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Crowdsourcing Augmented Reality Environment (CARE) for aesthetic evaluation of products in conceptual stage

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ABSTRACT

Decision-making activities affect to a larger extent the quality, cost, time and success of a product. However, there are fewer alternatives when it comes to supporting in aesthetic evaluation during the product design stages.

Therefore, is proposed a Crowdsourcing Augmented Reality Environment (CARE) that use the user's mobile devices for getting the feedback from the evaluation of products using a Semantic Differential (SD) that consider the user's context-light interaction in real time.

Finally, two products were evaluated using CARE vs. the real products under different lighting and surrounding conditions. Obtaining a similar measure of products aesthetic perception between CARE and the real product, with slight variations. Additionally, an evaluation pattern among users was recognizable in the same context with slight variations using different lighting setup, that was similarly recreated with CARE.

1. Introduction

Decision-making activities throughout the product design process are crucial for the final product success but, currently, there are limited computational tools available to provide better support to the designer at the earlier stages of the design process, especially at the conceptual design stage [44]. These stages affect to a larger extent the quality, cost, time and success of a product in the market [6]. Additionally, the cost of fixing errors or making changes to a design escalates dramatically as the design process advances in the product life cycle [41].

Pahl et al. [33] define the conceptual design as a process where, through the identification of the essential problems using the abstraction and combining working principles into a working structure, a basic solution path is laid down. In this way, conceptual design specifies the principle solution through a path that involves definition, creation, evaluation, and decision. Ulrich and Eppinger [41] proposed a final stage of concept prototyping or a test with the final user in order to get feedback about the concept using sketches, rendering and other techniques.

Therefore, computational tools aimed to support the designer during the evaluation of different concepts involving the target user, specifically from the aesthetic point of view, would reduce the lead time and would allow a better adoption rate of the product.

Further, the aesthetic aspects of the product play an important role; attract consumers, communicates, add value and, in general, influence the purchase decision [7]. But at early design stages these aspects are often evaluated with the final user through prototypes, sketches and renders or physical models. This limits the range of possible solutions to evaluate and does not fully consider the product-user-context interactions.

Augmented Reality (AR) is novel technology that aims to mix virtual information into the real world. And it (AR) has proved to improve the experience in the evaluation of proportions, functional and ergonomic aspects of prototypes [32].

Additionally, the use of AR has demonstrated to be a valid alternative to the traditional way to evaluate the user interfaces and also showed that it is possible to involve the users in the design processes [8].

Although many commercial applications use AR in order to allow the user to visualize an existent or conceptual product in their own context, few of them are used as support in the design stages related to aesthetic decisions.

In this paper, a new tool for mobile devices (Android®), so-called CARE, Allows visualizing the product's concept in the user context using AR with real-life lighting using the context information. In order to get feedback via the Internet from several target users about the aesthetic perception using a Semantic Differential [30], considering context, lighting and demographic information. Additionally, there are no

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special requirements for the mobile device, just that it has camera and touchscreen. The system is made up of two parts, a server was all the assets are uploaded by the designers and a client, where the possible customer evaluate the product using AR. Additionally, the system was built using a Domain Driven Design (DDD) approach [13] described in Section 4.

The client application retrieves the colors of the context [12] and consider the real context lighting in order render the virtual product according to the surroundings. This would help the designer at the conceptual stage of the design process when decision-making occurs, allowing collaborative work with expected users of the product.

In contrast with previous research, here is proposed a framework for retrieving the visual perception feedback of a product's concept of multiple users. While the target user performs the aesthetic evaluation, the virtual product is lighted with the same diffuse light of the environment (Section 4.1.3). And the evaluation is sent together with the seen colors of the environment while the user was doing the evaluation.

General information about evaluation of concepts, aesthetic aspects of the product and different AR tools used in the decision-making process are analyzed in the next section in order to elicit the requirements of the CARE in Section 3. The proposed CARE is presented and explained in Section 4. The experimental setup for a case study is described in Section 5. Obtained results are presented in Section 6 and, finally, conclusions are stated in Section 7.

2. State of the art

2.1. Concept evaluation

Generally, the evaluation stage defines a value of one solution with respect to an objective (criteria), compared with the available concepts or already existent solutions. But if the idea is totally new it must be compared with an imaginary ideal. Additionally, it is necessary to keep the evaluation in terms of general objectives and not individuals. For that reason methodologies like Cost–Benefit Analysis and VDI Guideline were analyzed by Pahl et al. [33], defining the next steps for the concept evaluation:

i. Identify the evaluation criteria based on the requirements list.
ii. Weight assignation to the criteria: in such a way that the evaluation will be focused on the main characteristics.
iii. Compile the parameters:
    a. List the parameters in a checklist.
    b. Assign every measurable parameter available to the criteria.
iv. Assign values: Different scales can be used.
v. Determine the total value.
vi. Compare the concepts: Having an absolute scale helps to compare the concepts. All the concepts that are under 60% do not worth to be continued in the development.
vii. Uncertainty estimation: The evaluation methods are simple tools no automatic decision mechanisms. Then, uncertainties must be identified but by the moment they are just white spaces that can affect the concepts.
viii. Searching weak spots.

Complementary, Ulrich and Eppinger [41] proposed a method, complemented from Pugh [35], that selects concepts through matrix and comparison with a reference, in general, a standard in the industry or a base concept. This method considers the following steps:

i. Prepare the selection matrix with the design criteria listed in the left part of the matrix and the concepts sorted in the top of the matrix.
ii. Score the concepts with a relative scale, of “better than” (+), “same than” (0) and worse than (−), to the reference concept.
iii. Sort the concepts.

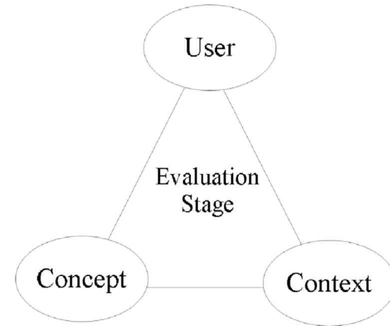


Fig. 1. Elements that need to be considered in the evaluation of a product concept and the relation among them (concept, context or environment and user).

iv. Combine and improve the concepts.
v. Select one or more concepts that could be improved at a future stage. The selection is directly related to the available resources.
vi. Reflect on the obtained results.
vii. Detailed selection with a second evaluation matrix. This involves weighting the criteria to evaluate, similar to the second step proposed by Pahl and Beitz.

Therefore, there could be two main score assignations to the concepts, the first one is comparing against other “base” concept (scale: +, 0, −) and the second is score against a criteria parameter (scale range of integers). The first method allows subjective evaluation, adequate for the conceptual stage because most of the concepts are not well defined, however, the second method can avoid some uncertainty.

