

# QoE in the Web: A Dance of Design and Performance

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**Abstract**—Web services and applications are an increasingly pervasive fixture of modern life and business. This paper reports on a Web-based crowdsourced subjective assessment campaign in which we studied the effects of network performance and design aspects of manipulated Web sites on the perceived performance, perceived ease-of-use, visual appeal, as well as on the overall Quality of Experience of users browsing a given Web site. We consider the simultaneous impact of multiple factors on different dimensions of QoE, as well as their interplay, with a focus on the interactions between page/element loading times and Web site visual appeal and ease-of-use. Key results have shown the following: page loading times and visual appeal have a significant effect on overall user QoE; both higher perceived aesthetics and higher perceived ease-of-use result in an increased user tolerance to delay; and overall QoE is strongly correlated with perceived aesthetics, perceived ease-of-use, and perceived network performance.

## I. INTRODUCTION

Understanding how end users form evaluative quality judgements when interacting with Web content is of fundamental importance in driving the advances in both networking technologies and Web design and implementation. It is clear that an understanding of the factors that impact the user experience when accessing Web sites, as well as their interplay, will not only contribute to both continued evolution and increased technology adoption, but likely be a key ingredient in developing competitive new services and applications.

Going back over a decade, researchers have recognized that a user's preference for a particular Web site will most likely be influenced by factors such as aesthetics, usability, information richness, loading speed, and relevance [1]. Further studies have confirmed that content, usability, and aesthetics are core constructs in end users' perception and evaluation of Web sites [2]. Focusing on the quality of the user experience while accessing Web sites, studies have followed two different lines of research. The first, focusing on the field of human-computer interaction (HCI) in the context of user experience (UX) research, has clearly shown that the aesthetics and usability of an interface impact the end user's overall evaluation and experience of a system (e.g., [3]–[5]). [6] investigate user experience dimensions when using Web sites, influenced by both pragmatic quality (user-perceived usability) and hedonic quality (pleasure-producing product qualities). [7]

have proposed a Web site aesthetics model which structures aesthetics into two dimensions: visual appeal and organization. In [8], the results of two large-scale experimental studies (with over 350 users each) are presented which aimed at quantifying the impact of design choices on the perceived visual appeal (a scalar rating for aesthetics) of tested Web sites.

Studies addressing Web usability drawing on a user-centred design approach [9], [10]. Recent works have also addressed usability aspects of specific types of Web-based content, such as social networking sites [11] and location based services [12]. As summarized in a comprehensive review given by [5], usability has been manipulated in previous studies addressing user perception of computer-based systems in such ways as setting different system response times, varying the number of clicks (keystrokes) to complete a task, and by varying the amounts of available resource information.

Studies coming from the networking community (and drawing from fundamental relationships known from psychology), have focused on the user perception of waiting times, in particular page/element load time, as the key aspect impacting so-called Web QoE (e.g., [13]–[15]). *Web QoE* has been referred to as the “Quality of Experience of interactive services that are based on the HTTP protocol and accessed via a browser” [16].

*Web QoE* and HCI-related Web UX studies have to-date been for the most part diverged, focusing on different factors and methodologies, but with an ultimately common goal being to understand and potentially find ways to improve aspects of the end user Web experience. While both of these research lines are valid on their own, they have generally neglected to address the interactions between network-related performance aspects (e.g., page or element load times) and Web site design and usability. From a practitioner's point of view, these interactions are important, as they can make performance improvements moot in some cases, or very important in others.

Our focus in this work is on a joint consideration of multiple dimensions impacting the overall user judgement of quality in interacting with a given Web site. Prior research has generally neglected to address the simultaneous impacts of aesthetics, usability and loading speed on the quality of the overall user experience. We have focused on studying three key dimen-

sions as contributing to overall QoE: perceived performance (in terms of page loading time), perceived aesthetics, and perceived ease-of-use (which we consider as a sub-dimension of usability). As we will show in the results, the QoE of Web services and applications cannot be properly understood while focusing only on some of these factors and ignoring others, inherently calling for a multi-disciplinary approach bridging both QoE and UX studies. Furthermore, for different types of Web sites (e.g., news portals, on-line shops, picture galleries), the aforementioned dimensions may have different degrees of impact on overall quality judgements. It has been previously noted that a user’s judgement of system quality depends on the user’s goal in interacting with a specific Web site, whether it be a functional goal (e.g., purchasing a product on-line) or a hedonic goal (e.g., browsing a news portal or reading a blog) [6]. Consequently, we consider three different types of Web sites, namely a news site, a photo sharing application, and an e-commerce site. With regards to test methodology, given the large number of conditions we aim to test, we shift from conducting QoE measurements in a controlled lab environment to large scale crowdsourcing tests.

