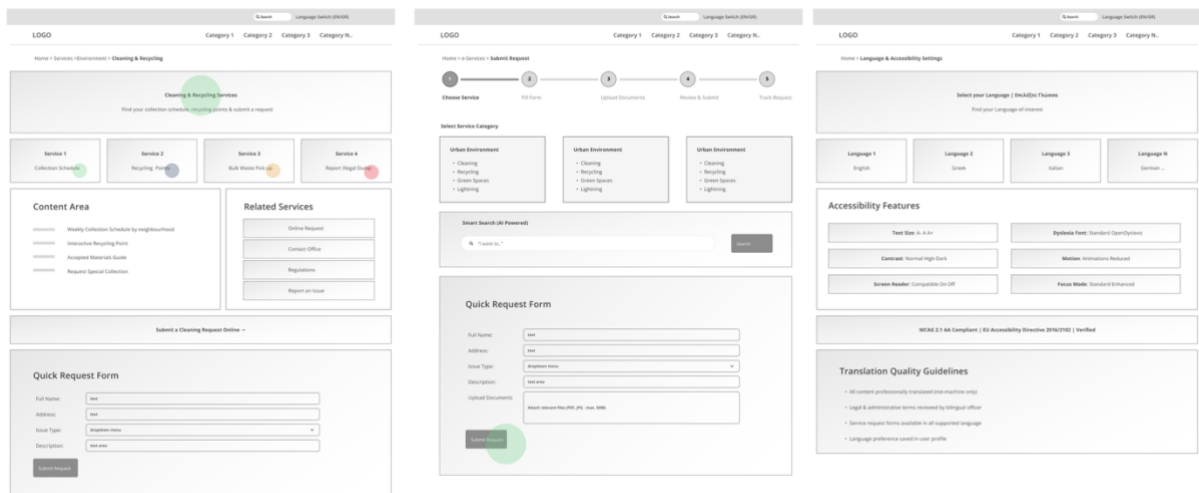


Figure 6. Key Interface Page Wireframes. (Left) Services Page: Task 2-optimized Cleaning & Recycling section. (Middle) e-Services Portal: Task 3-optimized request submission with 5-step progress indicator. (Right) Language & Accessibility: Task 4-informed mandatory multilingual support with WCAG 2.1 AA compliance. ***IP Protected — conceptual prototypes only.***

4.4 Three-Level Implementation Model

Greek municipalities vary enormously in digital capacity, financial resources, and organizational readiness. The framework is therefore structured around a three-level implementation model (Table 6) that allows municipalities to adopt the Neurocognitive Design Principles incrementally, beginning with high-impact, low-resource interventions and progressing toward full NCE-monitored implementation.

Table 6. Three-Level Implementation Model

Dimension	Level 1: Basic	Level 2: Intermediate	Level 3: Advanced
Language Access	Translate homepage + key services (EN)	Full multilingual (EN, TR, BG)	AI-assisted + citizen language preference profile
Navigation	2-level menu, task-oriented labels	Service finder + smart search	Predictive nav + personalized shortcuts
e-Services	PDF forms downloadable	Online form + email confirmation	Full workflow: submit, track, appeal
Accessibility	WCAG 2.1 AA compliance	Screen reader + contrast toggle	Full suite: dyslexia font, motion control
Engagement	Static content + news feed	Interactive calendar + map	Live counters, chatbot, push notifications
NCE Monitoring	Annual SRQ survey	Quarterly usability testing	Continuous NCE Index dashboard

NB. All levels presuppose WCAG 2.1 AA compliance as a baseline legal requirement (EU Web Accessibility Directive, 2016/2102). Level classification is indicative and should be adapted to each municipality's specific resource context.

Two cross-level principles apply regardless of resource level. **First**, multilingual accessibility (minimum: EN translation of homepage and key services) must be treated as a Level 1 baseline, not deferred to advanced implementation stages, as demonstrated by the Task 4 finding. **Second**, NCE monitoring in some form should be embedded in the digital governance cycle from the outset: even an annual SRQ survey (Level 1) establishes a baseline against which future improvements can be measured and investment decisions justified. The framework presented in this paper represents a shift in how UX quality is conceptualized in the context of public digital services, from a structural property measurable through expert checklists, to an emergent property of the interaction between a citizen's neural architecture and the design of the digital environment. This shift has implications at three levels.

For **UX evaluation practice**, the framework argues that audit-based methods should be supplemented, not replaced, by neurophysiological and behavioral measurement. The NCE Index provides a replicable composite metric for this purpose. As the cost and complexity of

portable EEG and eye-tracking systems continue to decline, the barrier to implementing NCE-based evaluation in applied public-sector contexts will diminish. The monitoring dashboard proposed in Section 6.2 represents a practical pathway for institutionalizing this approach within municipal digital governance structures.

For **digital investment decisions**, the central finding of the companion study — that Medium and Good UX websites generate near-identical neurocognitive engagement despite a 25-point audit gap, implies that incremental structural improvements beyond a certain quality threshold may not yield proportional experiential returns. Municipal digital transformation budgets are finite. The three-level roadmap is designed to direct investment toward the dimensions most strongly associated with NCE score improvement, particularly language accessibility, cognitive load reduction, and content relevance, rather than toward broad structural overhauls of already-adequate interfaces. A municipality that raises its website from 59% to 84% on the UX Audit may see no corresponding improvement in how citizens neurally engage with the platform; one that adds an English-language version and streamlines its request submission pathway will.

For **e-democracy and citizen participation**, the framework highlights that digital exclusion operates at multiple levels simultaneously. A citizen who cannot navigate a poorly organized website faces an obvious, visible barrier. A citizen who can navigate a well-designed website but finds it no more cognitively engaging than a mediocre one faces a subtler, invisible barrier, one not surfaced by satisfaction surveys but detectable in the neural and behavioral record. Addressing both forms of exclusion requires the citizen-centered, multimodal evaluation approach embodied in the NCE Index and the design framework presented here.

5. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

The framework and wireframes presented in this paper are conceptual contributions derived from pilot empirical evidence. Several limitations should be acknowledged.

Pilot sample size. The empirical evidence underlying the framework is derived from a study of $n = 10$ adult male participants across three municipal websites. While directional findings are theoretically coherent and consistent with the broader HCI literature, replication with larger, gender-balanced, and generationally diverse samples is required before the principles can be proposed as universal design standards.