Besides, in the evaluation of a product, three elements should be considered: concept, user, and context. These elements are all related and influenced one by each other (see Fig. 1).

In general, concepts are evaluated against criteria based on the objectives that the design must reach. The evaluation must consider the user's needs and wishes, but in some cases, a parameter does not fully describe users opinion. Each criterion should have a measurable parameter in order to quantify the evaluation, but some criteria have relative parameter as the aesthetical evaluation. Consequently, each criterion should have a different way of evaluation.

A survey of 27 undergraduate and graduate students from product design engineer was carried out in order to identify some informatics tools and techniques used in the concept evaluation.

Furthermore, the tools used in the evaluation stage are presented in Fig. 2. Where the three most used tools are: Excel, 3d modeling software, and image editing software. Both 3d modeling and image edition software are used to simulate functional and visual characteristics of the concept, which can then be saved into an Excel matrix.

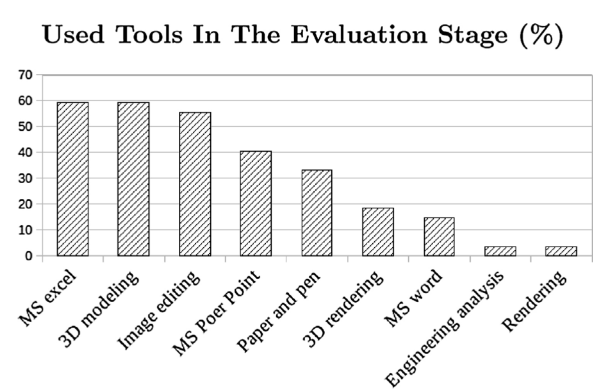


Fig. 2. Survey of used tools in the evaluation stage by undergraduate and graduate students from product design engineer.

The main characteristics of the used software (Fig. 2) are that in the conceptual stage it allows the designer to have an interaction with the user receiving feedback in different fields such as aesthetics or ergonomics.

This information evidences the importance of new tools to allow a direct interaction with the user during the evaluation and selection tasks of the difference produced concepts in order to get some certainty about the final impact of the product.

2.2. Aesthetics evaluation

Two possible different interpretations can arise from the term “aesthetics”: the first one related to the sensory perception, interpretation and understanding of the world and the second one about the pleasure attained from sensory perception [10,18].

The aesthetics perception is composed by the sensorial feedback, where senses (sight, hearing, taste, smell, touch) allow to identify an object and generate a positive or negative reaction, maybe related to some object characteristics such as harmony, proportion, balance, and symmetry. Thus, aesthetics is not an emotion, its experience can lead to an emotion.

In products, aesthetics can be considered as the feelings of (dis)like based on a sensory perception and it is just part of the product experience levels. The other parts are understanding and emotional levels and they deal with human mind faculties [36].

Hekkert et al. [19] propose some universal principles of design that could help to understand why people are aesthetically attracted to some properties. Anyway, although there seems to be a universal agreement with respect to aesthetics pleasure perception, people can differ in the matter of taste.

Several theories can predict the way people will react to designed objects, however, they do not work in practice because aesthetics preferences represent only one part of people's interaction with the goods [38].

It is also known that the things we design do not exist in the emptiness, instead they are in dynamic relationships with people, places and other things that carry personal, social and cultural connotations, and such experiences change over time [38].

Further, one of the most popular methods for aesthetic evaluation is the Semantic Differential (SD) which has been largely used to investigate user's perceptions regarding different aspects of the product such as style, colors or form [22,26,29,20,34].

The SD method was proposed by Osgood in 1952 [31] as a general method for measuring meaning. It involves the selection of number and nature of semantic description and a specific scale where the meaning of a particular concept for a specific person can be specified quantitatively. In the SD, a subject evaluates a set of concept against a set of bipolar Likert's like scale defined by verbal opposites (good–bad, fast–slow, etc.).

Additionally, Osgood analyzed a large set of SD scales establishing three dimensions (presented in Table 1) of affective meaning universal across cultures: evaluation, potency and activity [30].

In the proposed approach, the SD method is the way of gathering the user response related to a concept displayed in his/her own context. Since it allows to create a profile of the product according to several users perception.

Table 1
Dimensions of the Semantic Differential (SD) of affective meaning universal across cultures: evaluation, potency and activity [30].

Evaluation	Potency	Activity
Good–Bad	Hard–Soft	Active–Passive
Kind–Cruel	Strong–Weak	Fast–Slow
Wise–Foolish	Heavy–Light	Difficult–Easy
…	…	…

For evaluation of functionality or usability, there are more tools and ways to ensure the right decisions based on numerical results. But as soon as pleasure-like objectives arise, it is difficult to predict what will be the verdict of the user interaction with the product.

Furthermore, in pleasure-like evaluation, the context in which the product will be located can be affected the way in which the user perceives the concept. For instance, it has been proved that color carries different meanings in different context and therefore, it has different implications for feelings, thoughts, and actions in different contexts [12]. The context is full of information about the user, his or her preferences, products, and colors that can be used in the early stages of the design.

People tend to surround themselves with objects that reflect their self-image (houses we live in, cars, even dogs). Together, all the pieces make up the visual image that we project of ourselves [6] because “whatever the product is, what the customer sees is first, the physical performance comes later. The visual performance is always first” [35].

Additionally, the current software allows creating images or videos that can be later shown to users in order to get feedback, but not in a personalized way since the users can not interact with their own context of use. This can be useful when the designer is working with techniques, such as “*personas*” [27], which is a technique that allows to somehow create an ideal user (imaginary) and use it to define the product style.

This imaginary user is created based on the brands or style the final user wants to reflect. Or by using “*Cultural Probes*”, where some representative user is interviewed and general characteristics are created and used as inputs to the design process.

Based on these commonly used techniques (personas and cultural probes) classic presentation of the products (3D rendering) can be used to see if the product aesthetics fits in the collage of products of the idealized user. However, this approach is not suitable to consider several users with different contexts and lighting and, somehow, the decision is left to the designer criteria.

2.3. Augmented Reality tools in aesthetics decision making

Augmented Reality (AR) is a technology that aims to modify the user perception of reality by mixing it with virtual elements. Where AR meets three characteristics [5]:

1. Combination of virtual and real objects in the real environment.
2. Interaction in real time.
3. Registration in the 3D space.

Some AR tools to evaluate concepts and reduce lead time and resources have been identified: Fiorentino et al. [14] proposed Spacedesign, a Mixed Reality application for aesthetic design, that allows the construction of free-form surfaces. Also, the natural interface lets designers keep the same tools and environment found in a physical prototype and it allows corrections and changes by different skilled experts.

Ahlers et al. [2] investigated about an AR application for collaborative interior design with multiple users working together and they proposed a solution to share objects in a network, assuming users from different roles and locations. One of the main problems arose when several users were present in the same “reality”.