## II. METHODOLOGY

### A. Independent and dependent variables

While it is clear that aesthetic design, ease-of-use, and waiting times all have an impact on the end user’s subjective quality perception, we further look into the statistical effects when manipulating these factors to determine the degree to which they have an impact on QoE. Considering also different perceptual dimensions, we explore to what extent we find overall QoE to be correlated with user’s subjective ratings of perceived aesthetics, perceived ease-of-use, and perceived performance. Furthermore, we are interested in the interplay between these factors. For example, we explore whether or not perceived Web site aesthetics or perceived ease-of-use have an impact on the end user tolerance to page load times. As mentioned, most QoE-related research addressing Web QoE (including existing ITU recommendations such as G.1030, G.QoE-Web, P.STMWeb) focuses on network performance and consequently page (or element) loading time as the main factor impacting user perceived quality. We look to further explore to what extent the overall QoE can be modulated by the visual appeal or ease-of-use of a Web site. The independent variables considered are described below.

**Page load time:** a choice of three levels of performance sampled from realistic per-element load time distributions taken from real (and popular) Web sites similar to the contents we used. We performed a long-term (several days’ worth) speed measurement campaign for ten different popular Web sites covering several types of content (news site, shopping site, photo sharing site, etc.). We derived statistics in order to know the distribution of the load times for different element types in each site (e.g. html, images, css, javascript). For each element in each Web page created for testing, we assigned a random load time drawn from derived distributions. We then created three performance levels for testing, corresponding to

$1 + \log_2 m$ , where  $m$  is the number of times the load time of given elements was doubled (1..3, with 3 being longest load time). The test instrumentation was designed to load the content in the background, as users read the instructions about the task to come, and then simulate the rendering of the page using realistic timings. In this way, we ensured that for any given conditions, all users would experience the same loading times, regardless of their location and network connection speed.

**Visual appeal (a proxy measure of aesthetics):** a choice of three aesthetic levels: *bad* (1), *mediocre* (2) and *good* (3). In order to manipulate the aesthetics of the tested sites in a consistent manner across different sites, we followed the results reported in [8], limiting the manipulations to the number and suitability of typefaces (e.g. content-appropriate typefaces vs. unsuitable display faces) and colors (e.g. Analogous-, Triadic- and Tetradic-based palettes, resulting in different levels of color “goodness” for the content in question) used in the design and using three levels determined empirically by those authors. Figure 1 shows two examples of the aesthetics levels used.

**Ease-of-use (a proxy measure for usability):** a choice of three difficulty levels in the completion of tasks, measured by the number of pages visited (or *clicks*) needed to complete a given task. Each level of ease-of-use represents a step needed to complete the task. For each content we designed two tasks, and created alternative paths for them in the Web site according to the condition being tested, in such a way that each task could be completed in  $n$ ,  $n + 1$ , or  $n + 2$  clicks, with  $n \in \{1, 2\}$  depending on the content. The different tasks for each content were designed to be very similar in terms of the steps to carry them out, but ostensibly different in their meaning, to provide the subjects with more variety during the tests, and minimize learning effects.

**Content:** Three different contents (Web sites) were used (a news site, a photo sharing application, and an e-commerce site), with site designs based on commercial templates (and in the case of news, a simplified version of a popular site).

With regards to dependent variable (QoE features), we note that it is well-established that aesthetics and usability are multi-faceted, complex constructs, and that in order to properly understand them, different instruments are needed, be them subjective [3], [17], [18], or objective [19]. For our experiment, however, we deliberately aimed to keep the questionnaire as short and simple as possible by considering both aesthetics and usability via simple scalar ratings, keeping in mind the limitations of crowdsourcing. The dependent variables considered were the overall QoE  $Q$ , the perceived performance (load times)  $P$ , the perceived aesthetics  $A$ , and the perceived ease of use  $E$ . We used 5-point ACR scales (with adapted wording) for all variables except for ease of use, for which a 5-point Likert scale was used.