Absence of formal expert validation. The Neurocognitive Design Principles have not been formally subjected to expert review by UX practitioners, e-government specialists, or

neuroscientists. Future work should conduct structured expert evaluation of the framework for example, through Delphi studies or design critique sessions and should incorporate citizen feedback through participatory design processes.

Conceptual prototype status. The wireframes are conceptual prototypes that have not been usability-tested with real citizens. They illustrate structural and functional principles; their effectiveness in reducing cognitive load, improving task completion, and increasing NCE scores remains to be demonstrated through empirical testing. A follow-up study implementing and evaluating the proposed design framework with a representative municipal website would constitute a natural and valuable extension of this work.

NCE Index validation. The NCE Index is a pilot-stage composite metric with heuristically determined component weights. A dedicated validation study, including test-retest reliability, convergent validity with established UX scales, and sensitivity analysis is needed before the index can be adopted as a standard evaluation tool. The present paper proposes the framework as a starting point, not a validated standard.

IP constraints. The full computational specification of the NCE Index is subject to intellectual property protection and is not disclosed in this paper. This limits the immediate replicability of the NCE component of the framework; researchers wishing to implement the NCE Index are invited to contact the authors directly.

Despite these limitations, the framework represents a principled and empirically motivated contribution to the emerging field of neuroscience-informed e-government UX evaluation. It invites researchers and practitioners to engage with the evidence, refine the principles, and contribute to the development of citizen-centered, brain-informed public digital services.

APPENDIX 1

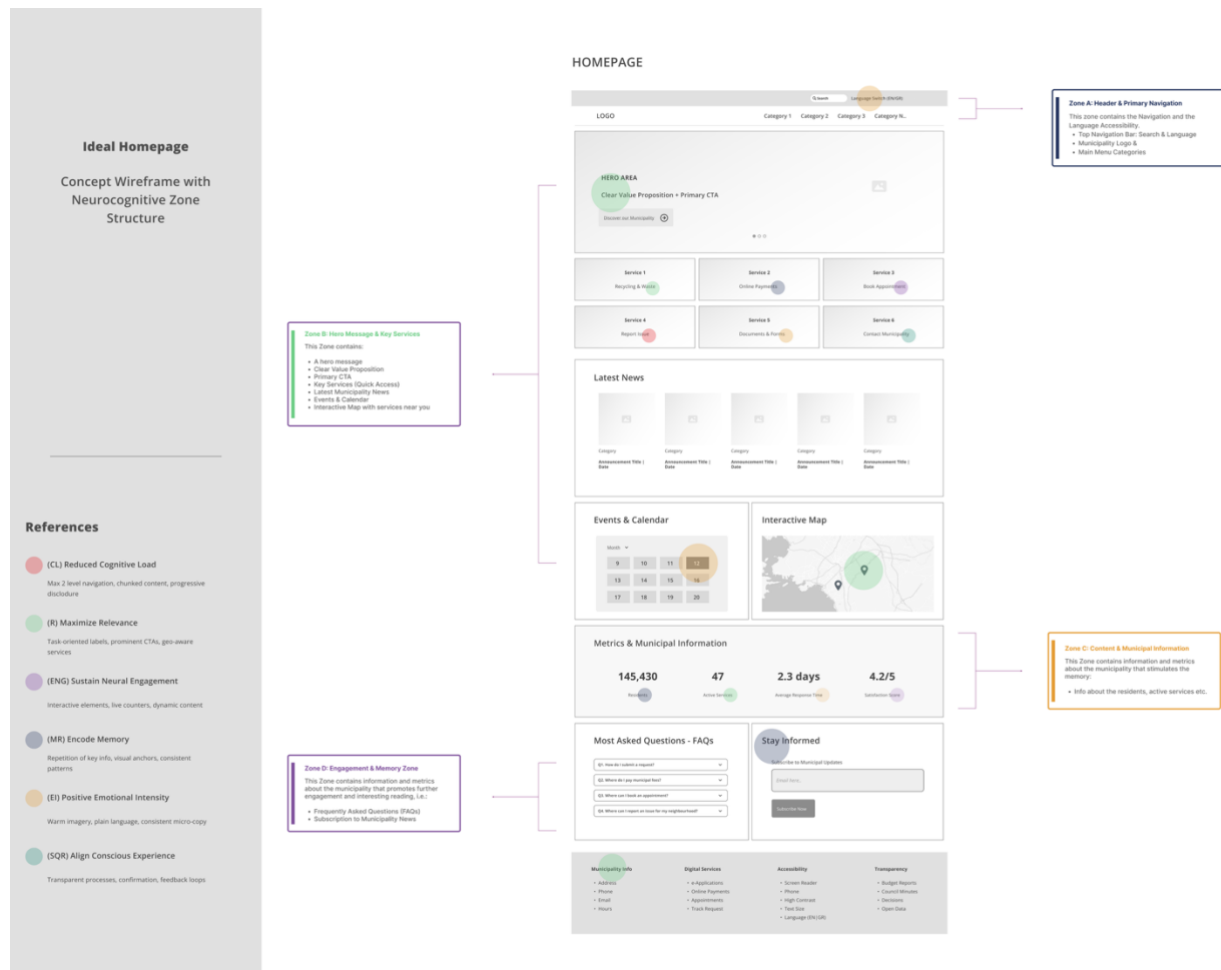


Figure 7. Homepage Wireframe — Neurocognitive Zone Structure. Five zones (A–E) correspond to distinct neural processing stages. [N] annotations reference specific pilot study findings. Zone A: Navigation & Language Access (FEF, language systems). Zone B: Hero & Quick Services (Amygdala, attention capture). Zone C: Content & Information (Hippocampus, PFC). Zone D: Engagement & Memory (ENG, MR). Zone E: Footer & Accessibility (SRQ, CL). IP Protected — conceptual prototype only.

