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Research Paper

EmoWeb: An Infrastructure for Adapting User Interfaces Based on Desired Emotions

Alex Sandro Rodrigues Ancioto [Federal Institute of Education, Science and Technology of São Paulo | *alex_ancioto@ifsp.edu.br*]
Rogério Aparecido Campanari Xavier [Federal Institute of Education, Science and Technology of São Paulo | *rogerioacx@ifsp.edu.br*]
Fernando Miguelão da Silva [Federal University of Sao Carlos | *fernandomiguelao@gmail.com*]
Patrícia Deud Guimarães [Federal University of Sao Carlos | *patricia.deud@inep.gov.br*]
Letícia Gabrielly Zacano da Silva [Federal University of Sao Carlos | *leticia.gabrielly1@gmail.com*]
Valter Vieira de Camargo [Federal University of Sao Carlos | *valtervcamargo@ufscar.br*]
Vania Paula de Almeida Neris [Federal University of Sao Carlos | *vania.neris@ufscar.br*]

Department of Computing, Federal Institute of Education, Science and Technology of São Paulo, Av. Nações Unidas Norte, 16-100, Parque Roosevelt - Bauru- SP - 17031-280.

Abstract. This article systematizes and analyzes the evolutionary development of EmoWeb, a computational infrastructure designed to adapt web interfaces according to users' desired emotional states. Although the integration of emotional models into adaptive systems has received increasing attention in Human–Computer Interaction (HCI), consolidated studies examining the architectural evolution and longitudinal validation of such infrastructures remain scarce. Grounded in Scherer's Semantic Space of Emotions and structured according to the IBM MAPE-K self-adaptive architecture, the proposed infrastructure integrates theoretical, methodological, and technical contributions derived from a longitudinal research program. This trajectory encompasses hybrid approaches to emotional assessment; the design of an adaptive architecture; studies on visual interface elements; emotion recognition using physiological sensors and machine learning techniques; and the development of self-report instruments. The infrastructure was evaluated through a comparative architectural analysis focusing on software maintainability, as well as a controlled user experiment that assessed its potential to guide users toward desired emotional states. The results indicate improvements in maintainability and architectural flexibility, along with a tendency for users to shift toward more positive emotional states. These findings highlight the potential of EmoWeb as a foundation for emotion-oriented adaptive interfaces and contribute to advances in HCI, particularly regarding the personalization of users' emotional experiences, in alignment with the GranDIHC-BR 2025–2035 agenda.

Keywords: User Interface, Emotions, Sensors, MAPE-K, Infrastructure

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1 Introduction

Emotions play a fundamental role in human interactions, significantly influencing cognitive, behavioral, and social processes [Norman, 2004; Scherer, 2005]. In addition, they promote coordinated changes in the body and mind of the individual in response to the evaluation of an external or internal stimulus deemed relevant to the individual [Scherer, 2005]. The recognition and consideration of emotions contribute to user engagement, motivation, and well-being, thereby enhancing learning potential, satisfaction, and performance in technology-mediated environments [Lim *et al.*, 2008; Dalvand and Kazemifard, 2012; Ahmed, 2022].

In this context, understanding the user's emotional state is essential for the development of more adaptive and personalized experiences, since stimuli originating from the interface itself can influence their emotions. For instance, when interacting with a user interface (UI), design elements such as colors, typography, and visual composition can evoke feelings of pleasure, comfort, and satisfaction when perceived as aesthetically pleasing [Moshagen and Thielsch, 2013]. These elements may also help users feel more comfortable and less stressed [Lavie and Meyer, 2010; Makris and van Eekelen, 2016], as well as provide better, often personalized, experiences [Rathnayake *et al.*, 2019; Zhang *et al.*, 2020; Schölkopf *et al.*, 2021].

The ability to recognize the user's context, including emotional aspects, and to intervene in ways that support changes in their emotional state and well-being represents a growing field of study within the discipline of HCI. Systems capable of identifying emotional patterns and adapting their communication, content, or appearance tend to foster more humanized and contextually relevant interactions with users [Guimarães, 2022]. This approach contributes not only to improving the quality of interface use, but also to promoting users' emotional and cognitive well-being, aligning with the principles of human-centered design.

Considering these theoretical aspects, it is observed that, in recent years, several studies have proposed infrastructures aimed at detecting and adapting systems according to users' emotional well-being. However, most do not explore the development of an infrastructure that promotes the emotional state desired by the user.

In this context, this article presents a systematization of studies derived from a research program, carried out during the development of a computational infrastructure, EmoWeb. The proposed infrastructure integrates the self-adaptive MAPE-K architecture with Scherer's Semantic Space of Emotions, establishing a control loop capable of monitoring, analyzing, planning, and executing adaptations oriented toward the user's desired emotional state. Furthermore, it evaluates the resulting architecture, highlighting its advances, contributions, and potential applications in the field of adaptive interfaces.

The synthesis of the studies contributes to the literature by consolidating results into a unified infrastructure, highlighting its potential, gaps, and limitations. As an example, the Color Circle proposed by [Bianchi and de Almeida Neris, 2015], an artifact that associates colors with the octants of Scherer's Semantic Space of Emotions [2005], structured along the dimensions of valence (pleasure/displeasure), activation (arousal), and sense of control. In addition, the work examines the influence of font type and size on users' emotions [Bianchi *et al.*, 2021] and the effectiveness of supervised algorithms for classifying emotional states. In this context, Naive Bayes algorithms applied to ECG and GSR achieved accuracies of 96% and 77%, respectively, while Support Vector Machines (SVM) applied to EEG data reached 99% accuracy [Souza, 2019]. Furthermore, the evaluation of users' emotional transitions, based on Scherer's Semantic Space of Emotions [Scherer, 2005], traces the trajectory of users' emotional states during web-based activities [Guimarães *et al.*, 2023].

The comparative analysis, grounded in the application of the MAPE-K model [IBM, 2005], yielded significant improvements in system maintainability. The adoption of this architecture resulted in a reduction of code smells, a decrease of approximately one day in the estimated time required for code maintenance, and a 0.9% reduction in the defect rate [Serikawa *et al.*, 2016; Martín *et al.*, 2020]. These advances positively contributed to the flexibility and sustainability of EmoWeb, enabling emotion-based interface adaptations to be performed more efficiently and at greater scale. It is worth noting that the development of the infrastructure, integrating the MAPE-K model [IBM, 2005], and the evaluation of improvements in the system's maintainability confer originality to this study.

The relevance of this study lies in its multiple contributions to the HCI literature. First, by consolidating previously dispersed results into a unified infrastructure, the work addresses a methodological gap by providing a systemic perspective that highlights the potential and limitations of prior research. Second, it presents the adoption of the MAPE-K architecture, which contributes to the flexibility and sustainability of EmoWeb, enabling emotion-based interface adaptations to be carried out more efficiently and on a larger scale.

The contribution of this article is twofold. First, it systematizes a longitudinal research trajectory and consolidates previously dispersed theoretical, methodological, and technical contributions into a unified description of the EmoWeb infrastructure. Second, it incorporates the MAPE-K model, evaluates its impact on maintainability and architectural flexibility, and presents a comparative architectural analysis. In this sense, the article does not merely report isolated studies, but examines how their results were progressively integrated into an emotion-oriented adaptive infrastructure.

2 Related Work

The literature presents several approaches to system personalization based on affective states. For example, Märtin et al. [2016] developed an adaptive system based on users' behavior, emotions, and intentions to help them achieve a predefined emotional state. The architecture proposed by Galindo et al. [2017], on the other hand, adapts interface elements (such as font size, audio, screen brightness, as well as the overall UI structure) so that the user interface can adjust to the user's emotional state.

Donati et al. [2020] proposed a study on the transition of interface elements (e.g., colors, layout, menus, graphical elements, and component positioning) that guide users experiencing negative emotions toward positive ones. Meudt et al. [2016] employed a multilayer architecture that records the history of user interactions with the system and their corresponding emotional responses. This architecture enables more precise long-term adaptations, fostering more empathetic interactions between the system and the user. Dalvand and Kazemifard [2012]; Bianchi and de Almeida Neris [2015]; Donati et al. [2020] investigated color adaptation and its effects on users. Other studies combine color adaptation with additional types of adaptation; for instance, Herdin and Märtin [2020] present color adaptation alongside content and media adaptation (such as pop-ups, product reviews, and chart types).

These works illustrate different ways in which systems address users' affective changes. For instance, studies such as Donati *et al.* [2020] and Märtin *et al.* [2016] focus on emotional transitions, investigating how design techniques and interaction patterns can guide users from negative to positive emotional states. Complementarily, Galindo *et al.* [2017] and Dalvand and Kazemifard [2012] emphasize support for such transitions, employing structural and chromatic adaptations to mitigate the impact of adverse emotions and sustain higher levels of user satisfaction. In this context, Dalvand and Kazemifard [2012] rely on chromatic adaptations (interface colors), whereas Galindo *et al.* [2017] employ both structural adaptations (UI variants) and chromatic adjustments. Finally, a more analytical perspective is proposed by Meudt *et al.* [2016] and Herdin and Märtin [2020], who emphasize understanding the context and underlying causes of emotional changes through interaction history and situational awareness, enabling systems to respond in an empathetic and personalized manner to users' long-term needs.