Similarly, Shen et al. [37] studied the use of AR for concurrent collaborative product design allowing multiple users at different locations to modify the product in real time.

Klinker et al. [23] proposed a system where car designer carries a wearable computer displaying the virtual car in a Head-Mounted Display (HMD). Main issues were image quality and response time and requirements of car designers like effects, shadows, and reflections used in product rendering.

Osorio-Gómez et al. [32] proposed the use of AR glasses for validation of design concepts in mock-ups, in an academic scenario. They proved that the use of Virtual Reality techniques improves the experience in the product validation of aesthetical, proportional, functional and ergonomic aspects.

Ye et al. [45] applied Virtual Reality (VR) for computer-aided evaluation of products, finding that VR technologies are an efficient and effective support throughout the product lifecycle. Nevertheless, several improvements to their VR evaluation system could be applied, like auditory evaluation, realistic color and texture and full hand haptic interaction. The proposed system does not allow a real context visualization for the evaluation.

Arroyave-Tobón et al. [4] proposed an AR system to include the information of the context in the conceptual 3D modeling stage. By proving the environment information increase the efficiency by allowing the designer to 3D modeling in natural scale on the real scene.

Bruno and Muzzupappa [8] evaluated the feasibility and efficacy of a VR tool for collaborative product interface comparing the results of using VR vs. the real product. Additionally, a second study using VR in a focus group for product redesign was conducted showing that VR is a valid alternative to the traditional way to evaluate the interface and also showed that it is possible to involve users during design processes. The main limit of their proposal is that the user is out of his/her daily context.

Another approach was proposed by Hsiao and Tsai [21,40], using Grey's and Neural Networks to predict an image evaluation of a product based on a small amount of surveyed users. A model based on 3D parameter allowed to predict the perceived image of the product and to adjust the design.

The application of AR in the conceptual design stage has been proved to be useful to simulate the products in order to make decisions and get more accurate evaluations from other stakeholders of the product. But the feedback from users interacting in their own context and taking advantage of the growing proficiency of mobile devices in order to provide a better support for the aesthetics perception is not fully considered yet.

Current AR commercial applications allow to display 3d models, and most of the software for AR in mobile devices, such as tablets and smartphones, are developed for uses such as gaming and geo-location information. Therefore, there are not applications that fully support the process of getting feedback for the product evaluation process, in order to enhance the user experience.

3. Considerations for the proposed approach

Evaluation of the aesthetic aspect of a product considers interdependence between Shape-Material-Illumination (S-M-I triad). Therefore, in order to know any of the components of the triad, assumptions about the other two components should be done. Also, the context elements, such as lighting and surrounding objects, have an important effect on how shape and color are perceived. Based on these elements the requirements for the proposed Crowdsourcing Augmented Reality Environment (CARE) are elicited.

Schifferstein and Hekkert [36] relates the physical phenomena that influence perception to shape, material, lighting, and color.

Furthermore, considering available AR solutions, there are two aspects to be considered: on one hand, the methods should allow the users to work with the context in their workspace, independently of where the user context is located, giving more freedom and also knowledge about the user context at the design time. On the other hand, the method should allow the target user to interact with both the concept and context.

Hereinafter, the current methods for defining some of the elements that influence perception and how they interact with each other are presented.ShapeThe perceived shape can significantly vary with the change in the lighting direction. Increasing the ambient light can make shapes look flatter too. Likewise, specular illumination can be highly informative about the shape.The main ways of modeling (to define the shape for visual representation) are: polygonal modeling with subdivision surface method and digital sculpting with brush presets that allow the deformation of polygonal surfaces. Also, another common modeling tool is NURBS (non-uniform rational B-spline) for the creation of mathematically based surfaces.MaterialThe main subject is the contrast between the context and the subject because the human being perceives relative intensities instead of absolute ones. Most of the programs allow to configure the parameter of established models that define the next shaders:

1. Reflection: it defines the behavior of light when hit an object and it is reflected in the next parameters:
   - Specular reflection: “mirror-like” reflections.
   - Diffuse reflection: when the light is reflected in different angles.
   - Index of refraction: describe how light behaves when entering into a material.
2. Refraction: It defines the behavior of light when changes of medium and it is controlled usually by:
   - Index of refraction: it refers to the change of direction of the light when changes of medium.
   - Opacity: transparency without considering the change of angles.
   - Roughness of the surface: measurement of the texture of the surface.
   - Subsurface scattering: the scatter of light when it penetrates a translucent object.
3. Displacement and Bumps: it defines how the surface is deformed at the rendering time.
4. Custom material: it defines the combination of existing shaders.

LightingLight has an influence on the perception of shape and material. Usually, it can be simulated as a point defined by its coordinates, the color, and intensity of the light.ColorIt can be a sign of use or a sign of the object condition and it is highly influenced by the spectrum of lighting, e.g. the color of an object is different under daylighting than under nocturnal lights.Context and userIn addition, it is necessary to include the interaction between the Schifferstein's elements, the surrounding elements, and the user in order to get an accurate feedback of user's perception.In commercial software, this group consists of model, texture, and setting of the complete scene of the context in which the concept will be located. This technique can be used when the final product is located in a specific place that will not be modified by the user, e.g. furniture designed especially for a place.Also, modeling of a context can be useful when it is necessary to set up an ideal scenario for the context or when the user should see how his or her product looks like when changing elements of the context. Next, four different techniques for context simulation are presented.

1. Camera mapping or projection: it is based on the already known parameters of the camera and a photograph of the context, trying to match an element of the photograph with a virtual one (a plane or cube) and positioning the camera in order to fit the model with the photograph.
   This technique is useful because it allows matching the user's perspective easily in order to get a quick feedback.
   The main disadvantages are that it just allows seeing the concept from one point of view (the same that the photograph). If you want to use another context or another photograph it is necessary to do all the matching process again. Additionally, the lighting depends on the designer's criteria and this can produce unreal results.
2. Camera solving through motion tracking: it is based on the previous method. The software calculates position based on differentiable points of the video and the camera parameters. It presents the same advantages and disadvantages of the previous method.
3. 3D context scanner (Photogrammetry): it allows reconstructing the position, orientation, shape, and size of the objects from a sequence

of photographs [24]. The main advantage is that it allows correcting the display and interaction with the elements of the context, though the main disadvantages are that lighting is not considered and it can be time-consuming.

4. Photomontage: it is the process of composing an image with the concept. It is completely based on the ability and criteria of the designer; it can lead to fast results but not so accurate ones

Regarding the Shape-Material-Illumination (S-M-I triad) interaction in objects perception, the proposed use of AR for getting feedback from users presents several benefits regarding to other methods such as Virtual Reality (VR) or classic computer graphics. It is not required to 3D model the user's environment, and given that CARE can be download and run in any Android® running device, the evaluation could be performed in the users own context without given major efforts.