### B. Participants

The experiment was carried out by crowdsourcing, using the Microworkers platform. The use of crowdsourcing allows



Fig. 1. News site content, at the two extremes of the visual appeal scale: (a) high, (b) low

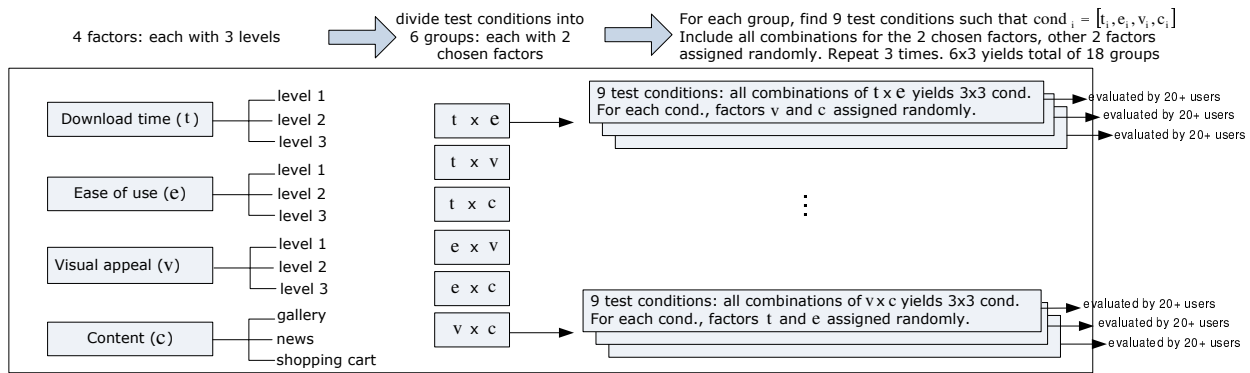


Fig. 2. Methodology for assigning test conditions

for larger-scale experiments than are possible in a lab setting (especially in terms of costs and time of running the test campaigns), but it implies certain trade-offs in terms of the data quality that can be expected, and in terms of how the tests should be instrumented [20]. Our test campaign was set up for 450 users (ages 16-65; median=25; 95 females, 355 males), aiming each of the conditions tested to have between 20 to 60 assessments. While the collected results met the target, after the data cleaning phase, the conditions had on average 32.50 assessments and some conditions only 8 assessments. After the filtering there were 55 conditions (81% of the total) that have at least 15 assessments, which is in line with the usual recommendations for subjective testing [21] (the remaining conditions were also found adequate in terms of variability, despite their lower number of assessments).

### C. Experimental design

The experiment was instrumented via a Web-based application. The test procedure is illustrated in Figure 3. Participants taking part in the user study were directed to a landing page which gave a concise explanation of the assessment task, and described how the assessment should take place, including a description of the rating scales, and an illustrated workflow chart for the whole process. The participants first provided

some basic data, including gender, age, country of origin, and experience in accessing certain types of Web sites (*step 1*).

A short training stage was provided by having the users go through two dummy test conditions and assessment cycles, which also served as hidden anchors to calibrate the users' internal rating scale (*step 2*). The users were then guided through nine different test conditions (plus a repeated one) to assess. A test condition refers to a user completing an assigned task for a given Web site, with a set page load time, visual appeal level, and ease-of-use level. Starting with the first condition, a landing page explained the task that the user had to perform (*step 3*). After the task was completed, the user was asked to provide a subjective evaluation (*step 4*) before proceeding with the next task. One of the nine conditions tested was randomly chosen for a consistency check, for filtering unreliable users afterwards. A total of 10 tasks were completed and evaluated (*steps 3-22*), after which the end user received a token indicating successful test completion, which they then pasted into the Microworkers site in order to receive payment (*step 23*).

**Test Conditions.** For each of the factors under consideration, we chose three possible values, yielding a total of 81 possible conditions to test. Tasks (of equal "difficulty") were varied within each content, but were not considered explicitly

as independent variables. Since when doing crowdsourcing it is not advisable to have very long tasks [20], it was not possible for each user to test all conditions. Therefore, we divided the test conditions into groups, with each group containing all possible combinations of two of the independent variables, and for each such condition, the other independent variables were drawn randomly from their respective domains. This setup yielded six groups, and we repeated this three times, for a total of eighteen groups of nine conditions each (68 unique conditions tested). Each group was then assessed by at least twenty subjects (resulting in between twenty and sixty assessments per tested condition), in order to obtain statistically significant results. This methodology is illustrated in Figure 2. During the test, users were presented with the conditions in a randomised order, to avoid learning effects biasing the group’s assessments.