APPENDIX 2

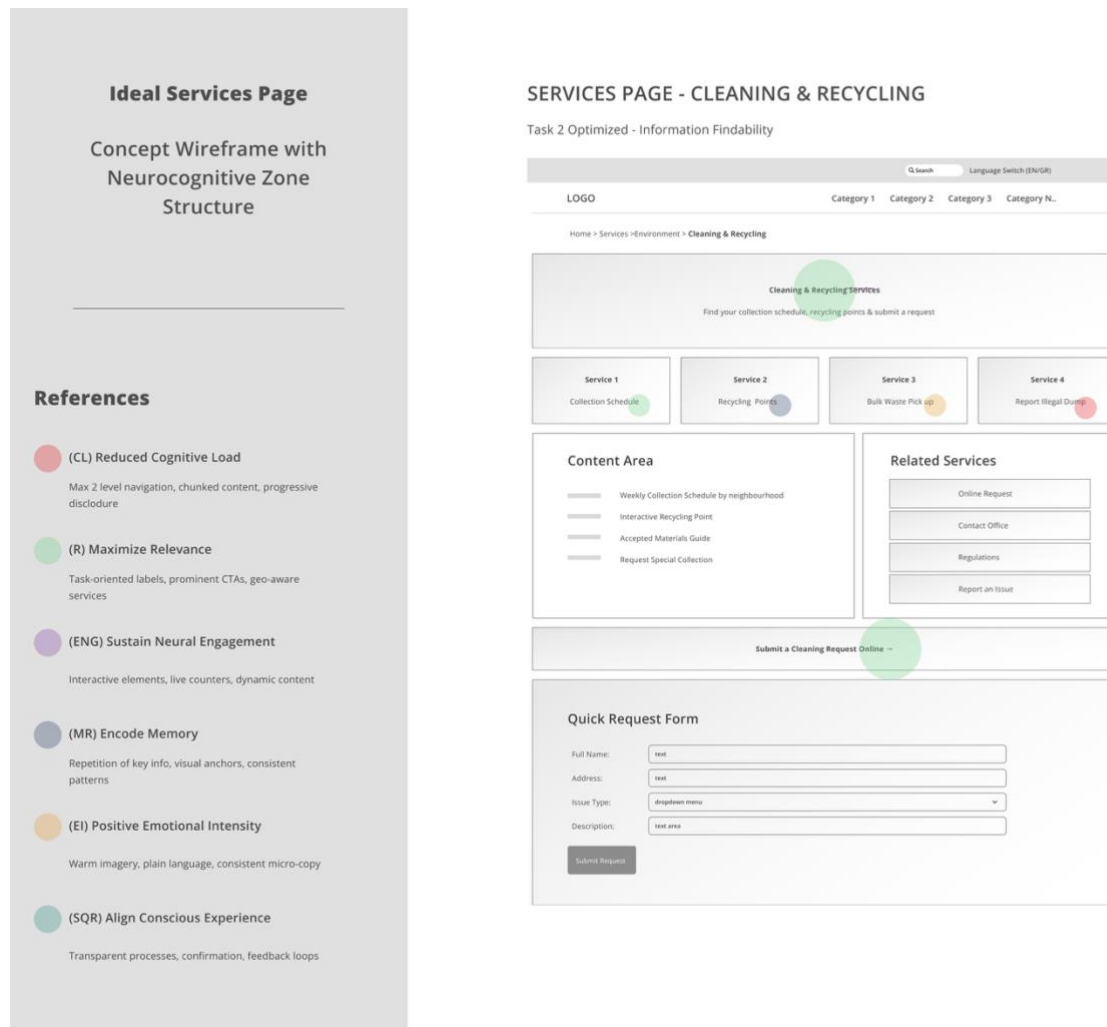


Figure 8. Services Page Wireframe — Task-Oriented Information Architecture. Conceptual wireframe illustrating the structure of a municipal services page optimized for efficient information retrieval (e.g., Cleaning & Recycling). The layout prioritizes task-relevant content in the primary viewport, supported by clear service categorization, prominent action tiles, and an inline request form. [N] Annotations reference pilot study findings related to cognitive load (CL), relevance (R), and visual search effort (FEF). The design emphasizes alignment with users' mental models, minimizing navigation depth and reducing search complexity. IP Protected — conceptual prototype only.