Similarly, the lighting information (color, as proposed here) of the user's own context could be used for more realistic perception (described in Section 4.1.3). Also, the real environment background is used by the definition of AR.

Additionally given that the proposed framework work under low specs devices that are of common use such as smart-phones or tablets. No cumbersome hardware is imposed on the user typically used in VR environments.

Further, some issues arise for the current implementation. First regarding real-time realistic reflections that include surrounding information, although this is feasible with current ray tracing techniques [42]. The proposed application is made to run on tablet-like devices in which the camera can only access one portion of the environment that it is not sufficient for recreating the whole surrounding. Therefore, only the diffuse light was simulated for this project.

Similarly, with the available rendering algorithms and taking into account that the background information is available (AR application), it will be possible to simulate realistic refraction. Nevertheless, in this project is out of the scope.

Finally, all this information (surrounding colors and lighting) is sent back to the designers for having a complete understanding of the elements in the time of the perceptual evaluation.

4. Proposed Crowdsourcing Augmented Reality Environment (CARE)

Nowadays, AR has been used in many commercial applications in order to allow the users to visualize an already existent product in their own context. But, few efforts have been carried out in order to understand the nature of such perception or used as support in aesthetic stages of the product design process.

Therefore, authors propose a Crowdsourcing Augment Reality Environment (CARE) that brings the virtual concepts to the user context (physical location). Emulates the context diffuse light (Section 4.1.3) and asks for the user's perception through a Semantic Differential (SD) previously defined by the designer. Finally, the feedback (SD, context colors, and lighting) from several users is sent to the server in which the information can be visualized by the designers through a web page.

The proposed system is composed of two parts a server and a client. The server is where all the assets are uploaded by the designers such as 3D models or the SD adjectives. Also is where the final evaluations of the users are processed and accessed through a website. And the mobile devices (client) that is used by the target user. The "target user" is a possible future user of the product (customer). The target user opens the application and the assets are downloaded. Then is asked to evaluate the available concepts and send back to the server this evaluation.

The client application was developed for mobile devices (smartphones and tablets) and once the application is opened it asks the user for some demographics information such as age, name, or gender (Fig. 5). After that, the AR starts showing a virtual product when the marker is visualized. The user can evaluate each one of the products

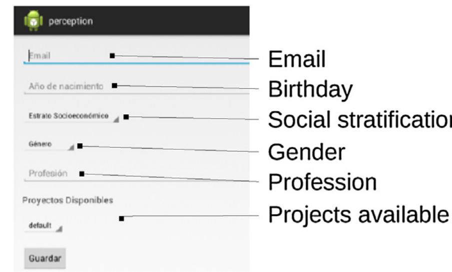


Fig. 5. Log activity from target user application. First screen that the user sees when the application is launched and it is composed by input-data-boxes, validated in real time.

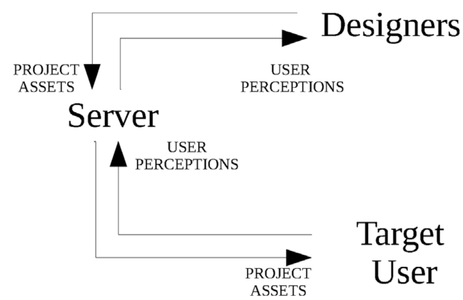


Fig. 3. Proposed AR based system parts: the project assets containing the concept information and SD are loaded into the target user application. After users evaluation the information is sent back to the server containing the answered SD, lighting and representative colors of the context.

once it appears on the screen. Also, the user can loop between the available virtual products using finger gestures over the screen. Finally when all the products have been evaluated the application asks the user to send this information to the server. The process is illustrated in Fig. 8.

The proposed system is represented in Fig. 3:

1. Target user application: this application, in an Android® mobile device, allows potential users of the product to evaluate the concept according to how it looks in the context and send that information to the server.
2. Server: it stores the projects that can be uploaded by the designers via HTTP through a web page, receives the feedback of the concepts via the Internet and deploys a web page in which different inquiries can be conducted.

Android® is an operative system for touchscreen mobile devices (mobile phones and tablets), and it is based on Linux with a Java programming interface. The main library used for the graphical development and for the initial testing was *Processing*, version 2.0.1, which is an open source programming language focused in the development of graphical applications.

One of the advantages of *Processing* is that it can be used alone for the initial prototypes of the application and, later on, it can be easily ported to an Android development as a library for more complicated projects.

In the target user application, the main functionality is divided into threads: The main thread loads AR, the obj loader and the interface in a loop. Other threads manage the communication and the color computation for the lights and the scene color displays.

For gestures and sensors, the *Ketai* library has been used to ease the work with both the hardware and sensors of android devices.

In essence, the CARE is composed of an AR application for mobile devices and a web server that allows getting information about the aesthetics perception of concepts by several users. It considers the

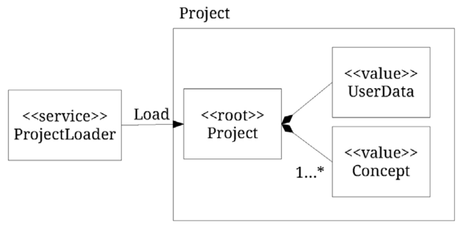


Fig. 4. The proposed domain model has a main project aggregate that is made by an entity composed by an user and all his/her information.

lighting and the context colors, in order to increase the available information at the concept evaluation stage.

4.1. Mobile application overview

The mobile application has the main purpose of visualizing the concepts generated in the design process considering the users real context and lights. And also gets their aesthetics feedback to enhance the concept evaluation.

The proposed domain model (using a Domain Driven Design (DDD) approach [13]) has a main aggregate, so-called Project, that is made by an entity composed by a user and all his/her information. This information includes segmentation, context colors, and lighting. Additionally, the Project contains concepts. The domain model basically maps the product's evaluation relationship items (product-context-user) as it is presented in Fig. 4.

The mobile application is composed of 2 main "activities": log and AR activity (Section 4.1.2). The log activity is intended to get the user information such as name, birthday, gender among others (Fig. 5). The AR activity is made up of several services (Section 4.1.3), and it starts after the log activity. In this activity, the virtual concept is positioned accordingly to a fiducial marker, the lighting of the scene is calculated and the main colors of the surrounding are stored by using the RGB camera of the device (Further explained in Section 4.1.3). At the same time, a SD appear on the screen for evaluating each virtual concept. Finally, when the user has finished the evaluation, these elements are sent back to the server (Section 4.2). This process is shown in Fig. 8.

In the next sub-sections, the main components of the application will be explained.

4.1.1. Project

The project is the main component of the domain and it is composed by a root element where the information required to perform the evaluation is located, such as the list of adjectives (Semantic Differential), concepts and user data (Fig. 4).