Given that not all users tested all possible combinations, we also check to see how many users ended up rating conditions covering 1, 2, or 3 levels of a given independent variable. Results showed that in the majority of cases, a given user was exposed to all three levels of a manipulated variable (i.e., more than 200 users rated conditions covering all three levels of each independent variable).

### III. RESULTS

The tested conditions in QoE studies executed as crowdsourcing campaigns are assessed by unknown participants in an uncontrolled environment, calling for various data reliability checks and subsequent data filtering. We eliminated the votes of participants that completed less than all 10 tasks, declared suspicious combinations of nationality and language, had session completion times over 1 hour, were assumed to be overly insensitive to the manipulations based on standard deviation of given votes, and were highly inconsistent when rating a repeated test case. In total, votes from 49% of the users who completed all the tasks (i.e. votes from 221 users) were included in the analysis.

As a first step, we performed a manipulation check to ensure that the dependent variables  $P$ ,  $E$ , and  $A$  were successfully

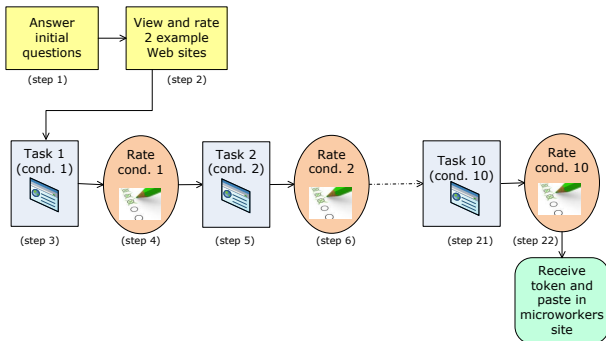


Fig. 3. Crowdsourcing test procedure

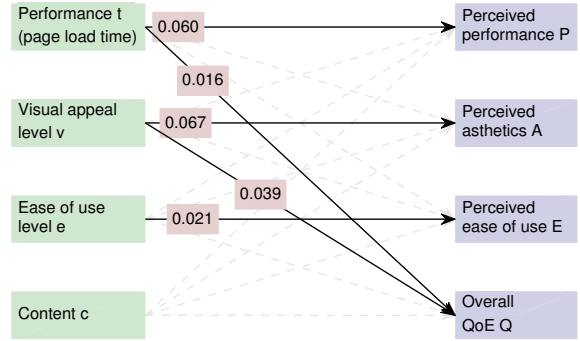


Fig. 4. Summary of effects of independent variables on dependent variables (partial  $\eta^2$  values shown).

manipulated. Analysis of Variance (ANOVA)<sup>1</sup> results revealed significant effects of all three variables: visual appeal on perceived aesthetics ( $F(2, 2142) = 76.45$ ;  $p$ -value  $< 0.001$ ), page load time (PLT) on perceived performance ( $F(2, 2142) = 68.95$ ;  $p$ -value  $< 0.001$ ), and ease of use on perceived ease of use ( $F(2, 2142) = 22.86$ ;  $p$ -value  $< 0.001$ ).

With regard to factor interactions, in the case of perceived performance, we note that in addition to loading times, content type had a significant effect ( $F(2, 2142) = 11.24$ ;  $p$ -value  $< 0.001$ ). The interaction between loading time and content was also found to be significant ( $F(4, 2142) = 3.37$ ;  $p$ -value = 0.009).

For the overall QoE ratings, aesthetic level and PLT were found to have a significant effect. No significant interactions were found for the dependent variable overall QoE. A summary of the effects is given in Figure 4. We note that while PLT level 3 corresponds to the worst case of perceived performance (highest page loading times), level 3 for visual appeal and ease-of-use correspond to the best case scenarios.