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APPENDIX 4

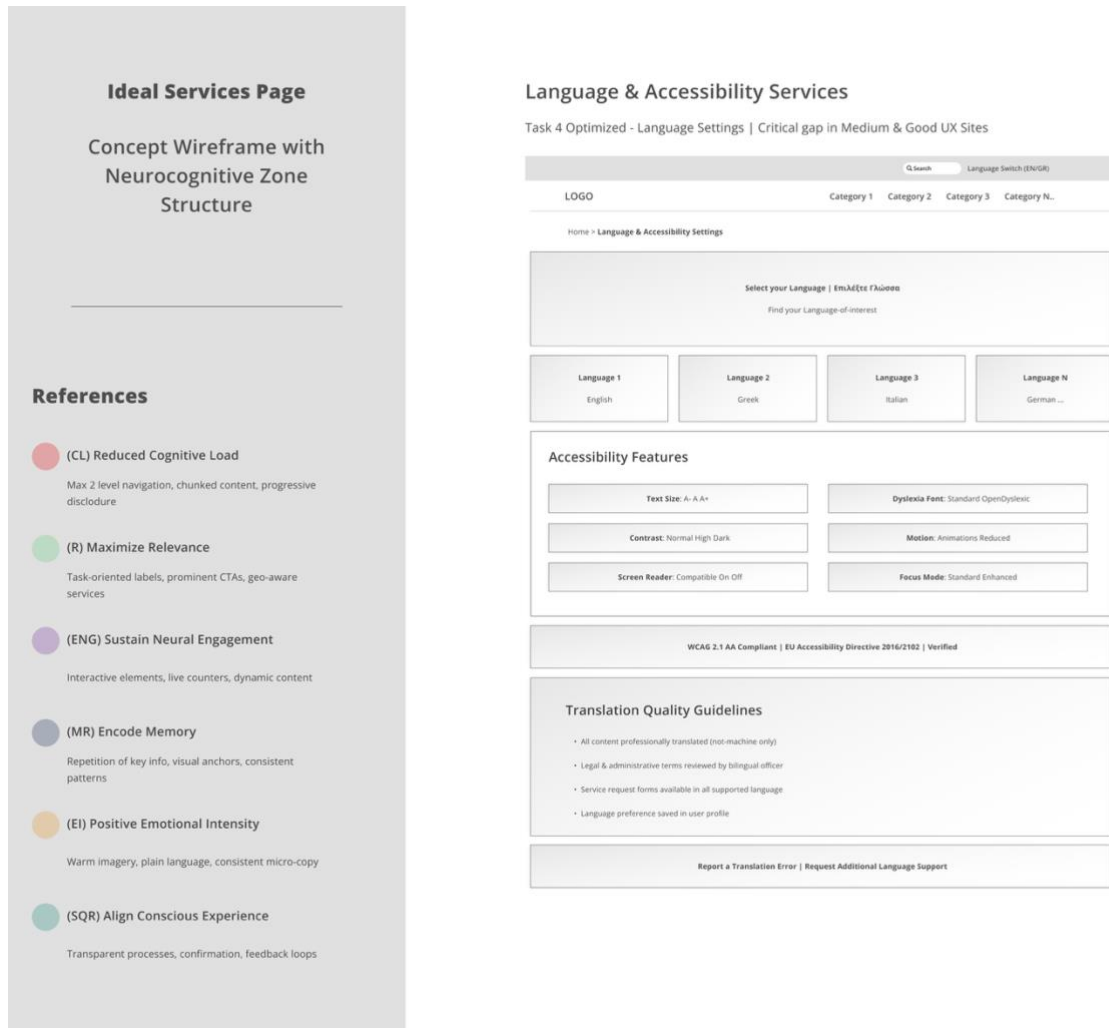


Figure 10. Language & Accessibility Interface and NCE Monitoring Dashboard. Conceptual representation of a dedicated language and accessibility interface. The language interface provides multilingual support and accessibility controls (e.g., contrast, text size, assistive features), addressing inclusivity and relevance (R) across diverse user groups. [N] annotations link design elements to pilot findings related to accessibility, engagement, and cognitive processing. IP Protected — conceptual prototypes only.

6

Chapter 6

General Discussion & Strategic Implications

6

6. GENERAL DISCUSSION

This doctoral dissertation starts from a simple but important observation: there is often a gap between how digital platforms are evaluated and how users actually experience them. While systems may perform well technically, they do not always deliver a positive or effective experience at a cognitive and emotional level.

This gap has direct implications for organizations and public institutions. When user experience is not accurately captured, digital tools may remain underused, citizen engagement may decline, and investments in digital transformation may fail to deliver the expected value. As a result, stakeholders may allocate resources based on misleading indicators of success, focusing on technical performance rather than actual user impact.

The COVID-19 pandemic accelerated digital transformation and significantly raised citizens' expectations for online services. Today, people expect digital platforms to be not only functional, but also easy to use, intuitive, and engaging. However, as this research shows, Greek municipal websites have not fully adapted to these expectations. The issue is not only about technical quality, but more importantly about how these platforms are experienced by real users.

Chapter 1 sets the foundation by bringing together insights from psychology, neuroscience, and user experience (UX) research. It argues that evaluating digital platforms based only on technical performance or usability metrics is no longer enough. To truly understand user experience, we also need to consider how people think, feel, and process information when interacting with digital services. Over time, UX has evolved from focusing mainly on efficiency to also including factors such as trust, emotional response, and memory, aspects that traditional evaluation methods often fail to capture.

The studies presented in Chapters 2 to 5 build on this idea by providing real data and practical insights. Together, they offer a comprehensive view of how users interact with municipal digital services in Greece and highlight key gaps between expected and actual user experience. The discussion that follows brings these findings together and explains their implications for digital design, public services, and decision-making.

6.1 Overview of the Research Program

The dissertation is structured as a progressive inquiry, with each chapter building on the findings of the previous to arrive at a more complete and actionable understanding of citizen digital experience. Table 6.1 summarizes the research questions, key findings, and scientific contributions of each empirical chapter.

Table 6.1 Research Program Overview: Questions, Findings, and Contributions by Chapter

Chapter	Research Question	Key Finding	Contribution
2	Do Greek municipal websites exhibit early UX deficiencies?	Systematic performance, accessibility, and usability gaps confirmed across a representative sample using Lighthouse and an adapted UX Audit framework	First multi-tool structured evaluation of Greek municipal websites; establishes empirical baseline for subsequent chapters
3	How usable are Greek municipal platforms across 138 municipalities?	Majority of sites score below 50% on composite UX quality; significant regional disparities; navigation, accessibility, and digital services as primary failure dimensions	Largest UX audit of Greek municipal websites to date; original 9-dimension framework; citizen survey integration; regional mapping of digital inequality
4	Do neurocognitive measures reveal what self-report and audits cannot?	NCE: Medium $\approx$ Good UX ($\Delta=0.13$) despite 25-point Audit gap; Task 4: only Bad UX site had English version; SRQ ranking reversal (Medium > Good)	First multimodal neuro-UX study in Greek e-government; introduces the NCE Index; demonstrates the systematic limitations of expert audit and self-report methods
5	How can municipal websites be redesigned to better serve citizens?	Neurocognitive-Informed Design Framework: Brain Map, 6 Principles, annotated wireframes, Three-Level Implementation Model — all grounded in empirical evidence	First neurocognitive-informed municipal website design framework in Greek context; practical implementation roadmap; IP-protected NCE monitoring dashboard

NB. Contributions represent the primary novel scientific contribution of each study relative to the existing literature on Greek e-government UX.

Read sequentially, the four empirical chapters tell a coherent and theoretically grounded story. Greek municipal websites are structurally deficient, a finding established with rigor and scale in Chapters 2 and 3, consistent with the broader literature on e-government usability deficiencies across European and developing country contexts (Shareef et al., 2011; Chatzopoulos & Economides, 2009; Verdegem & Verleye, 2009). But structural deficiency, as Chapters 4 and 5 reveal, is only part of the picture. The more fundamental problem is that the methods conventionally used to evaluate and improve these websites are themselves inadequate to capture the full complexity of citizen digital experience, precisely the argument advanced by Corneille & Gawronski (2024) and Bell et al. (2018) in their critiques of self-report-only approaches to user evaluation.