Although these proposals have contributed to advances in the field, most focus on mitigating adverse feelings or guiding users from negative to positive emotional states, without exploring the development of an infrastructure that actively promotes the user's desired emotional state. It thus becomes essential to analyze, over time, the evolution of a computational infrastructure, examining its advances, limitations, and gaps, particularly with regard to the integration of emotional models into an adaptive interface architecture aimed at promoting the user's emotional state.

3 Fundamental concepts

3.1 Emotions

There is no academic consensus regarding the definitive classification of what constitutes an emotion [Quigley *et al.*, 2014]. According to the conceptualization proposed by Russell [1980], affect is understood as a set of affective states organized within a dimensional space. In his circumplex model of affect, affective experience is fundamentally defined by two bipolar dimensions: pleasure–displeasure and degree of arousal–sleep. Through the continuous combination of these dimensions, various affective states are distributed along a circular structure, in which similar states occupy adjacent positions and opposing states are located at diametrically opposite points. Consequently, affective states are distinguished from one another not by abrupt qualitative shifts, but by gradual variations in levels of pleasure and activation. This framework supports the understanding of affect as a continuous spectrum that underlies the emotional categories commonly employed in everyday language.

While Russell [1980] conceptualizes affect as a dimensional space defined by valence and arousal, Scherer [2005] expands this perspective by embedding affective experience within a dynamic and multicomponent process of emotion elicitation. Scherer [2005] defines emotion as a dynamic process composed of multiple interacting components (cognitive appraisal, physiological responses, motivational tendencies, expressive behavior, and subjective feeling) that unfold in response to the evaluation of an internal or external stimulus relevant to the individual. In this framework, the subjective feeling component may be described in dimensional terms, thereby establishing a point of theoretical compatibility with Russell's model, while situating affect within a broader processual architecture of emotion.

Given the variety of existing definitions of the concept of emotion and the lack of consensus among scholars in the field, the choice of a theoretical perspective is generally based on its affinity and alignment with the research objectives. In this regard, the adoption of Scherer's model is grounded in its ability to extend Russell's (1980) circumplex model. While the baseline model focuses on valence and arousal, Scherer introduces two additional variables: Goal Conduciveness, which assesses whether an event facilitates or hinders an individual's goals, and Coping Potential, which refers to the perceived level of control over the situation.

Compared to other multidimensional models, such as the PAD Emotional State Model [Mehrabian and Russell, 1974], which characterizes emotions along the dimensions of pleasure, arousal, and dominance, Scherer's model offers greater specificity by integrating components of cognitive appraisal. This integration enables a more fine-grained and theoretically grounded differentiation of emotional states for the analysis of interactive systems.

3.2 Scherer's Semantic Space

Scherer [2005] defines emotion as a multicomponent process, conceptualized as the Component Process Model. This model defines emotion as a series of coordinated changes in the body and mind of an individual, occurring in response to the appraisal of an external or internal stimulus considered relevant to oneself. These changes involve five main areas: thinking (cognitive appraisal of the event to which the individual is exposed), bodily reactions (responses that occur in the body and are expressed through physiological changes), action tendencies (motivational impulses that can influence behavior), expressions (such as facial expressions and tone of voice), and subjective experience (referring to the conscious perception of the emotional state).

According to Scherer [2005], these five areas of emotion interact in an integrated manner, creating a dynamic system that guides human behavior. This conceptualization influences research ranging from mental health studies to the development of technologies that aim to interpret and respond to emotional states.

The author also proposes four dimensions of emotional appraisal, arousal, sense of control, valence, and goal conduciveness, which compose the Semantic Emotion Space. This space is divided into eight "octants" that allow the graphical representation of emotional states and their association with specific domains, such as high valence. High valence encompasses octants 5, 6, 7, and 8. In octant (7), it is possible to map emotions such as happy, loving, passionate, and determined, as shown in Figure **??**.

These models enabled the research group to systematically represent emotions and provide a theoretical framework for measuring the user's emotional state. This allows the emotional experience of an individual to be assessed based on the relationship between emotional responses (subjective and objective, self-reported or collected by sensors) and the octants of the semantic space.

3.3 Adaptations

In the literature, a wide range of interactive systems has been developed to learn about users and adapt their behavior based on interaction characteristics, user needs, or contextual factors. User adaptation constitutes the central premise of adaptive systems. These systems are variously classified in the literature as adaptive interfaces, user modeling systems, software agents, and intelligent agents [Jameson, 2007], or more broadly as intelligent interfaces [Maybury, 1998; Völkel *et al.*, 2020].

Other studies have introduced related terms, such as smart, context-sensitive, multimodal, flexible, self-adaptive, adaptable user interfaces, recommender systems, and intelligent tutoring systems [Gonçalves *et al.*, 2019; Sanchez *et al.*, 2017; Van Velsen *et al.*, 2008; Schlungbaum, 1997; Wang and Stroulia, 2003; Innocent, 1982; Fischer, 2001, 2023].

Although these classifications provide useful distinctions, they reflect a fragmented understanding of adaptation and highlight the complexity of the topic, especially when the goal is to improve the user's emotional state. Given this lack of standardization in terminology and the inherent complexity of adaptation, it is necessary to establish the most commonly used terms and distinguish them from others in this article.

Fischer [2001] distinguishes adaptive systems from adaptable systems based on the degree of control over adaptation. In adaptive systems, control is autonomous; that is, adaptation occurs dynamically by the system itself, based on its objective or goal, on the user's profile [Fischer, 2001; Rashid *et al.*, 2023], or on context models [Fischer, 2023]. This allows personalization and reduces information overload [Fischer, 2023]. Furthermore, adaptive systems are generally grounded in Artificial Intelligence (AI), which, through models and algorithms, analyzes data, learns from it, and makes predictions or decisions based on that data [Fischer, 2023].

On the other hand, in adaptable systems, the user controls the modification process and can alter the system's functionality with the system's support. In this case, the burden of

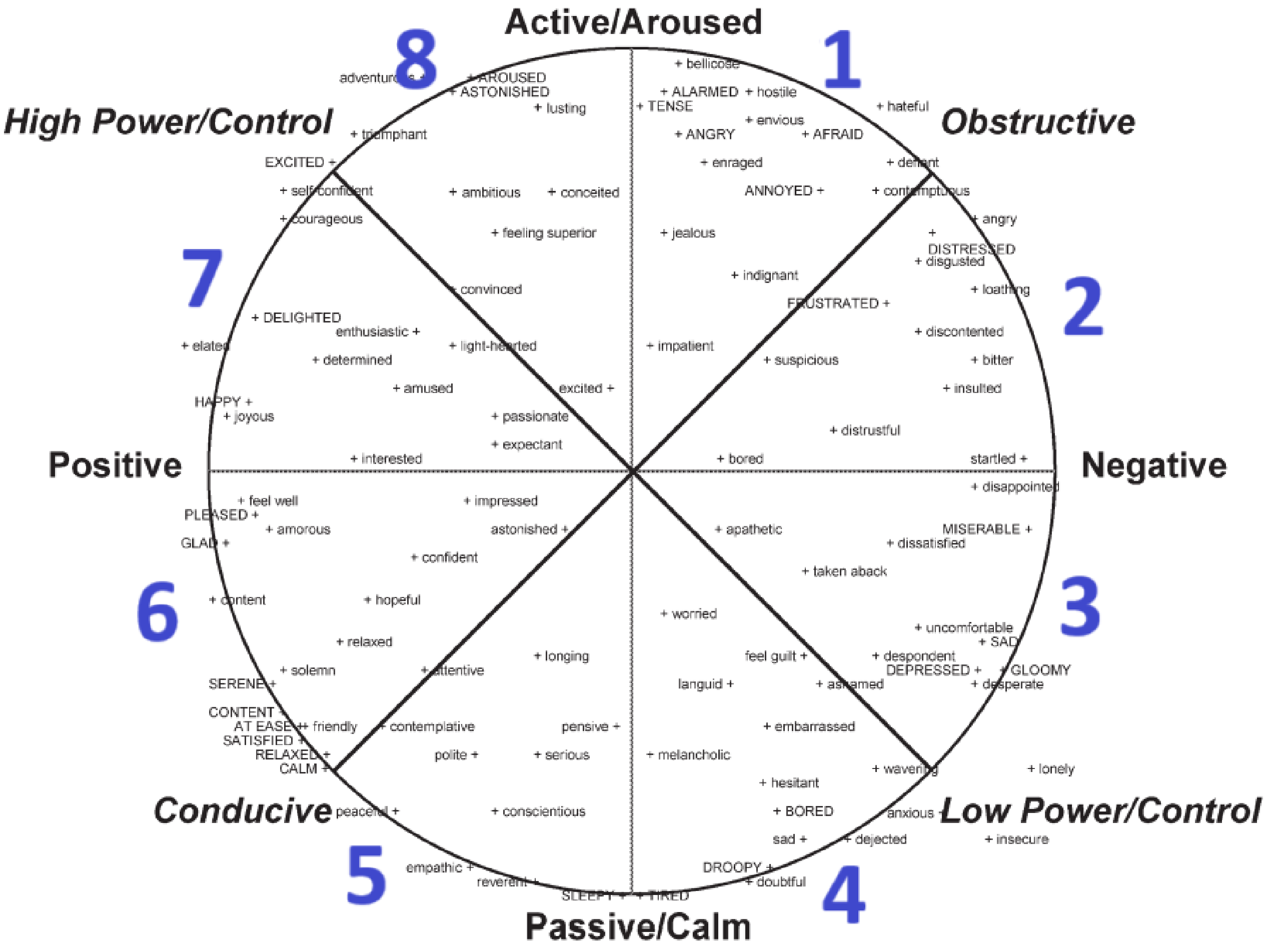

Figure 1. Structure of the Semantic Emotion Space. **Source:** Adapted from Scherer [2005]. Numbers identify how we refer to the octants.