The user data contains the user demographics and the context information. The context information is related to the lighting and context colors that were present during the concepts evaluation. Later on, this information is sent to the server in order to be processed and classified. Such information can be used to define the target user of the product or the different product variations based on the user's perception.

Additionally, the product concept is stored and defined by two attributes: texture and geometry, that is defined by a mesh in an OBJ file format loaded by an external library [11].

The OBJ file format is commonly used in 3d graphics and it defines the geometry properties of vertex, edges, faces, UV coordinates and normal vectors. Additionally, visual characteristics of the material are defined in the MTL file where characteristics such as color, reflection, transparency, and refraction coefficients can be defined. This allows loading defined concepts in different 3d software with formal and visual characteristics.

The project is loaded into the user's application using the project loader service that is launched when the AR activity starts. This service searches the.obj model in the project folder, loads it into an array of concepts and creates and assigns a project.

4.1.2. Activities

An Android activity represents a single screen with a User Interface (UI). In other words, a single thing that the user can do and it usually implies the interaction with the user. The activity class takes care of the window creation in which the UI can be placed [3].

The interaction with the application is carried out through two main activities: log and AR activities.

The log activity is the first screen that the user sees when the application is launched for the first time (shown in Fig. 5), and it is composed by input-data-boxes, validated in real time to prevent input mistakes. All the requested information is filled and verified. Some of the information asked the user is related to email, birth date, social stratification, profession and project to evaluate.

When the user completes the form and save the data, the "Project Manager" is launched and the "Ar Activity" will start loading the setup from the files. The concepts and the configuration files needed to create the Augmented Reality using both "Project Loader" and "AR Loader" services. Finally, the draw method is called the AR service.

4.1.3. Services

The AR service identifies the marker in the camera video stream whose parameters are defined previously (described later), sets the transformation matrix of the current displayed 3d model with the adequate lights and over-poses the 3d model onto the video.

In addition, other supported services are used:

(a) Semantic differential drawer: it is launched when a marker is identified and it draws the SD on the screen. Additionally, an initial clue about the use of the application is presented for a short time. When all the concepts have been evaluated, a notification appears indicating to the user to send the evaluation to the server.
(b) Context thread: The context class has the function of calculating the colors and lighting of the context where the concept is displayed. This information is used to render the 3D model and, also, is sent back to the server.
   i. Context colors: the main functionality is performed by a loop over all the pixels of the camera, and the histogram is stored as a HashMap with the configuration: Key = color, value = amount.
   ii. Lighting: this service calculates the light of the context using Eq. (1) in order to define the color of the diffuse light influencing the concept:

$$l = \frac{1}{t}\sum_{i=0}^{w}\sum_{j=0}^{h}(I_{ij}) > \left\langle r_{ij}, g_{ij}, b_{ij} \right\rangle \quad (1)$$

   In Eq. (1) the tint of the illumination l is calculated by the average of the number of pixels t that meet the condition in each RGB channel.The context light is approximated by the light influencing the marker, and it is calculated as the tint of the white parts of the fiducial marker used for the matrix perspective calculation. First, the points of the four external corners of the marker are obtained, next, the region of the marker, defined (w, h), is calculated. The brightness I and each RGB color channel for each pixel are available (shown in Fig. 6). Further, when the evaluation is finished the used illumination is stored in the server.

Finally, all the required parameters are loaded for each project from a.json file located inside the folder of the project and it is supposed to be provided by the designer with the specifics needs of the project. Some parameters are:

1. Size of the marker.

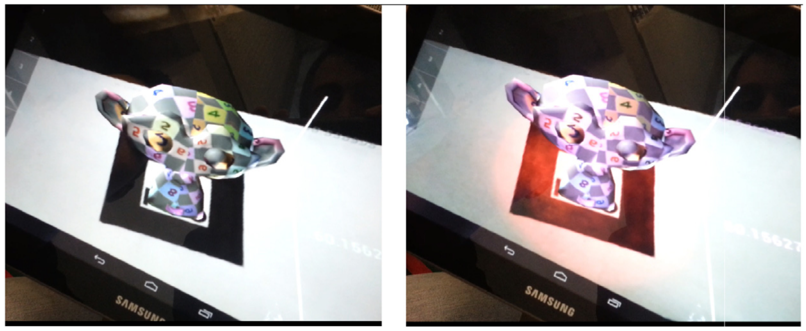


Fig. 6. Context-light interaction with the virtual model. On left the fiducial marker and the virtual model are lighted with white light from the environment. On right, the same model captures the red light of the fiducial marker in order to simulate the same lighting color of the environment.

2. Number of markers.
3. Threshold values.
4. FPS (frames per second) of the application.

4.2. Server

The server of the project was developed using Node.js, that is an asynchronous event-driven cross-platform framework designed to build scalable network applications and maximize the efficiency through the use of non-blocking I/O (Input/Output)[15]. Several studies have been made regarding the performance of this framework, finding that is light and efficient for handling intensive I/O operations and is a suitable tool for developing fast and scalable network applications [39,25,9,28].

Moreover, it offers an easy and safe way to build network applications in JavaScript adjusting to the needs of the project and allowing to build an easily tested server.

The server is used for:

1 To store the compressed files of the projects uploaded by the designers.
2 To manage the database for each project.
3 To process the perception information received from the user's application (Section 4.2.1).
4 To deploy a web page where the designer can interact with the data from the user's perception (Section 4.2.2).

The architectural style used in the server is REST (Representational State Transfer), which it is defined by a group of constraints setting its components and interactions, following the next design principles: a client/server protocol without state, each message contains all the communication needed in the request, a defined set of operations (HTTP methods) and each resource is only reachable through a URI (Uniform Resource Identifier) [43].

In order to create a REST server the Express module has been used, which is a web application framework that allows to simply configure a web application and link a URL with a specific JS (JavaScript) function. As a result, the server script is divided in two: in the first part the Express module is requested and configured, configuring and registering the handlers, and, in the second part the functions, that are executed in each request and returned a response, are located [16].