6.2 Integrated Findings: What the Research Reveals

6.2.1 The Scale and Consistency of UX Deficiency in Greek Municipal Websites

Chapters 2 and 3 establish, with unprecedented empirical rigor in the Greek academic context, that UX deficiencies in Greek municipal websites are systematic, widespread, and measurable. The preliminary evaluation of Chapter 2 identified pervasive gaps in technical performance, accessibility, and usability across a representative sample, providing the first structured multi-tool assessment combining Google Lighthouse metrics with an adapted UX Audit framework specifically developed for this research. These findings are consistent with earlier, smaller-scale Greek studies (Vasilikopoulou, 2017; Delopoulos, 2015; Chatzopoulos & Economides, 2009; Yannas & Lappas, 2007) but extend them substantially in both methodological sophistication and sample size.

Chapter 3 extended this analysis to the largest sample ever examined in Greek municipal website research, namely 138 municipalities evaluated across nine UX dimensions using a validated, original framework that integrates expert audit, Lighthouse technical assessment, and citizen survey data. The findings are stark: the majority of Greek municipal websites score below 50% on composite UX quality, with fewer than 20% meeting the threshold for "good" UX. Regional disparities are significant, with island municipalities and smaller communities consistently underperforming, a pattern consistent with the broader literature on digital inequality in local governance (Omweri, 2024; Kuhlmann & Bogumil, 2021). Navigation architecture, digital service provision, and accessibility emerge as the most critical and consistent failure dimensions.

These findings directly respond to the challenge articulated in Chapter 1 regarding the failure of Greek public sector digital initiatives to adequately centre user needs (1.2). The scale of structural deficiency documented in Chapters 2 and 3 provides the empirical motivation for the more nuanced question pursued in Chapter 4: whether structural quality, as measured by expert audits, actually predicts citizen neurocognitive experience.

6.2.2 The Neurocognitive Evidence: What Citizens Experience vs. What Audits Measure

Chapter 4 constitutes the methodological and conceptual heart of the dissertation. By applying a multimodal neuroscientific evaluation framework to three Greek municipal websites representing the spectrum of UX quality identified in Chapter 3, the study generates a form of evidence about citizen experience that is, to the best of the author's knowledge, entirely novel

in the Greek e-government research context and rare in the international literature (Bataineh et al., 2017; Albayrak & Çagiltay, 2013).

The central finding is both striking and consequential: despite a 25-percentage-point difference in UX Audit scores between the medium and good UX websites, the Neurocognitive Engagement (NCE) Index produced near-identical scores for both conditions (5.20 vs 5.07, $\Delta = 0.13$). Both sites fell within the same "Moderate Engagement" category. This is not a measurement artifact, it is a signal corroborated across multiple independent instruments including EEG, eye-tracking, implicit memory testing, and self-report, that the experiential gap between a "medium" and a "good" municipal website, as assessed by expert evaluation, does not translate into a meaningful difference in how citizens' brains process and engage with those interfaces. This finding extends and empirically validates the theoretical concerns raised in the HCI and NeuroIS literature regarding the limitations of single-method evaluation approaches (Corneille & Gawronski, 2024; Bell et al., 2018; Frey et al., 2016).

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Equally significant are the secondary findings that surround this central result. The SAM Valence gradient confirms that citizens consciously recognize quality differences, they feel more positive about better-designed interfaces, consistent with Hassenzahl & Tractinsky's (2006) foundational framework distinguishing hedonic from pragmatic UX dimensions. Yet this conscious recognition does not extend to implicit cognitive engagement, attentional efficiency, or memory encoding. The SRQ ranking reversal, medium UX participants rating their experience more positively than good UX participants (6.13 vs 5.00), is consistent with the growing literature on the unreliability of self-reported satisfaction as a proxy for actual engagement (Da Silva, 2023; Baumeister et al., 2011; Chartrand, 2005).

The Task 4 finding further illustrates the inadequacy of aggregate scoring methods: the website with the lowest overall Audit score (28%) was the only one to provide multilingual support, achieving 100% task completion on language accessibility, while both the medium (59%) and good (84%) UX sites achieved 0%. This finding, consistent with the broader literature on digital exclusion and linguistic accessibility (Djatkiko et al., 2025; Helsper, 2021), highlights that functional gaps affecting linguistically diverse populations, including tourists, migrants, and refugees, are systematically invisible to expert audit methods and general satisfaction surveys, but immediately apparent in behavioral task data. No heuristic evaluation, no technical performance tool, and no post-session questionnaire surfaced this gap.

Central Finding: Despite a 25-point gap in UX Audit scores, Medium and Good UX municipal websites generate near-identical neurocognitive engagement. Expert audit scores and self-reported satisfaction measures **systematically overestimate the experiential differences between websites that are "adequate" and those that are "good"**, with direct and measurable consequences for **how digital investment decisions are made and justified** (Tsatsani & Pollalis, 2025).

6.2.3 From Evidence to Design: The Neurocognitive-Informed Framework

Chapter 5 closes the research loop by translating the empirical evidence of Chapters 2–4 into a coherent and actionable design contribution, in the tradition of design science research (Gregor & Hevner, 2013; Hevner et al., 2004). The Neurocognitive-Informed Design Framework, comprising the Multimodal Cognitive and Affective Brain Map, six Neurocognitive Design Principles, annotated wireframes, and a Three-Level Implementation Model, represents the applied synthesis of the dissertation.

The Brain Map provides practitioners with an accessible, empirically grounded visual reference connecting EEG channels and behavioral measures to specific brain regions and design implications, including the Prefrontal Cortex (cognitive load, Frontal Theta), the Parietal Cortex (attentional relaxation, Alpha), the Temporal Cortex and Amygdala (emotional valence, SAM), the Hippocampus (implicit memory encoding, IMT), and the Frontal Eye Fields (gaze control, Eye-Tracking). This translation of neuroscientific evidence into practitioner-oriented guidance is a defining aspiration of the NeuroIS field (Riedl et al., 2010) and is directly responsive to the call articulated in Chapter 1 for design practices that "account for the psychological and cognitive dimensions of user experience" (1.2).

The six Neurocognitive Design Principles, one per NCE Index component, provide a structured, evidence-based minimum baseline for citizen-centered municipal website design. Particularly significant is the Relevance (R) principle, which establishes multilingual accessibility not as an advanced feature but as a baseline functional requirement, a policy implication directly motivated by the Task 4 behavioral evidence and consistent with the EU Web Accessibility Directive (2016/2102) and WCAG 2.1 guidelines. The Three-Level Implementation Model acknowledges the resource heterogeneity of Greek municipalities and provides scalable pathways from basic compliance to full NCE-monitored digital governance.