adaptation falls on the user, granting them the ability to modify and extend the system's functionality and empowering them as a co-designer to meet specific needs within their domain [Fischer, 2023].

According to Rashid *et al.* [2023], a system's ability to adapt in relation to its goal or context is commonly referred to as self-adaptivity. For the author, the prefix "self" indicates that the system can autonomously decide or independently modify itself in order to adjust to changes in its environment. Although many self-adaptive systems operate without requiring any human interaction, some still rely on guidance in the form of high-level objectives [Rashid *et al.*, 2023].

As stated by Rashid *et al.* [2023]; Weyns [2021], for a system to adapt effectively, it must be aware. In this case, awareness requirements represent a special type of requirement that demands the system be capable of perceiving both its environment (context-awareness) and itself (self-awareness). Furthermore, factors such as the analysis of significant changes, planning how to react, and executing decisions must be taken into consideration [Rashid *et al.*, 2023; Weyns, 2021].

Understanding these concepts is essential for building solutions capable of autonomously and contextually promoting users' desired emotional states. Within the research group, these concepts provide the foundation for developing architectures that integrate perception, decision-making, and adaptation mechanisms. The infrastructure proposed by the group lies within the domain of adaptable and adaptive systems, as it employs emotional models and self-adaptivity mechanisms to adjust the interface according to the users' chosen emotional state as well as their interaction profile.

Furthermore, the processes of monitoring software entities and the environment, analyzing significant changes, planning reactions, and executing decisions described by Rashid *et al.* [2023] directly correspond to the phases of the MAPE-K model (Monitor, Analyze, Plan, Execute, Knowledge). Proposed by IBM, this model is widely used in self-adaptive systems. These characteristics of self-adaptive systems are also shared by Weyns *et al.* [2013], as they enable the organization of a control loop within such systems. The infrastructure proposed by the EmoWeb research group adopts this approach, incorporating the MAPE-K model to guide emotion-based interface adaptation, thereby reinforcing its self-adaptive nature.

3.4 Context

Adaptive systems, on a HCI perspective, are based on the assumption that there is no "typical" system user, but rather a diversity of profiles whose individual needs evolve with experience [Fischer, 2023]. To operate effectively, these systems rely on context-sensitive mechanisms that include models of their users and specific tasks. One of the central goals of user modeling in HCI is to ensure that such systems can interact cooperatively, which presupposes the ability to discern what individual users actually know, do, and intend [Fischer, 2023].

To this end, two main techniques can be employed: (1) being directly informed by users (for example, through questionnaires, preference settings, or specification components) and (2) inferring knowledge from their actions (for instance, by collecting and analyzing usage data) [Fischer, 2023].

Data collected by sensors (such as cameras, microphones, accelerometers, GPS, heart rate sensors, etc.) constitute a passive form of contextual usage data and can typically be used to enrich and refine contextual understanding. In addition to the user explicitly reporting their preferences or state (technique 1), an adaptive system can infer such information by analyzing data from these sensors.

In the literature, several studies employ this mechanism to monitor and infer users' emotional states through physiological signals, since, according to the model proposed by Scherer [2005], emotions correspond to episodes of coordinated changes across the organism's subsystems, manifested through physiological, cognitive, motivational, expressive, and subjective responses [Scherer, 2005]. For example, stress significantly affects higher cognitive functions, and its effects can be observed through electroencephalogram (EEG) signal recordings. In this case, stress can be identified through EEG signal features related to arousal, such as asymmetry, beta/alpha band ratio, or an increased presence of beta rhythm. Stress also regulates active sweat glands, increasing skin conductance under stressful conditions, which can be detected using Galvanic Skin Response (GSR) measurements [Giannakakis *et al.*, 2017]. These physiological changes occur due to the activation of eccrine sweat glands, which are exclusively innervated by the sympathetic nervous system [Paredes *et al.*, 2018].

Several studies employed combinations of multiple sensors for this purpose [Honka *et al.*, 2022; Kasuya *et al.*, 2017; Calatrava-Nicolás *et al.*, 2021; Birenboim *et al.*, 2021]. By integrating information provided by users with data obtained from physiological sensors, context recognition can be significantly enhanced, resulting in computational systems that are more personalized to users' specific needs.

The theoretical foundation of Scherer's semantic space, combined with the use of sensors for context recognition and adaptive systems, establishes the groundwork for the discussions presented in the following sections on the evolution and validation of the EmoWeb infrastructure.

4 UIFlex-EmoWeb Infrastructure

This section provides a synthesis of the studies conducted within the scope of the Flexible and Sustainable Interaction Laboratory (LIFeS) research group culminated in the development of a computational infrastructure aimed at promoting the user's desired emotional state through adaptive web interfaces. The process began with investigations focused on the theoretical foundations of detecting, analyzing, and inferring the user's emotional state, as well as on understanding the context of use. Subsequently, these studies evolved toward the development of the technological solution and its corresponding evaluation. Figure **??** summarizes the workflow undertaken during this process. The timeline details the evolution of the research, organized into the stages of Background and Context, Infrastructure (Design), and Evaluation.

Each stage of the infrastructure development process is described in detail in the subsequent subsections. It is worth noting that the presentation of the studies does not follow a strict chronological order, as some works were published after their development, and therefore do not necessarily reflect the exact temporal sequence of the research activities.

4.1 Foundations and Context Identification

Xavier and de Almeida Neris [2013] proposed a hybrid approach to minimize the detection of false positives in the assessment of the user's emotional state during interaction with computational systems. This need arises from the fact that emotions are inherently difficult to measure, as they are linked to several components such as subjective feelings, behavioral tendencies, motor expressions, cognitive aspects, and physiological responses [Xavier and de Almeida Neris, 2013]. The model is grounded in the theory of emotion proposed by Scherer [1984, 2005] and enables designers to verify whether the system elicits an emotional reaction (positive, neutral, or negative). To achieve this goal, the hybrid approach developed by Xavier employs multiple measurement instruments, each targeting a specific of Scherer's model, thereby ensuring a complementary evaluation and reducing false positives.

To assess subjective feelings, the Self-Assessment Manikin (SAM) [Bradley and Lang, 1994] was applied, a non-verbal pictorial instrument that evaluates the dimensions of pleasure, arousal, and dominance. Behavioral tendencies were measured through efficiency and effectiveness metrics, such as task completion time and number of help requests [Mahlke and Minge, 2008]. Motor expressions were analyzed using the Ten Emotion Heuristics [De Lera and Garreta-Domingo, 2007], based on video recordings, while cognitive evaluations were investigated through Subjective Discourse Analysis [Lefèvre and Lefèvre, 2005], identifying and classifying key verbal expressions during interaction. The combination of these methods provided an integrated, robust, and complementary view of the emotional state, thereby minimizing the occurrence of false positives.

As previously noted, typographic elements such as font color, size, typeface, and background color, as well as typographic composition elements, including bold, italic, and bold-italic styles and their combinations, can influence users' evaluation and decision-making processes. These elements have an immediate impact on emotions, satisfaction, preferences, and the intention to reuse the media [Moshagen and Thielsch, 2013; Koch, 2011; Tsonos *et al.*, 2008; Lavie and Meyer, 2010; Makris and van Eekelen, 2016].

In this context, Bianchi and de Almeida Neris [2015] and Bianchi [2016] investigated the relationship between colors and emotions within the field of HCI, as illustrated in Figure 3. The authors established theoretical foundations to guide designers in selecting colors capable of evoking specific emotions in users. Based on their analyses, they proposed the Bianchi Color Wheel, which associates hue, saturation, and brightness with the emotional dimensions of Valence, Arousal, and Sense of Control, as defined by Scherer's Semantic Emotional Space Model [Scherer, 2005].