The main effects for overall QoE are illustrated in Figure 5. Results of a two-way ANOVA have shown that the PLT factor had a significant effect on overall QoE ( $F(2, 2142) = 17.62$ ;  $p$ -value  $< 0.001$ ), as did the visual appeal factor ( $F(2, 2142) = 43.796$ ;  $p$ -value  $< 0.001$ ), while ease-of-use did not have a significant effect and neither did content type. We note that while perceived ease-of-use correlated with overall QoE, objectively, ease-of-use did not have a significant impact on overall QoE. We also checked four-way ANOVA results (omitted due to space restrictions), which confirm the findings related to the relevant effects.

We further calculated the relevant Spearman correlation coefficients between dependent variables. A summary of correlation coefficients and confidence intervals is given in Table I. All were found to be significant ( $p$ -value  $< 0.001$ ). The highest correlation was found between perceived aesthetics and overall QoE, even though the performance and aesthetic manipulations were of comparable strength. We also found this to be the case when checked individually for all content

<sup>1</sup>Shapiro-Wilk tests were conducted on the assessment results for each dependent variable, and all were found to be normally distributed.

TABLE I  
SPEARMAN CORRELATION COEFFICIENTS  $\rho(X, Y)$  FOR DEPENDENT  
VARIABLES  $X$  AND  $Y$  AND THEIR 95% CIs.

Variable X	Variable Y	Corr.	Conf. Int.
Overall QoE Q	Aesthetics A	0.80	[0.78; 0.81]
Overall QoE Q	Performance P	0.59	[0.57; 0.62]
Overall QoE Q	Ease-of-Use E	0.53	[0.50; 0.56]

types. One possible conclusion to be drawn is that the aesthetic level had a dominating impact on overall QoE and hence had a “masking” effect with regards to other quality dimensions (in an analogous way as video quality has been known to mask audio quality in audio-visual tests). Previous studies have discussed the different impacts that aesthetics and usability have on product evaluation, with aesthetics being perceived immediately [22], while usability-related judgements may be either inferred or made following interaction with a given product. Drawing on the study reported by [5], the authors proposed a conceptual model to explain the process of user preference making, whereby pre-use judgements are affected mainly by the visual aspects of an application, and post-use judgements are affected by both usability and aesthetic aspects. In our case, we note that we focused on perceived ease-of-use as a sub-dimension of the usability construct. As stated previously, our results showed that given our manipulations, the manipulated ease-of-use level (number of clicks to complete a given tasks) did not have a significant impact on overall QoE. Hence, it would appear that users’ overall quality judgements were affected to a greater degree by the visual appeal manipulations and consequently by the perceived aesthetics. It is also interesting to note the findings of [23], who found that visual aesthetics could enhance user performance in completing a task under conditions of poor usability. Consequently, given high aesthetics and low usability, there is potential in improving overall qualitative judgements.

For different PLTs, we further analyzed to what extent users accessing a Web site that they perceive as aesthetically appealing will provide higher QoE ratings than in the case of

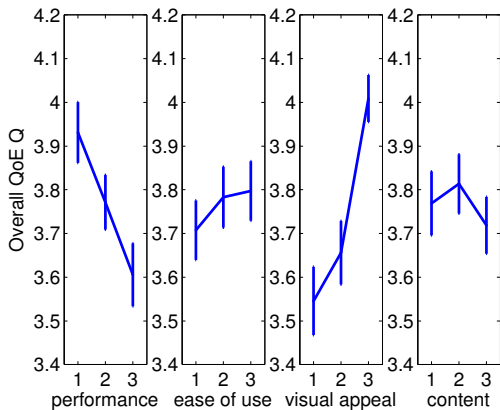


Fig. 5. Main effects plot for overall QoE in relation to independent variables.

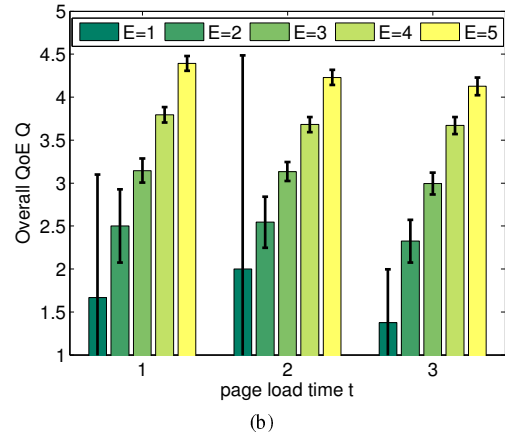
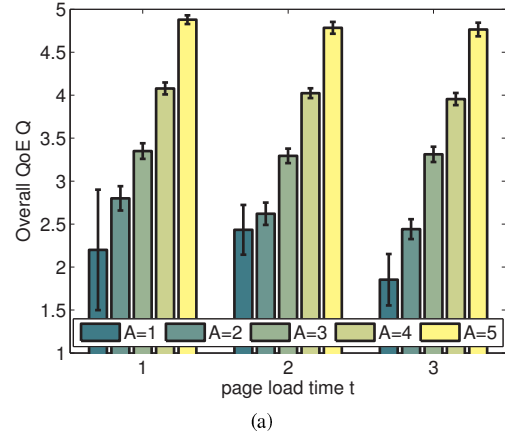