6.3 Theoretical and Scientific Contributions

6.3.1 The NCE Index: A Novel Composite Metric

The Neurocognitive Engagement (NCE) Index is the dissertation's primary theoretical contribution. By integrating six complementary dimensions, Emotional Intensity (EI), Engagement (ENG), Cognitive Load (CL), Relevance (R), Memory Retention (MR), and Self-Reported Quality (SRQ) — into a single composite score on a 0–10 scale, the NCE Index provides what no existing single-method evaluation tool offers: a holistic, neurocognition-informed measure of citizen digital experience that captures both implicit and explicit dimensions of engagement.

The index builds on established traditions in cognitive neuroscience (Kamzanova et al., 2015; Antonenko et al., 2010; Klimesch, 1999;), behavioral psychology (Holmqvist et al., 2011; Rayner, 1998), memory science (Macmillan, 2002; Schacter, 1987), and self-report psychometrics (Hassenzahl & Tractinsky, 2006), synthesizing these traditions within a unified evaluative framework that is both theoretically grounded and practically applicable. Its modular architecture allows adaptation to different evaluation contexts and resource levels. The intellectual property underlying the NCE Index is subject to formal copyright protection, reflecting both its practical value and its novelty: no equivalent composite neurocognitive UX metric has been published in the Greek or, to the best of the author's knowledge, international academic literature.

6.3.2 Advancing the NeuroIS Paradigm in e-Government Research

This dissertation makes a substantive contribution to the field of Neuro-Information Systems (NeuroIS), an interdisciplinary area that applies neuroscientific methods to the study of information systems and human-computer interaction (Dimoka et al., 2012; Riedl et al., 2010). While NeuroIS research has grown significantly over the past decade, its application to e-government and public digital services remains sparse in the European context and entirely absent from the Greek academic literature. By applying EEG, eye-tracking, and implicit memory testing to Greek municipal websites within the NCE framework, this dissertation demonstrates that NeuroIS methods are not only applicable to public-sector digital contexts but uniquely valuable in them.

The political and social stakes of e-government design its implications for democratic participation, inclusive access, and public trust, themes developed in Chapter 1 (1.5), make the accuracy and depth of evaluation methods more consequential than in commercial contexts. A

company that misestimates user satisfaction loses revenue; a municipality that misestimates citizen engagement undermines democratic efficacy (Milakovich, 2012; Coleman & Norris, 2005; Macintosh, 2004). This dissertation provides the first empirical demonstration of this argument in a Greek local governance context.

6.3.3 Challenging the Audit Paradigm in e-Government UX

A third theoretical contribution is the dissertation's systematic, evidence-based challenge to the adequacy of the expert audit paradigm as the primary tool for evaluating e-government website quality. Chapters 2 and 3 demonstrate that structured auditing provides valuable baseline data, particularly for identifying structural deficiencies at scale. But Chapter 4 provides neuroscientific evidence that audit scores do not reliably predict citizen neurocognitive engagement, and that audit-based quality rankings can be systematically misleading as a basis for investment decisions. **This is not a critique of auditing per se, it is a critique of its use as a sufficient and final evaluation framework.**

The dissertation argues for a hierarchical evaluation model in which structural auditing provides a necessary but insufficient first layer of assessment, supplemented by behavioral and neurophysiological measurement to capture the deeper dimensions of citizen experience. This argument is consistent with emerging calls in the e-government literature for richer, more citizen-centred evaluation approaches (Schwoerer, 2025; Kumar et al., 2017) and directly responds to the methodological gap identified in Chapter 1's review of cognitive and neuroscientific approaches to digital interaction (1.4).

6.4 Strategic Implications

6.4.1 For Greek Digital Governance Policy

The dissertation's findings carry immediate and actionable implications for Greek digital governance policy. The large-scale audit of Chapter 3 provides the most comprehensive empirical baseline of Greek municipal website quality currently available, a resource that could directly inform the prioritization of digital transformation investments under ongoing national and EU-funded programmes, including the Βίβλος Ψηφιακού Μετασχηματισμού and the Digital Decade Policy Programme 2030.

The neurocognitive findings of Chapter 4 challenge the adequacy of current evaluation frameworks for public digital investment. If investments are guided primarily by technical audit scores and satisfaction surveys, which, as the dissertation demonstrates, can significantly overestimate the experiential gap between medium and good UX, resources risk being allocated

to incremental structural improvements that generate no measurable improvement in how citizens actually engage with digital platforms. The three-level implementation model of Chapter 5 provides a practical framework for redirecting this investment toward dimensions that genuinely drive neurocognitive engagement: multilingual accessibility (a Level 1 baseline requirement, not a luxury), cognitive load reduction, and content relevance.

The consistent evidence that language accessibility generates high-impact improvements in citizen reach and task completion, with Bad UX achieving 100% Task 4 completion versus 0% for both Medium and Good UX sites, has direct policy implications for EU Web Accessibility Directive implementation across Greek municipalities, and for the integration of linguistic inclusion as a baseline requirement in digital procurement standards (Djarmiko et al., 2025; Paul, 2023).

6.4.2 For Digital Investment Decisions in the Public and Private Sectors

Perhaps the most immediately consequential strategic implication concerns the basis on which digital investment decisions are made and justified, a theme that connects directly to the business value of UX argument developed in Chapter 1 (1.3). The dissertation demonstrates that user satisfaction scores are an incomplete and potentially misleading proxy for actual citizen engagement. A website rated 84% by expert auditors and 5.00 by its users may generate the same neurocognitive engagement as one rated 59% and 6.13, and the investment required to raise it from 84% to 95% may generate no measurable improvement in how citizens actually experience and use the platform.