The authors also investigated the emotional effects elicited by different font types and sizes on web pages, with the aim of understanding how typographic elements influence

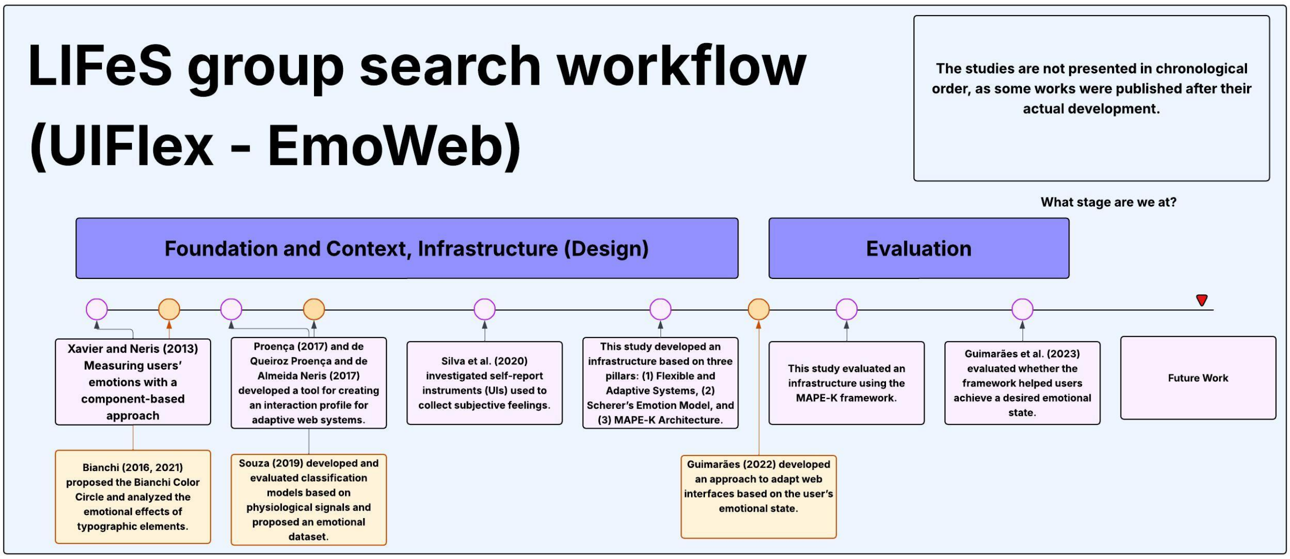

Figure 2. Research Workflow. **Source:** Authors.

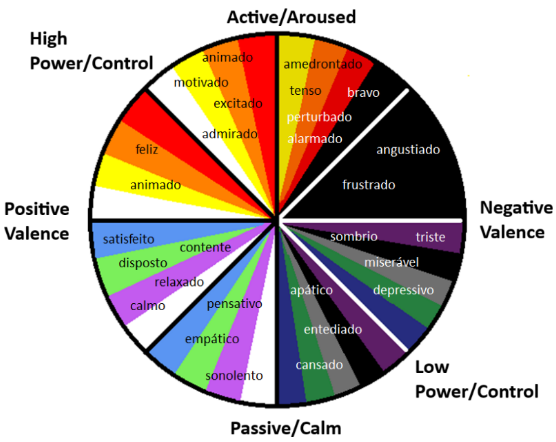

Figure 3. Bianchi Color Wheel. **Source:** Adapted from Bianchi and de Almeida Neris [2015].

the user's emotional experience during reading. The study was motivated by the observation that most existing research focuses on users' preferences for specific font types rather than on the emotions they evoke. Furthermore, as noted by the authors, few studies have explored the emotional impacts associated with font size.

Silva *et al.* [2020] investigated four self-report instruments used to collect subjective emotional experiences, specifically a set of emojis, the Self-Assessment Manikin (SAM), scroll sliders, and the Semantic Emotional Space. The goal was to determine which instrument provides information about a subjective feeling that most closely aligns with a pre-classified emotion from the literature for a given stimulus. The authors argued that different instruments (pictorial, verbal, continuous, or discrete) may vary in precision, granularity, and usability. To this end, they based their study on Scherer's definition of emotion as changes occurring within organismic subsystems and used Scherer's Semantic Emotional Space to organize emotions within a circular structure divided into eight octants, encompassing four main domains: valence, arousal/excitation, potential/control, and goal conduciveness. This Semantic Space served as a reference for mapping the participants' emotional responses.

The instruments feature different scales (discrete vs. continuous; verbal terms vs. pictorial figures), which represents a challenge in the field. To mitigate this challenge and enable comparison among instruments, the authors employed the Self-report Instrument Mapping Method by Intensity and Polarity for Emotions (MSIPE) (or MAIPE, its acronym in Portuguese) to map User Interface 2 (UI-2) and User Interface 3 (UI-3). This method allows the mapping of discrete or continuous scale data from self-report instruments to the octants of Scherer's Semantic Emotional Space. For User Interface 1 (UI-1), each emoji already had a pre-classified emotion, and for UI-4, no mapping was required, as the final octant was known once a point was plotted in the space. The results suggested that the scroll slider (UI-3) produced emotional responses that most closely matched pre-classified emotions.

Proença [2017] presented an extension (UIFlex) for the Google Chrome browser, developed in accordance with standards from reference organizations such as the World Wide Web Consortium (W3C), Mozilla Developer Network, and Section 508, among others. The extension enables users to define their interaction profile and, through it, apply design rules to web interfaces during browsing. This interaction profile aims to empower users in adapting the interface by defining their usage context.

The extension operates in two main stages: modeling and interaction application. In the first stage, users complete a questionnaire inspired by the "Who am I?" collector, which identifies personal characteristics, preferences, and specific interaction needs. This profile is then combined, through a remote server, with a set of design rules based on accessibility and usability guidelines. Examples of such rules include improving web page readability for visually impaired users (particularly those with color blindness), by altering contrast, increasing font size, and creating keyboard shortcuts for main pages. The second stage consists of the automatic application of these adaptations by injecting JavaScript and CSS code into accessed pages, thereby modifying visual and structural aspects such as contrast, font size, focus visibility, and caption display. The studies reported by Proença [2017] indicated a significant improvement in user satisfaction, with approximately 75% of users reporting a better browsing experience when using the extension.

Souza [2019] proposed a study on the classification of physiological signals for inferring users' emotional states. His work was grounded in Scherer's model, addressing the dimensional perspective of emotions across four emotional domains: valence (pleasure/displeasure), arousal (calmness/agitation), sense of control, and goal conduciveness. The study aimed to formalize a dataset of labeled physiological signals based on these four emotional dimensions, using ECG, EEG, and GSR sensors. Participants were exposed to film and music video clips pre-labeled according to their emotional valence. The collected signals underwent a pre-processing stage, during which low-pass, high-pass, and Wiener filters [Wiener, 1964] were applied to eliminate noise and inconsistencies. Subsequently, Linear Discriminant Analysis was employed for dimensionality reduction and the extraction of the most relevant physiological signal features.

In the classification stage, Souza evaluated a set of seven supervised machine learning algorithms, specifically K-Nearest Neighbors (KNN), Naive Bayes (NB), Decision Tree (DT), Random Forest (RF), XGBoost, Support Vector Machine (SVM), and Artificial Neural Networks (ANN). This evaluation utilized K-fold cross-validation and the Friedman and Nemenyi statistical tests for performance comparison.

The studies conducted by Xavier and de Almeida Neris [2013], which proposed a hybrid approach to minimize false positives in user emotional evaluation, together with the investigations of Silva *et al.* [2020] on the accuracy of self-report instruments (UIs), and the works of Bianchi [2016] and Bianchi *et al.* [2021], which established the Bianchi Color Circle and analyzed the emotional effects of typographic elements on web pages, provided the theoretical foundation necessary for developing interfaces capable of influencing users' emotional states through self-report mechanisms.

In this context, the research by Proença [2017] materialized this approach by developing a browser extension that allows users to define their interaction profile and inform their emotional context, while the work of Souza [2019] advanced this line of research by inferring users' emotional contexts through the classification of physiological signals.

4.2 Infrastructure (Design)

This study extends the UIFlex plugin [Proença, 2017; Queiroz, 2017] by incorporating the MAPE-K Architecture [IBM, 2005], resulting in a flexible and adaptive computational infrastructure capable of reconfiguring web user interfaces based on both the user's current emotional state and their intended emotional experience. The research is grounded in three main pillars: (1) Flexible and Adaptive Systems - according to Koch and Wirsing [2002], and Gullà *et al.* [2015], adapt to user behavior and can be categorized as adaptable (user-selected profiles) or adaptive (automatic runtime changes). (2) Scherer's Model [Scherer, 2005], adopted as the theoretical foundation. (3) The MAPE-K Architecture [IBM, 2005], which enhanced the solution's maintainability and flexibility. The study also employed Bianchi's Color Circle [Bianchi and de Almeida Neris, 2015], which associates colors with emotions, allowing the visual design to be adapted according to emotional states.