4.2.1. Handlers

The handlers are scripts managing the request-response operations of the server. Their main functions are:

- Find projects: to return a list of the available projects.
- Add user perception: to insert the received perception of the user to the corresponding database collection.
- Filtering: to filter project evaluations considering gender, concept, social stratification, age, profession, colors, and lights; in order to construct an object containing the request that will be made to the database and to return the items. Two functions were developed for processing the returned items from the database: calculating the mode and the average of a list of perceptions, which are an array of integers indicating the evaluation. Such integers go from one, which is the first adjective, to five, which is the second adjective. Therefore, these two functions are applied to every search in the database in order to return the perception from several users. The context related functions perform the next tasks:

A. Light average from user: lights used in a particular user evaluation are stored in a packed 32-bit integer representing the alpha, red, green and blue, which are the Processing color data structure necessary to apply a bit shifting function that returns the color into RGB (Red, Green, Blue) format. Then, a regular average function is applied to each RGB component of the list returning a single data per user. Indeed, it is possible that during the evaluation process the same light affects the concept [17].
B. Estimation of representative lights from the entire project c using Eq. (2): this process takes the average lights w from all the project users L as a parameter and then compares them, between each other, using the Euclidean distance over each RGB data. If the distance is greater than a defined threshold, then it is added to the project lights c:

$$c = \sum_{i=0}^{L} \sum_{j=0}^{C} |w_j w_{i+1}| \rightarrow 1 \tag{2}$$

C. Light in user's evaluation: this function returns a true value if a light is similar (based on Euclidean distance in RGB) to another light. It is useful to define if a user did the evaluation over the influence of a light.
D. User color context: this function returns the most representative colors of a user's context. All the colors identified during the evaluation are stored as an array ([32 in color: amount]). Therefore, the first step is to sort the data by the amount, and then a recursive operation is applied until 10 colors are returned. This operation works with the same principle of Eq. (2).
E. Project color context: this function receives the list of all the colors of the context of the project and returns the five most representative colors using the same principle of the past function.
F. Identification of color in user's evaluation: this function defines if a color is in a list of colors. It is used to define if a color was identified by a user during the evaluation.

4.2.2. Web page

A web page, stored in the database, is used to interact with the data obtained from the user in order to show the results. This web page can be accessed by the designers at any time with a local URL. And it contains the results of the evaluation with the current users at that time.

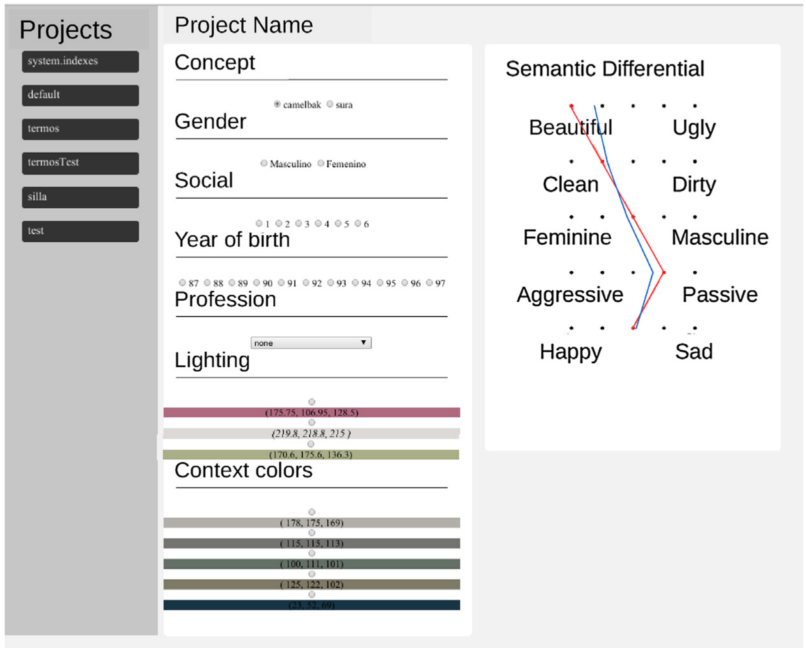


Fig. 7. Web page screen-shot. The web page allows the designer to visualize the information about the target users aesthetics's perception (SD and evaluation data) through different filters.

The web page allows the designer to select a project from a list of the available projects in the server, to use different filters to segment the SD data, and finally, to visualize the Semantic Differential (SVG graphic) that is loaded with the mode and the average of the user's filtered data. A screen-shot of the web page is presented in Fig. 7.

The web-page loads the project's data creating a “GET” request to the server. It also has a listener of the different filters. In this way, when a change is done, the script constructs a URL with different parameters and sends the petition to the server. The URL has the next format:

/find-by/:gender/:concept/:social-strata/:age/:profession/:light/:colors

If a parameter is not selected, it is replaced with “none”. Once the response is successful, the function which graphs the Semantic Differential is called.

As result, the web page allows the designer to visualize the information about the aesthetics’ perception through different filters. For example, the designer can filter how a specific user (age, social stratification, profession) perceives the product according to his/her segmentation characteristics.

Further, the designer can filter the user perception according to the most popular colors used in the evaluation time (of the context and the lighting) and use different search configurations.

4.3. User interaction

The first time the application is started, it opens a user questionnaire, as it is shown in Fig. 5. After the questionnaire is completed, the AR activity starts, displaying a full screen of the AR scene loading the first 3D concept as it is shown in Fig. 8.

Doing a horizontal flick (Swipe horizontally on the screen with a finger) the next concept is displayed. At the left side of the screen the semantic evaluation of the concept is available.

The user scores the concepts tapping the circles (Fig. 8) and, when the concept is totally evaluated, the color of the panel changes. Once all the concepts have been rated, the user can send the score swiping vertically (Swipe from lower part to the top of the screen with a finger).

All the user gestures (flicks) performed on the tablet screen are detected using the library *Ketai* library for *Processing* [1] that work over the Android motion detection services.

5. Case Study

In order to evaluate the user interaction with the proposed CARE, an experiment was carried out with a group of 30 professional engineers and engineering students, in an age range of 17–27 years, 56% males. Two different products were evaluated using both a real product with a questionnaire and the virtual application (Fig. 10).

The test consisted in evaluate two different plastic training water bottles (Fig. 9) in different contexts (surrounding colors and lighting) under controlled conditions. Both products are of a glossy plastic where the predominant color of the product 1 is white and blue for the product 2.

Additionally, two different backgrounds were randomly used during the product evaluation. The backgrounds were simulated using a bent colored paper (black and white) in where the products or the marker in the case of using CARE were placed on.

Three different lighting tones were used for lighting the scene: red, green and natural light. The color lights were achieved by placing a colored cellophane sheet acting as a thing light filter in front of the light source, for natural light, no filter was used. In our case, only one point of fluorescent light was used to light the scene. The light point was fixed on top of the products.

Each user was asked to evaluate first one real bottle with a questionnaire containing the Semantic Differential and, then, the virtual bottle using the application CARE. Therefore, each participant was asked to evaluate a real and a virtual product in different lighting and context conditions.

For the mobile application, a commercial computer tablet that has a screen resolution of 800 × 1280 pixels (∼149 PPI pixel density), a Dual-core 1.0 GHz processor, 1 GB of RAM and weights 581 g was used. And for the server a laptop with an Intel Core i5 of 2.5 GHz processor, and 4 GB of RAM.

It should be noted that although the mobile application could run on any device that has minimum this specifications. The required processing and memory capacity depend directly on the detail of the products (size of the mesh of the 3D models).