Chapter 1 noted that **"every dollar invested in UX design can return a 100% return on investment"** (Forrester, cited in 1.3), **but this return is predicated on the assumption that the UX improvements made actually improve user experience.** The neurocognitive evidence of this dissertation complicates this assumption: **investments guided by audit compliance and satisfaction scores may systematically miss the dimensions of experience that drive genuine engagement, retention, and use. The NCE Index provides a more reliable signal for investment decisions, identifying the specific experience dimensions, namely cognitive load, relevance, memory encoding, emotional tone, that drive genuine engagement rather than conscious ratings.**

This implication extends beyond the public sector. For businesses and digital product organizations, the same argument applies: design teams that rely solely on A/B testing, NPS scores, and user satisfaction surveys risk over-investing in features that improve conscious

ratings without improving real-world adoption or behavioral engagement. **The NeuroIS-informed evaluation approach embodied in the NCE Index offers a more reliable signal for product investment decisions, one that captures what users cannot or do not report.**

6.4.3 For e-Democracy and Citizen Participation

The dissertation's implications extend to the fundamental question of digital democracy, a thread woven throughout Chapter 1 (1.5) and central to the thesis title itself. Municipal websites are not merely service delivery platforms; they are the digital frontline of local democratic participation. When these platforms are cognitively demanding, emotionally unrewarding, and functionally inaccessible to significant citizen segments, **they undermine not only service uptake but civic engagement itself.**

The neurocognitive evidence is particularly significant in this context. A citizen who reports moderate satisfaction with a municipal website, and who is therefore unlikely to trigger any improvement intervention under conventional evaluation frameworks, may nonetheless be experiencing elevated cognitive load, reduced implicit memory encoding, and low behavioral engagement. These implicit indicators predict whether the citizen will return to the platform, whether they will complete service requests, and whether they will perceive their municipality as responsive and competent. The aspiration of the EU's e-Government agenda, that digital public services can strengthen democratic participation, reduce administrative barriers, and build public trust (Nulhusna et al., 2017; EC, 2010; Coleman & Norris, 2005; Macintosh, 2004), requires that **these services genuinely engage citizens at the cognitive and emotional level, not merely at the level of conscious satisfaction.**

The Task 4 finding adds a further dimension to this argument: **digital exclusion based on language inaccessibility affects citizens who are most likely to be marginalized in other domains, i.e. migrants, refugees, non-Greek speakers, and international residents.** A municipal website that scores 84% on an expert audit but provides no English-language access is, **for these citizen groups, functionally inaccessible.** The neurocognitive and behavioral evidence makes this invisible gap visible in a way that no satisfaction survey could.

6.5 Connecting Back to the Research Objectives

Chapter 1 articulated five core research objectives for this dissertation. The following assessment situates the empirical chapters' contributions against each objective.

Objective 1 to assess the current state of UX across Greek municipal websites using traditional and neuro-informed tools, is fully addressed by Chapters 2, 3, and 4, which provide

the most comprehensive empirical assessment of Greek municipal website quality available, integrating structural audit, technical performance, citizen survey, and neuroscientific evaluation.

Objective 2 to explore unconscious user responses through EEG, eye-tracking, and implicit memory testing is addressed by Chapter 4, which demonstrates that these methods reveal patterns of engagement and frustration systematically unavailable to self-report instruments. The EEG, eye-tracking, and IMT data each provide complementary, non-redundant evidence about the implicit dimensions of citizen digital experience.

Objective 3 to introduce and pilot the NCE Index is addressed by Chapters 4 and 5. The NCE Index is introduced as a novel composite metric in Chapter 4, piloted across three UX conditions, and operationalized as a practical monitoring tool in the NCE Monitoring Dashboard proposed in Chapter 5.

Objective 4 to translate insights into actionable design recommendations through a prototypical "Municipality Portal" is addressed by Chapter 5, which presents a neurocognitive-informed design framework including annotated wireframes, six design principles, and a three-level implementation roadmap, directly grounded in the empirical findings of the preceding chapters.

Objective 5 to propose the UX Multimodal Perceptual MindMap connecting design elements with cognitive and emotional processes is addressed by the Multimodal Cognitive and Affective Brain Map presented in Chapter 5, which provides the first empirically grounded, data-connected visual synthesis of the neural architecture underlying digital interface interaction in a municipal e-government context.

6.6 Positioning within the International Research Landscape

The dissertation's contributions can be situated within four intersecting international research traditions.

Within **e-government UX research**, the dissertation makes the largest empirical contribution to date in the Greek context and provides one of the few examples internationally of neuroscientific methods applied to public digital service evaluation (Bataineh et al., 2017; Albayrak & Çagiltay, 2013). It responds to persistent calls for evaluation approaches that go beyond technical performance and satisfaction metrics to capture the psychological and cognitive dimensions of citizen experience (Schwoerer, 2025; Kumar et al., 2017; Verdegem & Verleye, 2009).

Within **NeuroIS**, the dissertation extends the paradigm into the domain of local e-government, contributing a novel composite metric (NCE Index) and a scalable evaluation protocol that advances the practical applicability of neuroscientific methods beyond laboratory settings. It responds to NeuroIS calls for applied, domain-specific validation of neurophysiological evaluation tools (Xu et al., 2014; Dimoka et al., 2012; Riedl et al., 2010).

Within **design science research** (Gregor & Hevner, 2013; Hevner et al., 2004), the dissertation exemplifies the full cycle from problem identification through empirical investigation to artifact creation, producing design contributions directly grounded in and justified by empirical evidence, consistent with Level 2 ("Improvement") contributions in the Gregor-Hevner taxonomy.

Within **cognitive psychology and neuroscience applied to HCI**, the dissertation contributes evidence for the real-world relevance of well-established laboratory findings, cognitive load (Antonenko et al., 2010; Grunwald & Corsbie-Massay, 2006), attentional engagement (Bonnefond & Jensen, 2025; Chen et al., 2020), emotional processing (Hassenzahl & Tractinsky, 2006; Simon, 1981), and implicit memory (Tobias et al., 2014; Schacter, 1987), in the specific context of Greek municipal digital interface interaction. This strengthens the ecological validity of neuroscientific UX research beyond controlled laboratory conditions.

6.7 Limitations

Several limitations of the research programme warrant acknowledgement. At the level of the dissertation as a whole, three overarching constraints are particularly relevant, beyond those documented in the individual chapters.

The **pilot nature of the neuroscientific study** (Chapter 4, $n = 10$, male participants only) limits the statistical power and generalizability of the NCE Index findings. While directional findings are theoretically coherent and consistent with the broader HCI and neuroscience literature, replication with larger, gender-balanced, and generationally diverse samples is required before the NCE Index can be proposed as a universal evaluation standard. The author is transparent about this constraint throughout the dissertation and frames all claims accordingly.