Named EmoWeb, the infrastructure integrates principles of adaptive systems and emotional design to enable the dynamic, real-time adaptation of web interfaces. The project prioritized a modular and maintainable architecture, allowing for precise responses to user variations and the adjustment of visual elements according to the target emotional state. For this purpose, the infrastructure was structured into five interconnected subsystems operating sequentially and in coordination. This architecture follows the MAPE-K process model, where each component executes a specific role.

The project also includes physiological sensors [Souza, 2019] and a facial recognition API (Morphcast). The integration between objective data (such as facial expressions and physiological signals) and subjective data (emotional self-report) was enabled by a data fusion module, which, based on Scherer's Semantic Emotional Space, determines the octant corresponding to the predominant emotion. From this analysis, the system applies design rules to the web interface. These rules are grounded in Bianchi's Color Circle [Bianchi and de Almeida Neris, 2015], typographic elements (different font types and sizes) [Bianchi, 2016; Bianchi *et al.*, 2021], and accessibility and usability guidelines [Proença, 2017; de Queiroz Proença and de Almeida Neris, 2017]. They are applied through gradual visual transitions to induce or reinforce the user's desired emotional state.

As shown in the Figure **??**, the EmoWeb architecture was designed based on the MAPE-K blueprint and organized into interdependent components that monitor, analyze, plan, and execute adaptations based on a shared knowledge base.

The Monitor is responsible for the continuous collection of user data during interaction. This module captures emotional information through objective sources (sensors) [Souza, 2019] and subjective sources (interactive sliders) [Proença, 2017; de Queiroz Proença and de Almeida Neris, 2017]. These data represent the sensory stage of the system, enabling a better understanding of the user's emotional context.

The Analyzer processes and interprets the collected data to identify the user's current and desired emotional states. At this stage, the Method of Intensity and Polarity for Emotions (MAIPE) [Silva *et al.*, 2020] is applied, allowing emotions to be classified according to their intensity and direction within Scherer's Semantic Emotional Space. The analyzer also employs a data fusion module that consolidates information from different sensors and determines the corresponding emotional octant by synthesizing the results of valence, arousal, control, and conduciveness.

The Planner is responsible for defining the adaptation actions that should be applied to the interface based on the emotional analysis obtained. This phase uses the previously mentioned set of Design Rules [Bianchi and de Almeida Neris, 2015; Bianchi, 2016; Proença, 2017; de Queiroz Proença and de Almeida Neris, 2017]. For instance, when the system detects a transition from a negative to a positive valence octant,

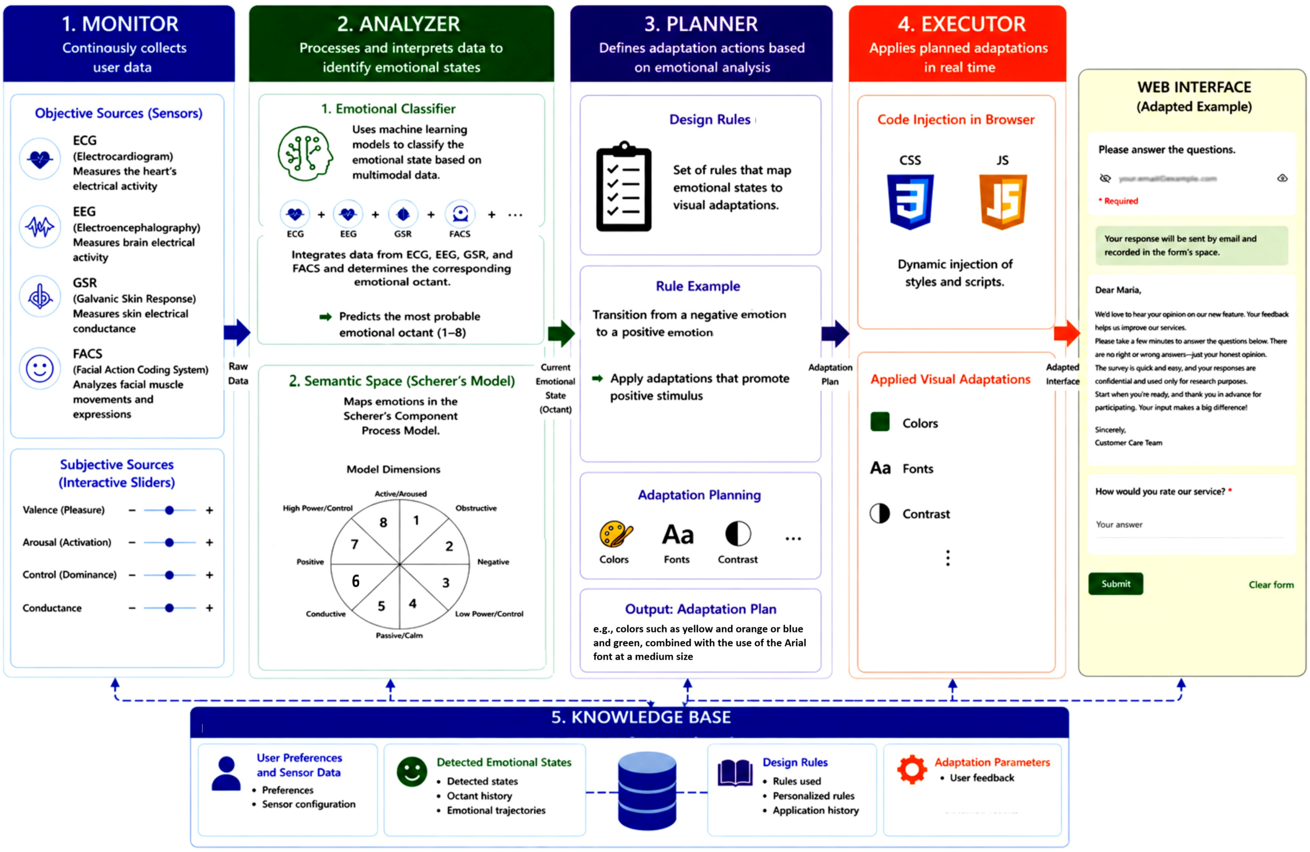

Figure 4. MAPE-K model used in UIFlex-EmoWeb. **Source:** Authors.

the planner triggers rules that gradually modify the web interface to promote a positive emotional stimulus. In the example shown in Figure **??**, the system injects color-based design rules. In the study by Guimarães *et al.* [2023], the user was asked to access a web page and type an email on a neutral topic with low affective involvement. Visually (Figure **??**), the page was adapted according to UIFlex-EmoWeb's rules, displaying a yellow background. This visual configuration indicates that the user's actual emotional octant was located between 1 and 4, while the desired octant corresponded to 7 or 8.

The Executor is responsible for effectively applying the planned adaptations to the user interface by injecting CSS and JavaScript code into the running web pages. This process modifies visual properties such as colors, fonts, and contrasts smoothly and without interrupting the user experience. It is worth noting that the executor operates directly within the browser, ensuring that the modifications occur in real time during interaction and remain persistent while the plugin is active.

Finally, the Knowledge Base stores all the information used and generated by the other modules, including the user profile, detected emotional states, applied design rules, and adaptation parameters. This repository is essential to enable learning and the reuse of information in future interactions, making the system progressively more accurate and personalized to each user.

5 Evaluation

The assessment presented in this article combines two complementary levels of analysis. The controlled user experiment, previously reported by Guimarães et al. [2023], is revisited here as evidence of the functional feasibility of the infrastructure. The comparative architectural analysis, in contrast, constitutes the original evaluation conducted in this article, focusing on the effects of incorporating the MAPE-K model on maintainability and architectural organization.

Accordingly, EmoWeb was assessed through two complementary approaches: (1) Comparative Architectural Analysis, which focuses on software quality attributes, particularly maintainability, and examines whether aligning EmoWeb with the MAPE-K blueprint resulted in architectural improvements; and (2) Controlled User Experiment, a mixed-factorial, double-blind study designed to assess the system's capability to guide users toward a target emotional state through adaptive interface interventions.

The results concerning the controlled user experiment were previously published in Guimarães *et al.* [2023], thereby providing a holistic view of the infrastructure's performance. The experiment was approved by the local Ethical Committee Board through certificate number 42671121.3.0000.5504. The comparative architectural analysis and the development of the infrastructure incorporating the MAPE-K architecture, as mentioned in the previous section, constitute the originality of the study.