Additionally, the screen dimensions play an important role in identifying details of the products and the visual comfort. In our case, a

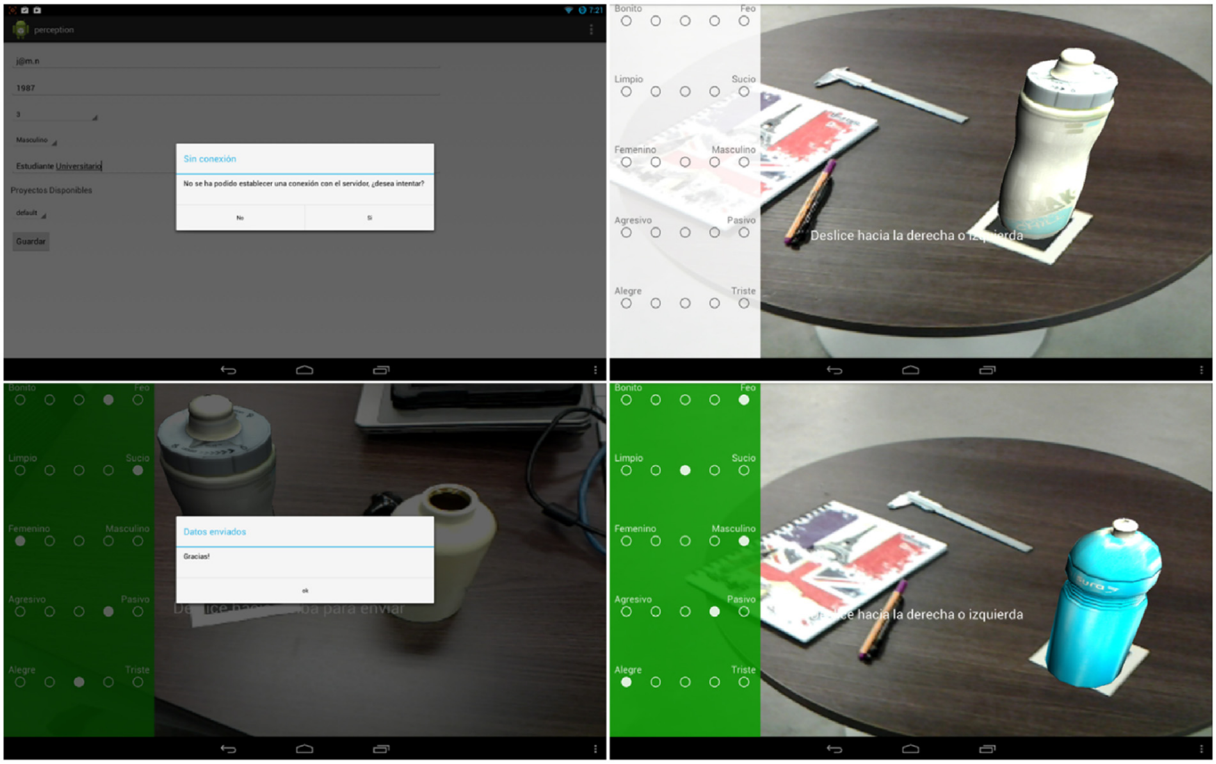


Fig. 8. Application interaction stages (upper left: starting application, upper right: concept evaluation, lower left: finished the evaluation, lower right: adjectives evaluated).

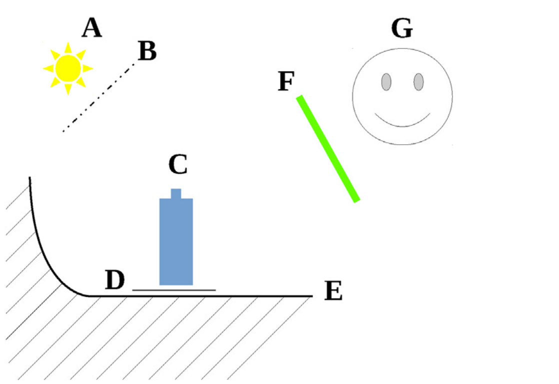


Fig. 10. Experiment layout: (A) fluorescent light. (B) Cellophane color filter. (C) Virtual or real product. (D) AR marker. (E) Bent color paper. (F) Tablet computer. (G) User.

(a) Product 1 (b) Product 2

Fig. 9. Photo of the products used for the test (front view). Two training plastic water bottles were used for evaluate the user perception with a SD. (For interpretation of the references to color in this figure citation, the reader is referred to the web version of this article.)

10 in. screen worked well.

The test was recorded using two cameras: one camera pointing to the user screen when using the application and the other camera pointing to the user's face in order to record his/her facial expressions for further analysis. Additionally, time records of the test were taken and a short questionnaire about the interaction with the application was carried out afterward.

6. Results

Two different aspects were evaluated during the test: user interaction (Section 6.2) and the difference of user perception (Section 6.1) of the products using the application CARE vs. using the real product.

6.1. Perceptions

The analysis of user's perception of the product was focused on the differences of SD evaluation between using the application CARE vs. the one obtained with the real product evaluation. Also, the analysis considered perception variation regards different contexts (surrounding colors) and light colors.

The first analysis was to prove the null hypothesis that both evaluation systems (CARE and Real) could be originated from the same

Table 2
P-values of normality (Shapiro), homoscedasticity (Levene) and Kruskal–Wallis tests of product 1 and 2 for each one of the dimensions of the Semantic Differential.

Dimension	Product 1				Product 2			
	AR (Shapiro)	Real (Shapiro)	Levene	Kruskal	AR (Shapiro)	Real (Shapiro)	Levene	Kruskal
Beautiful–ugly	2.54E−06	1.25E−05	0.872	0.598	6.24E−04	4.50E−04	1	0.353
Clean–dirty	1.24E−04	1.19E−05	0.628	0.893	4.79E−06	1.24E−04	0.553	0.503
Feminine–masculine	2.22E−03	4.04E−03	0.758	0.831	9.90E−03	1.38E−02	0.104	0.884
Aggressive–passive	2.81E−03	2.38E−02	0.382	0.474	4.52E−05	2.92E−04	0.692	0.63
Happy–sad	1.34E−02	8.22E−03	0.625	0.523	7.42E−03	6.77E−03	0.732	0.208

distribution. The evaluation from users for each dimension of the SD of both products and evaluation systems were tested of normality (Shapiro–Wilk) and homoscedasticity (Levene). Results were equal in CARE and the real evaluation in both products, showing a not significative *P*-value in the normality test but significative for the Levene test as Shown in Table 2.

As result, a Kruskal–Wallis test was performed to validate if samples from CARE and Real could come from the same distribution. The test showed for all the dimensions in both product a significative *P*-value meaning that both evaluations CARE and Real in both products seems to originate from same sample distribution.