The **conceptual prototype status of the design contributions** (Chapter 5), the wireframes, Brain Map, and implementation roadmap, means they have not been empirically tested with real citizens or implemented in real municipal contexts. They constitute evidence-informed design proposals rather than validated design solutions. Future action research

partnerships with Greek municipalities are needed to assess practical feasibility, organizational readiness, and implementation outcomes.

The **IP constraints** surrounding the NCE Index's computational methodology limit its immediate external replicability. While this is a deliberate and legally justified constraint, it represents a tension with open science norms that the author acknowledges and that future IP registration and licensing arrangements are intended to resolve.

6.8 Future Research Directions

The research programme opens several productive directions for future investigation.

The most immediate priority is **replication and validation of the NCE Index** with a larger, more demographically diverse sample including women, elderly users, and citizens with varying levels of digital literacy, and across a broader range of municipal websites. Such a study would provide the statistical power needed to confirm the directional patterns observed in the pilot and to establish empirically grounded NCE thresholds and component weighting schemes.

A second priority is **implementation and longitudinal evaluation** of the Neurocognitive Design Framework in real municipal contexts. Action research partnerships, implementing the three-level roadmap and tracking NCE scores longitudinally, would provide validation evidence and demonstrate the practical value of NCE-based monitoring for digital governance teams.

Third, **extending the NCE Index to private sector contexts**, such as e-commerce, financial services, healthcare would test its generalizability beyond the public sector and explore whether the weights and thresholds appropriate for municipal websites require adaptation for commercial interaction contexts. The dissertation's core argument, that self-reported satisfaction underestimates the complexity of user engagement — is not sector-specific.

Finally, **methodological innovation within the NCE framework**, including higher-density EEG, automated eye-tracking, galvanic skin response, and machine learning-based pattern recognition would enhance the precision, scalability, and diagnostic power of the index, moving it progressively closer to a real-time, continuous evaluation tool for deployment at scale (Bellos et al., 2025; Wiedbusch et al., 2023).

6.9 Conclusion

Toward a Neurocognitive Standard for Greek Municipal Digital Services

This dissertation began with an observation from Chapter 1, that is to improve digital interfaces, "organizations must look beyond technical functionality and account for the psychological and cognitive dimensions of user experience" (1.2). Five chapters later, that argument has been transformed from a theoretical aspiration into empirical evidence and applied guidance.

The research programme demonstrates that Greek municipal websites are, by and large, structurally deficient, and that this deficiency is both measurable and addressable. But it also demonstrates something more consequential, that the tools currently used to assess and improve these websites are themselves inadequate. Expert audits miss functional gaps that affect linguistically diverse citizens. Satisfaction surveys overestimate the experiential gap between medium and good quality sites. Neither captures the implicit neural and behavioral reality of citizen digital experience.

The Neurocognitive Engagement (NCE) Index, introduced and piloted in this dissertation, is a first step toward closing this gap. It is not a complete solution, it is a proof of concept, a demonstration that neuroscientific methods can be applied to e-government evaluation in a way that is practically feasible, theoretically grounded, and empirically illuminating. The findings it generates are qualitatively different from those produced by conventional methods: they reveal a systematic disconnect between expert-assessed structural quality and actual citizen cognitive engagement that has profound implications for how democratic digital services are designed, evaluated, and invested in.

The Neurocognitive-Informed Design Framework and the Brain Map of Chapter 5 translate these findings into practice, providing designers, product owners, and digital governance policymakers with the conceptual tools and structural guidance needed to build municipal websites that are not merely technically compliant or structurally sound, but genuinely engaging at the level of the citizen's neural and emotional experience. This is the standard that democratic digital services should aspire to. And this dissertation, for the first time in the Greek academic context, provides the methodological foundation to pursue it.

The work presented in this dissertation is offered as a foundation, not a final word. The most important research in this area remains to be done: in the implementation of neurocognitive-informed design in real municipal contexts, in the validation of the NCE Index

with representative citizen populations, and in the gradual institutionalisation of engagement-based evaluation as a standard component of Greek digital governance. The citizens whose democratic experience depends on the quality of municipal digital services deserve no less.

Research Program Contribution: This dissertation introduces the first multimodal neuroscientific evaluation framework for Greek e-government UX; the first large-scale neurocognitive comparison of municipal website quality; the NCE Index as a novel, IP-protected composite engagement metric; and a Neurocognitive-Informed Design Framework translating brain-level evidence into actionable design guidance. Together, these contributions establish a new methodological paradigm for citizen-centred digital governance research in Greece and beyond (Tsatsani & Pollalis, 2024; 2025; 2026).

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Curriculum Vitae

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Olga Tsatsani was born in Greece. She obtained her Bachelor of Science in Psychology from the National and Kapodistrian University of Athens in 2013. In 2014 she began her Master's studies in Cognitive Neuroscience and Neuropsychology at Erasmus University Rotterdam in the Netherlands, where she graduated in 2016. Following her postgraduate studies, she pursued a professional career in user experience research and digital consulting. She worked as a UX Researcher, Project Coordinator, and Consultant at Linakis Digital in Athens, where she led research projects across multiple sectors including banking, insurance, tourism, and e-commerce. She later joined Atcom as a Leader UX Researcher, where she contributed to the development of the company's UX research lab and led research initiatives aimed at improving digital product experiences. In 2024 she joined Betsson Group as a Senior Brand Experience Researcher, focusing on aligning product and brand strategy with user behavior insights through user research and data-driven methodologies. Alongside her professional work, Olga Tsatsani pursued doctoral research at the Department of Economics at the University of Piraeus within the iLeads Research Lab. Her doctoral research focuses on the intersection of user experience, information systems, cognitive processes, and neuroscience, examining how users cognitively and emotionally interact with digital environments in both public and private sector platforms. Her research combines traditional UX evaluation methods with neurophysiological techniques such as EEG and eye-tracking, contributing to the development of innovative methodologies for measuring user engagement. As part of her doctoral work, she introduces the Neuro-Cognitive Engagement Score (NCES), a neuroscientific metric designed to capture cognitive engagement during digital interactions. Her research interests include User Experience Research, Neuro-Information Systems (NeuroIS), Cognitive Neuroscience, Digital Governance, and Human-Centered Design.

Publications

Tsatsani, O., Patergiannaki, Z., & Pollalis, Y. (2024).

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