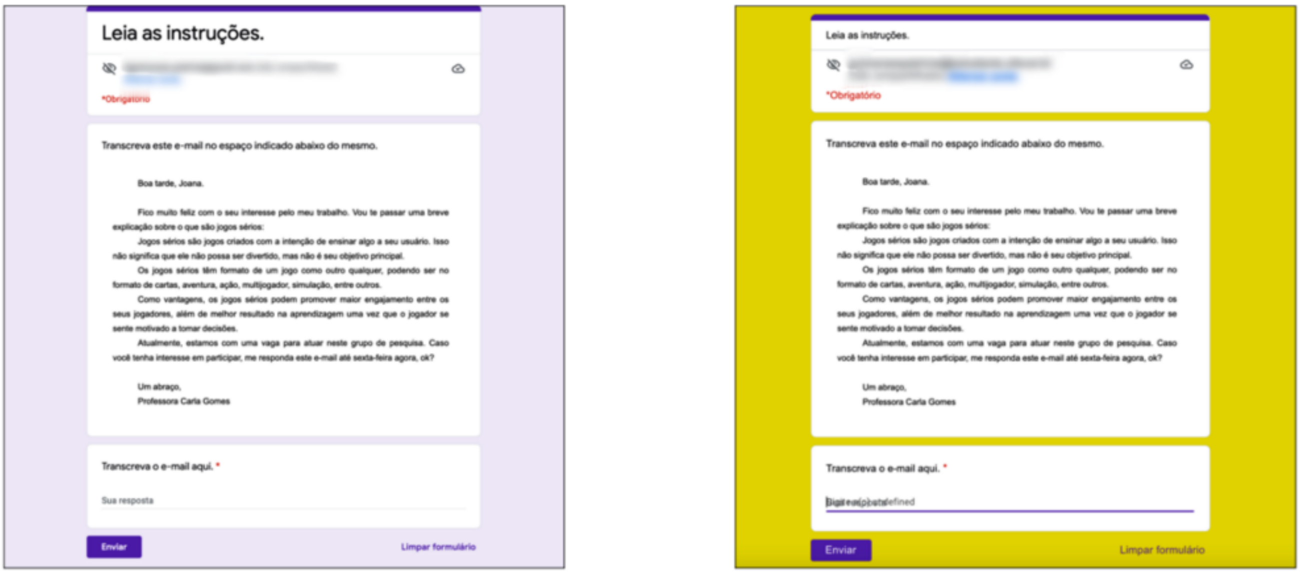

Figure 5. Web page adaptation provided by UIFlex-EmoWeb. **Source:** Guimarães *et al.* [2023].

5.1 Comparative Architectural Analysis

Software maintainability is a fundamental quality attribute and can be defined as the ease with which a system can be modified, corrected, or adapted to evolving requirements. According to Malhotra and Lata [2020], its importance is strategic, as the maintenance phase accounts for more than 60% of total software development costs. Recent studies on maintainability indicate a continuous annual growth in scientific output on the topic, especially in high-impact journals [Díaz-Arrieta *et al.*, 2025], reinforcing the relevance of continuously improving this attribute throughout the software lifecycle, as well as expanding research efforts in this area.

Furthermore, according to Díaz-Arrieta *et al.* [2025], the lack of efforts to ensure good maintainability can lead to increased technical debt, greater corrective effort, and reduced system lifespan. The authors argue that refactoring and the automated detection of code smells can help reduce maintenance costs, while a proactive approach to technical debt management contributes to lowering indicators such as the Technical Debt Ratio.

In this context, the infrastructure was evaluated through a comparative study of two versions of the EmoWeb system: one without the MAPE-K blueprint and another incorporating it. The evaluation aimed to assess the impact of the blueprint on architectural quality, with a particular focus on maintainability, given the evolutionary nature of the solution. Static source code analysis was performed using the SonarCloud tool.

The main metrics are presented in Table 1; these metrics make it possible to analyze how easily the software can be modified, extended, or corrected. They also allow verifying whether the structuring imposed by the MAPE-K model was essential for optimizing the code and improving the maintainability of UIFlex-EmoWeb. For example, technical debt analysis quantifies the additional effort required for both development and maintenance of the code [Seaman, 2011], while code smells represent portions of code associated with maintainability issues, typically resulting from inadequate implementation decisions [Fowler, 2018].

Table 1. Comparison of metrics with and without MAPE-K.

Metric	Without MAPE-K	With MAPE-K
Cyclomatic Complexity	981	1,014
Cognitive Complexity	1,632	1,707
Lines of Code (HTML)	680	846
Lines of Code (JavaScript)	3k	3.7k
Lines of Code (CSS)	571	1.1k
Technical Debt	8d 7h	7d 2h
Debt Ratio	3%	2.1%
Code Smells	214	166

Source: Authors

5.2 Controlled User Experiment

In addition to the maintainability evaluation [Guimarães, 2022; Guimarães *et al.*, 2023], UIFlex-EmoWeb was also tested for its ability to capture and process emotional data from multiple components, reinforcing its multimodal nature. Data collection combined subjective emotional self-reports and facial motor expressions to identify users' initial, desired, intermediate (mean), and final emotional states, all mapped within Scherer's Semantic Emotional Space.

According to Guimarães [2022] and Guimarães *et al.* [2023], statistical analyses using the chi-square test indicated that, although most users moved toward their desired emotional state, the differences were not statistically significant. Nevertheless, the emotional transition graphs showed a consistent trend toward more positive octants within the emotional space, suggesting that UIFlex-EmoWeb has the potential to guide users toward a desired emotional state, particularly when supported by a broader set of adaptive rules. This trend is illustrated in Figures **??** and **??**.

In Figures **??** and **??**, the edges connecting I.E.S. (Initial Emotional State) and M.E.S. (Mean Emotional State) represent the emotional trajectories followed by users when interacting with UIFlex-EmoWeb to reach the D.E.S. (Desired Emotional State). As illustrated in Figure 6, the user started in octant 4 and aimed to reach octants 6, 7, or 8. In this case, an M.E.S. located between octants 4 and 8 indicates progress toward the D.E.S., whereas a shift to octant 2 would indicate movement away from the target state. The edge connecting M.E.S. and F.E.S. (Final Emotional State) represents the user's emotional trajectory throughout the task performed, such as reading and transcription on the web.

According to Guimarães [2022]; Guimarães *et al.* [2023], as illustrated in Figure **??**, the user aimed to reach octants 6, 7, or 8 and completed the study in octant 7, indicating that UIFlex-EmoWeb has the potential to promote the emotional state desired by the user. Figure **??** presents the results of users' emotional trajectories while performing reading tasks.

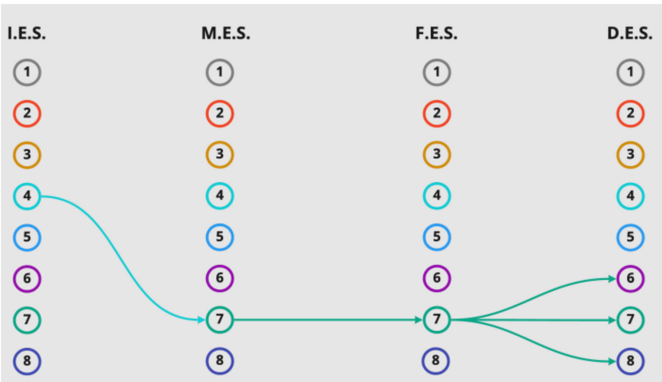

Figure 6. User's emotional trajectory. **Source:** Guimarães *et al.* [2023].

Although the studies reported in Guimarães [2022] and Guimarães *et al.* [2023] do not provide statistically significant evidence, the experimental process validated the technical and conceptual feasibility of the infrastructure, as the majority of users demonstrated movement toward their desired emotional state. It is worth noting that the use of the infrastructure does not imply a direct or guaranteed induction of the target emotional octant; rather, it functions as an adaptive solution that modulates users' emotional goals in conjunction with contextual and individual factors.

6 Discussion and Limitations

This section presents a discussion of the main findings of the studies conducted by the research group, highlighting how these works are interrelated, their primary limitations, and emphasizing the original contributions introduced by the adoption of both the MAPE-K architecture and Comparative Architectural Analysis.

The section is divided into two parts. The first presents an integrated overview of the research group's studies, as well as their limitations. The second addresses the application of the MAPE-K architecture and the comparative architectural analysis.

6.1 Integrated Overview of the Studies and Their Limitations

The studies by Xavier and de Almeida Neris [2013] demonstrated that the integration of multiple data sources (a hybrid approach) results in more consistent and contextualized analyses for assessing users' emotional experiences. The convergence between users' self-assessments of emotion, using instruments such as the Self-Assessment Manikin (SAM), and expert heuristic evaluations based on the "Ten Emotion Heuristics" enabled the identification of divergences and complementarities in users' perceptions of their interactive experience. Moreover, these studies established associations between usability problems and specific emotional responses, contributing to a deeper understanding of how design elements may elicit positive or negative emotions and influence satisfaction and interaction effectiveness.

The Hybrid Approach developed by Xavier and de Almeida Neris [2013] was fundamental for the research conducted by Bianchi [2016] and Bianchi *et al.* [2021], as it enabled the measurement of users' emotional experiences in relation to font types. In addition, it provided the theoretical foundation for subsequent studies by addressing Scherer's model.