Fig. 6. Relationship between overall QoE and PLT: (a) for different levels of perceived aesthetics; (b) for different levels of perceived ease-of-use

low perceived aesthetics. Analogously, we analyzed to what extent users accessing a Web site with high perceived ease-of-use will provide significantly higher QoE ratings than in the case of low perceived ease-of-use for different PLTs. Results illustrated in Figure 6b show large differences in mean scores. What is clear is that in the cases of both high aesthetics and high ease of use, users provided high QoE ratings, despite large PLTs, indicating an increased tolerance towards delays as opposed to cases of poor Web site design.

#### IV. DISCUSSION AND CONCLUSIONS

In this study we have sought to address the interplay between design and network performance aspects, with the goal of more clearly understanding the factors that impact the qualitative judgements made by users when accessing Web sites.

As regarding different content types, we found no significant effect of content type on perceived aesthetics or perceived ease-of-use. We did however find the content type of Web sites to have an impact on perceived performance, indicating that a user’s perception of the “speed” of a site will be influenced by the task that the user is performing. We note that the actual waiting operations differed between tasks. For example, while interaction with the news site involved only “browsing”

delay, interactions with the picture gallery and shopping site involved also “transactional”, or upload, delays (e.g., a user had to upload a picture to a gallery). Assuming that there is a tendency for users to prefer systems where they are able to complete a task more efficiently/quickly, we focus in particular on the impact of network-related loading time. As a consequence, we conclude that the impact of perceived waiting time should be studied in a context-dependent manner.

Compared with related work addressing the impacts of aesthetic and usability manipulations [6], [24]–[28], we have addressed a larger number of combinations, focusing in both cases on three different levels. Combined also with three levels of page loading times and three types of content, this gave us a large number of test conditions to consider (81). We employed Web-based crowdsourcing as a testing methodology (as opposed to lab studies) in order to access a larger population sample. Keeping this in mind, we summarize results as compared to previous work. Similarly to the results in [13] we can conclude that overall Web QoE is affected by the network performance in terms of page loading times, and that this effect follows a logarithmic relationship as reported in [14] and [29]. In line with the results presented by [30], we further confirm that aesthetics is a major component contributing to the perceived quality of Web sites. Hence, existing QoE models that consider QoE to be a function of PLT should also consider the visual appeal of a Web site as a key QoE influence factor. Our results are also in line with findings of [28] and [27] with regards to the aesthetics manipulation affecting the perceived usability. On the other hand [27] also found aesthetics being affected by usability manipulation which we could not confirm. However, we note that our usability manipulations were limited to manipulating the ease-of-use of completing a certain task, and did not consider usability in a wider sense. Our results also indicate that perceived aesthetics and perceived ease-of-use were statistically significantly affected by the performance manipulation (in terms of Web page loading times). However, the weakness of the effects calls for further tests.

In light of the results obtained we cannot confirm the effect reported by [31] stating that perceived time performance varied as a function of visual appeal (colors in [31]). As specific colors may be required to elicit the changes in the mental state of the subjects (which then would result in an altered view of performance), it is left for further study to attempt visual appeal manipulations with different sets of colors.

While the results obtained in this study provide a solid foundation for understanding QoE for Web sites, much remains to be done in order to build up, model and exploit the said understanding. Results can be generalized only to a limited extent, since the tested factors are sub-factors of more general concepts (e.g., ease-of-use is only one aspect of usability). There are several items and research lines that should be considered in future work, among which we can highlight: additional Web- and Laboratory-based studies for further exploration, addressing multiple dimensions of aesthetics and usability based on validated scales, building predictive

models for Web QoE, and exploring how to exploit Web QoE from different stakeholder perspectives.

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