The initial analyses of font types carried out by Bianchi [2016] and Bianchi *et al.* [2021] revealed a nuanced scenario. In the participants' subjective reports, the Arial font was more frequently associated with positive emotions. However, a contrasting finding was observed in motor expressions, where the same font elicited a negative emotional experience. This divergence underscores the importance of multifaceted approaches, such as the Hybrid Approach [Xavier and de Almeida Neris, 2013], to capture the complexity of emotional experience. In the final evaluation of this approach, it was found that although both Arial and Times New Roman fonts led to an overall positive emotional experience, Arial was associated with a higher reported sense of control (SAM). Font size is another factor that designers should consider when aiming to influence emotional experience. In the works of Bianchi [2016] and Bianchi *et al.* [2021], font sizes were associated with Scherer's Semantic Emotional Space; in this case, the 8pt size was statistically linked to negative experiences (being the only one located in octant 4), resulting in the highest number of errors and subjective rejection. In contrast, larger sizes (12pt and 16pt) were predominantly positive (octant 7), with 12pt being ideal for Arial and 16pt for Times New Roman [Bianchi, 2016; Bianchi *et al.*, 2021].

Furthermore, the work of Bianchi [2016] and Bianchi and de Almeida Neris [2015] made a significant contribution to the field of HCI by creating the Bianchi Color Circle (3), which integrates the state-of-the-art consensus on hue, saturation, and brightness into Scherer's Semantic Emotional Space [Scherer, 2005]. This integration provides designers with a conceptual tool that connects visual properties of colors to emotional responses, offering both theoretical and practical support for emotional design decisions [Bianchi, 2016; Bianchi and de Almeida Neris, 2015]. The research demonstrates that colors, understood through their three components (hue, brightness, and saturation), tend to be associated with the emotions they evoke. Moreover, depending on these vari-

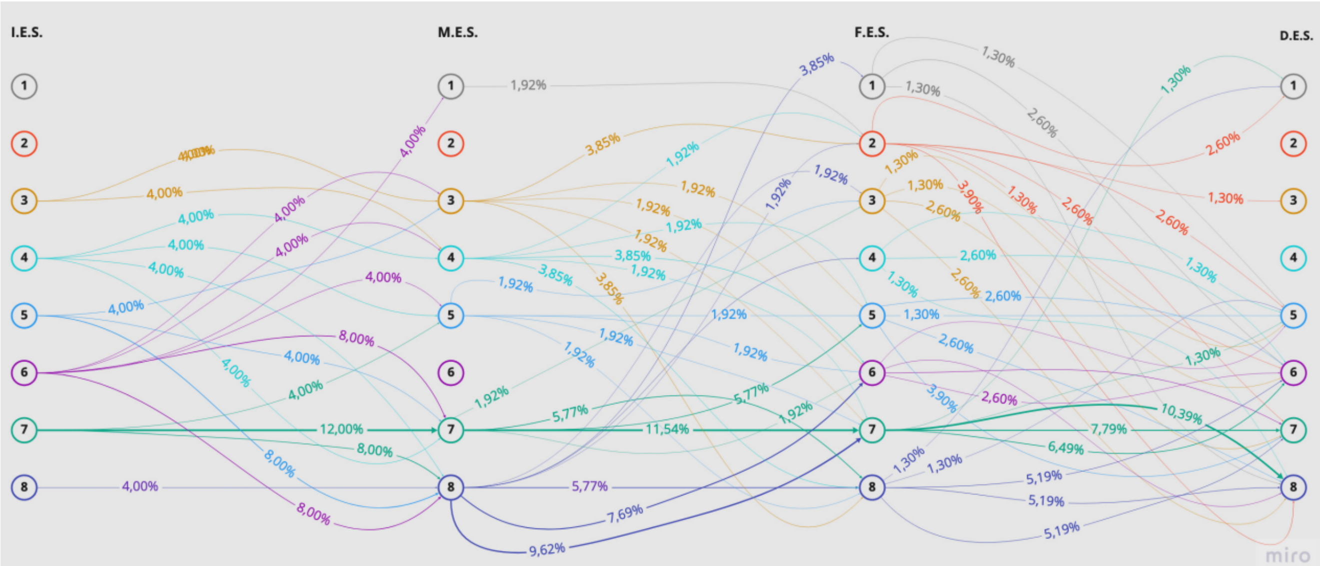

Figure 7. Users' emotional trajectories. **Source:** Guimarães *et al.* [2023].

ations, the same color may elicit different emotions. Red, for instance, can express either anger or happiness (as noted by Da Pos *et al.* [2007]), differing solely in emotional valence (positive or negative). Bianchi [2016]; Bianchi and de Almeida Neris [2015] highlight that brighter and more saturated colors tend to evoke positive emotions, while darker and desaturated colors are associated with negative ones.

The studies by Bianchi [2016], Bianchi and de Almeida Neris [2015] and Xavier and de Almeida Neris [2013] present hybrid approaches to reduce false positives in the evaluation of users' emotional states, as well as interface elements that contribute to users' emotional stimulation. However, in emotion-oriented adaptive interfaces, significant adaptation only occurs when the system is capable of understanding the environment, the purpose, and the user's emotional state, dynamically adjusting itself to promote experiences that are more aligned with the user's needs. The works of Souza [2019], Proença [2017] and de Queiroz Proença and de Almeida Neris [2017] address this gap within the infrastructure developed by the EmoWeb research group.

The studies by Souza [2019] provide significant results regarding the feasibility of using low-cost physiological sensors for emotional state inference. By collecting GSR, ECG, and EEG signals and applying machine learning algorithms, the author demonstrated that it is possible to recognize emotions in real time with high accuracy. Among the models tested, the algorithms that best suited the data characteristics were NB for GSR data, with 78% accuracy; NB for ECG data, with 99% accuracy; and SVM for EEG data, also with 99% accuracy. These results indicate that even when using affordable sensors and a low-cost infrastructure, it is possible to achieve performance levels comparable to those obtained with traditional databases and high-end equipment, such as DEAP and MAHNOB-HCI [Koelstra *et al.*, 2011; Soleymani *et al.*, 2012].

The studies by Proença [2017] and de Queiroz Proença and de Almeida Neris [2017] enable users to personalize and adapt different websites according to their needs and preferences, based on design rules supported by the literature and by guidelines from authorities such as the W3C. This approach shifts the traditional design paradigm centered exclusively on the developer, granting users an active role as co-authors in shaping their own usage experience, a fundamental principle of meta-design.

Guimarães [2022] and Guimarães *et al.* [2023] represent complementary steps in advancing the project by proposing and evaluating an infrastructure capable of adapting web user interfaces based on users' emotions.

In their work, the authors analyzed the emotional path followed by users while performing web-based tasks using the proposed infrastructure. The results allow observing not only the initial and final emotional states, but also the dynamics of the experience throughout the interaction. The users' trajectory graphs, as illustrated in Figure **??**, show that transitions do not occur linearly between an initial and a desired state; instead, users move across different regions of the emotional space, often passing through intermediate states before stabilizing [Scherer, 2005]. These findings are consistent with the literature, highlighting that interface adaptation acts as a gradual influencing factor rather than an immediate mechanism for emotional change, as also discussed by [Donati *et al.*, 2020].

Engagement with the task may, by itself, induce emotional shifts, regardless of interface adaptation. However, according to Guimarães [2022] and Guimarães *et al.* [2023], participants exposed to the infrastructure exhibited more directed trajectories within the octants of the emotional space. Although this result did not reach statistical significance, the authors suggest a possible influence of interface adaptation on the emotional experience.

In brief, the Hybrid Approach proposed by Xavier and de Almeida Neris [2013] established a solid methodological foundation for emotional evaluation by combining subjective and objective data to reduce false positives, thereby increasing the accuracy in identifying users' emotional responses.

This foundation enabled further investigation into the influence of visual elements (such as font types, font sizes, and color properties) on users' emotional experiences, with particular emphasis on the Bianchi Color Circle [Bianchi and de Almeida Neris, 2015; Bianchi, 2016]. The Bianchi Color Circle allows the correlation of hue, brightness, and saturation with Scherer's Semantic Emotional Space [Scherer, 2005], constituting a conceptual tool that supports emotional design.

Subsequent studies, such as those reported in Proença [2017]; de Queiroz Proença and de Almeida Neris [2017]; Souza [2019]; Silva *et al.* [2020]; Guimarães [2022]; Guimarães *et al.* [2023], expanded the scope of the research by incorporating machine learning techniques, physiological sensing, and meta-design principles, culminating in the development of the UIFlex-EmoWeb infrastructure.

Despite these contributions, the aforementioned studies present limitations that should be considered when interpreting the results and developing future research.

Although the hybrid approach proposed by Xavier and de Almeida Neris [2013] encompasses different dimensions of emotion, the study did not include physiological measurements such as heart rate or galvanic skin response, which limits the objectivity of the inferences about emotional states. The author also acknowledges that applying the hybrid approach requires time, resources, and specialized training, which may hinder its adoption in routine interface design evaluations. Finally, cultural and contextual factors were not examined systematically, even though they can significantly influence how emotions are expressed and perceived during interaction.

The works of Bianchi [2016] and Bianchi *et al.* [2021] present conceptual constraints related to the scope of the emotional model adopted. Not all emotions identified in the literature are represented in Scherer's Semantic Space, requiring the substitution of some terms with synonyms to maintain methodological consistency. Although this semantic adjustment is necessary, it may introduce interpretive bias, since semantically similar emotions can differ subtly in intensity or valence. Another important limitation concerns cultural aspects, as associations between color and emotion vary across sociocultural groups. Although the authors' work employed international references, the intercultural dimension of color (as demonstrated by Elliot and Maier [2014]) was not explored in depth, thereby restricting the generalization of results to specific cultural contexts.

Moreover, the study acknowledges the contextual influence of colors, which can alter their emotional meaning depending on the environment, task, and adjacent visual elements. However, the context of use was not empirically addressed, limiting the applicability of the Color Circle in real interface scenarios. Another limitation concerns the partial nature of the analysis, as the study focused on colors in isolation without considering their interaction with other visual elements such as typography and images. Bianchi [2016] and Bianchi *et al.* [2021] recognize that, in a complete interface, the emotional impact results from the simultaneous combination of these elements and suggest that future studies address the integrated composition of interfaces to evaluate emotional responses to the overall design.

Structural limitations were identified in the works of Souza [2019], de Queiroz Proença and de Almeida Neris [2017] and Proença [2017] In this regard, Souza [2019] discusses issues related to unbalanced classes and the lower statistical robustness of its classification models. This limitation affects the generalization of the results and highlights the need for new experiments with a larger number of participants and a wider range of emotional stimuli. The authors also emphasize the need to improve class balancing, perform feature selection, and combine classifiers according to the type of sensor in order to optimize the accuracy and stability of the models in real-world emotional inference contexts. As discussed in Proença [2017] and de Queiroz Proença and de Almeida Neris [2017], the performance of the developed tool depends heavily on the degree of conformity of websites to W3C accessibility standards and guidelines. Websites that do not adhere to these standards may exhibit limitations in the correct application of adaptations.

A limitation common to most studies concerns the small number of participants and the need to conduct evaluations in real-world usage contexts.

6.2 Application of the MAPE-K Architecture and Comparative Architectural Analysis

The comparative architectural analysis conducted in this study complements the existing literature by providing empirical evidence of improvements in the system's internal quality and maintainability.

The results presented in Table 1 indicate a reduction in technical debt, from 8 days and 7 hours to 7 days and 2 hours, suggesting a lower effort required for the evolution and maintenance of the system. This difference corresponds to approximately one day of effort in the analyzed modules, evidencing gains in terms of code organization and clarity. Additionally, a reduction in the number of code smells was observed (from 214 to 166), indicating a lower incidence of structural issues associated with maintainability. The technical debt ratio also decreased by approximately 30% (from 3.0% to 2.1%).

Taken together, these results suggest that the adoption of the MAPE-K model contributed positively to improving the maintainability of UIFlex-EmoWeb. Specifically, the structuring promoted by this model fostered modularization and separation of concerns, which are key aspects for sustainable software evolution.

Prior to the restructuring, the system exhibited limitations related to the centralization of functionalities and the difficulty of updating adaptation rules. With the introduction of the MAPE-K autonomic cycle, the system became capable of supporting the dynamic definition and modification of rules, thereby increasing its runtime adaptability.

However, the adoption of the MAPE-K architecture resulted in an increase in system size and complexity. A slight growth in cyclomatic and cognitive complexity was observed, which is consistent with the introduction of additional control and adaptation mechanisms. Similarly, the increase in lines of code (HTML, JavaScript, and CSS) reflects the incorporation of new components and functionalities.

Despite this increase in complexity, the results indicate a favorable trade-off: the moderate rise in structural complexity is offset by significant improvements in internal quality, particularly in the reduction of technical debt and maintainability issues. These findings reinforce the suitability of the MAPE-K architecture for the development of adaptive systems with a focus on sustainability and continuous evolution.

7 Conclusion and Future Work

In summary, the studies conducted by the research group reveal a solid and coherent evolutionary trajectory toward the development of systems capable of understanding and adapting to the desired emotional state. These studies constitute a relevant theoretical and experimental body of knowledge for the field of HCI. The progression of research within the group demonstrates a continuous evolution, beginning with the proposal and validation of hybrid approaches for emotional evaluation [Xavier and de Almeida Neris, 2013]. This advanced through the exploration of the influence of visual elements (such as typography and color) on emotional experience [Bianchi and de Almeida Neris, 2015; Bianchi *et al.*, 2021], and ultimately reached emotion recognition through physiological sensors and machine learning techniques [Souza, 2019], as well as the development of self-report instruments and adaptive infrastructures [Proença, 2017; de Queiroz Proença and de Almeida Neris, 2017; Guimarães, 2022].

The integration of these studies with the maintainability indicators enabled the development of a modular and scalable infrastructure (UIFlex-EmoWeb) with the potential to support practical applications in adaptive web interfaces based on users' interaction profiles and emotional states. These works, together with the contributions of this research, advance not only scientific knowledge regarding the role of emotion in human–computer interaction, but also the development of user-centered solutions that position users as active agents in regulating their own emotional states.

However, the limitations identified across the different studies highlight challenges that must be addressed for these advances to achieve greater applicability. Among them are the absence of physiological measurements in some hybrid approaches, the cultural constraints of the emotional models employed, the lack of experiments conducted in real-world contexts, and the limited number of participants in sample groups. Furthermore, issues such as class imbalance in machine learning models and dependence on compliance with technical standards (such as those established by the W3C) still restrict the robustness and generalizability of the results. Addressing these limitations is essential to strengthen external validity, reduce sociocultural bias in emotional inference and adaptation, and increase the reliability of end-to-end adaptive behavior under realistic conditions.

In addition to these identified challenges, the research group is currently developing studies across three main axes. The first axis concerns the recognition of emotional contexts through mobile sensors, expanding physiological monitoring to everyday situations and ubiquitous environments. This approach presents challenges ranging from the presence of imprecise and sparse data (resulting from these devices) to potential compromises in the accuracy of emotional inferences. The second axis proposes the incorporation of the Human-in-the-Loop (HITL) approach, in which the user remains actively involved in the adaptation cycle, contributing to the calibration and validation of system decisions in real time. From this perspective, machine learning techniques can be integrated to enhance the model's explainability and transparency (Explainable AI). Finally, the third axis involves the development of conversational agents capable not only of recognizing the user's emotional state but also of providing personalized interventions, supporting the promotion and maintenance of emotional well-being during interaction.

These research directions not only complement the trajectory established by the group but also align with the contemporary challenges proposed by GranDIHC-BR 2025–2035 [Pereira *et al.*, 2024], as they point toward the development of increasingly human-centered, contextually aware, and emotionally responsive systems. This alignment is particularly evident in Grand Challenge 4 (GC4), which emphasizes the importance of sociocultural contextualization in the design of adaptive systems to ensure inclusivity and cultural sustainability in a country characterized by profound diversity [Neris *et al.*, 2024]. The topic also converges with Grand Challenge 6 (GC6) by addressing ethical and algorithmic issues of artificial intelligence in Human-Data Interaction, stressing the need for transparency, fairness, and accountability in applications aimed at promoting well-being. This perspective reinforces the relevance of computational practices aligned with human values and committed to mitigating algorithmic biases [Duarte *et al.*, 2024]. Finally, the emphasis on emerging technologies and hybrid approaches is consistent with Grand Challenge 7 (GC7), which advocates an ecosystemic view of Human-Computer Interaction, oriented toward fostering meaningful, ethical, and sustainable interactions between humans and adaptive technologies [Zaina *et al.*, 2024].

Taken together, these axes extend the group's trajectory toward more human-centered, context-aware, and emotionally responsive systems, while keeping the user actively involved in the adaptation cycle and reinforcing commitments to transparency, fairness, and accountability.

Declarations

Authors' Contributions

AA is the primary contributor and lead author of this manuscript, responsible for drafting the text and synthesizing the results presented herein. The other authors contributed to the theoretical foundation, development, and evaluation of the UIFlex-EmoWeb infrastructure within the scope of the studies conducted by the LIFeS research group. VN served as supervisor and reviewer for the research carried out by the group, as well as for this manuscript. All authors reviewed the manuscript and approved the final version and its content.

Competing interests

The authors declare that they have no conflicts of interest.

Availability of data and materials

The softwares generated and/or analysed during the current study are available in https://github.com/Lifes-Ufscar/Uiflex-EmoWeb.git.

Further relevant information

The authors acknowledge that generative AI tools (ChatGPT, DeepSeek, and Gemini) were used exclusively to support spelling revision, in accordance with academic standards, text translation, and the creation of images in this article.

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