The distribution of evaluation of the two products for each dimension of the SD is shown in Fig. 11.

In general, in the first product, the variation between the aesthetics evaluation of using CARE vs. the real one is 0.2 in SD points (from 1 to 5) based on the total average difference of the mode (the value that appears more often) between CARE and real evaluation for each adjective. It is expressed in Eq. (3) where n is the number of pairs of adjectives and v_n are the scores performed by all the users in the i adjective using CARE. And r_i is the scores using the real product (Fig. 12a showed by adjective):

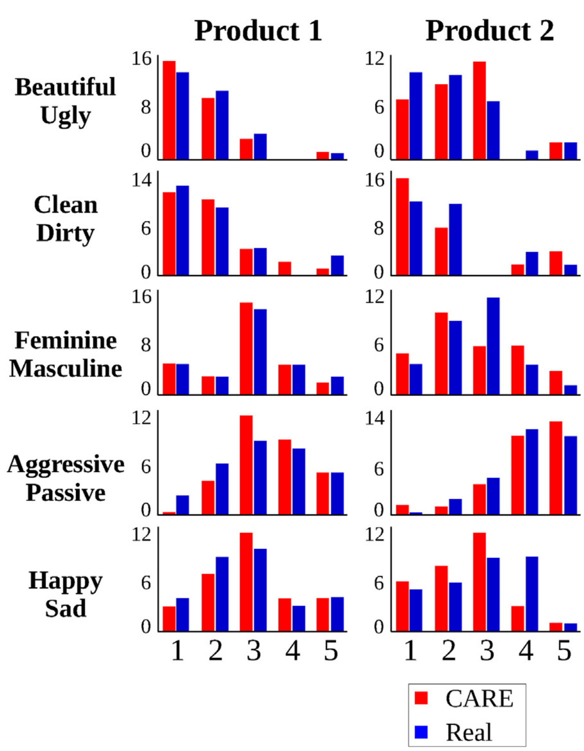


Fig. 11. Distribution of evaluation using real products (blue) vs. CARE (red) for each dimension of the Semantic Differential in product a and b. On vertical axis the number of persons and horizontal axis the position between the two adjectives. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

$$\sum_{i=1}^{n} |\text{mode}(v_i) - \text{mode}(r_i)| \tag{3}$$

Similarly the total average mean variation of 0.19 of SD points (Fig. 12a showed by adjective) is calculated using Eq. (4):

$$\sum_{i=1}^{n} |\text{mean}(v_i) - \text{mean}(r_i)| \tag{4}$$

Regarding the second product, there was a total average mode variation of 0.8 in SD points and total average mean variation of 0.76 in points of SD as it is observed in Fig. 12b.

Furthermore, a similar pattern can be observed in the graph of connecting the SD values in the evaluation of the real product with the same context. Indeed, slightly variations can be observed with the changes of lighting colors in the evaluations in Fig. 12a and b. Likewise, Fig. 13a and b present the total average mean variation in the SD between the real and the virtual product in different lighting conditions but the same context, for product one and product two, respectively. In a general overview, a large variation in the perception, both in the real and the virtual evaluation, can be noticed throughout different lighting and context colors, but, both evaluations have similar patterns.

6.2. Interaction

In order to evaluate the user interaction with the application CARE, different measurements and questions were asked. This also was supported by the analysis of face expressions recorded during the tests.

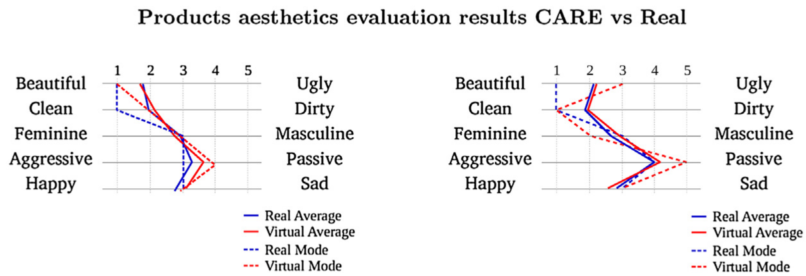
Fig. 14 presents the time used to perform the test using the virtual tool and the real product. The virtual evaluation, including the loading time of eight seconds for the AR module, was 47% slower than the handwritten test with the real product. It is observed that a major dispersion of the used time of the evaluation with the virtual application. The difference of time could be due to the novelty expressed by the users, that it is supposed to decrease with more usage.

At the end of the test, the user was asked about the most remembered thing about the interaction with the virtual application. Answers were classified into the following groups:

- Products (60%): the water bottles and the interaction with them.
- AR (23.3%): the technology, the code, and the 3d modeling.
- Realistic problems (10%): the bottles look different in the application.
- Adjectives (6.6%): choose between the different adjectives.

Additionally, Fig. 15 presents the difficulty of the interaction level expressed by the users. It goes from one, that is not difficult, to three, a difficult task. The general perception was not difficulty (63.3%) vs. a 26.7% of the users considering it a difficult task. Some users expressed to feel some confusion because the application did not display the AR immediately, and it was required to move the tablet forward and back to start the augmentation due to the difficult lighting conditions that cause a low contrast in the fiducial marker.

Another source of confusion was the time that the AR activity took to load and identify the marker (8 s), making the user think that the



(a) Product 1 (b) Product 2

Fig. 12. Summary of CARE (red) vs. real (blue) evaluation of product 1 and 2. In continuous line is presented the average of the evaluation for each adjective and in dashed line the Mode. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

application was not working. Furthermore, the general opinions during the experiment were classified in:

- Positive (63.3%): Good impressions about the application
- Improve (33%):
  - Stability (16.6%): identification of the marker and augmentation.
  - Realistic (16.6%): achieve a more similar looking to the real one.
- Other (3.3%): Did not understand it or dislike it.

In most of the cases, a sense of surprise was expressed when the 3D model appeared and the augmentation was identified in the video. In contrast, the bad perception was explained by the difficulties in the marker recognition, due to the difficult light condition in which the test was carried out and the lack of realism compared to the real object.

7. Conclusions and future work

In this article is presented a crowd-sourcing framework for getting feedback of several user regarding the visual perception of product concepts considering the user lighting and surroundings using Augmented Reality. The major conclusions in this project are:

- A perception pattern is recognizable along the same context with a slightly variation of lights similarly recreated with the SD evaluation obtained from the AR application. This proves that getting a real user perception is necessary to simulate the context interaction with the product.
- Interaction with the CARE application was evaluated in difficult lighting conditions where the marker contrast is lower because of the incidence of the color lighting. Such situation results in user's discomfort (33% of the opinions).
- In general, a good impression (63% of positive comments) of the application was expressed, having a good acceptation overall the users because of the newness of the AR technology. Further work could be in the relationship between user experience with AR, age

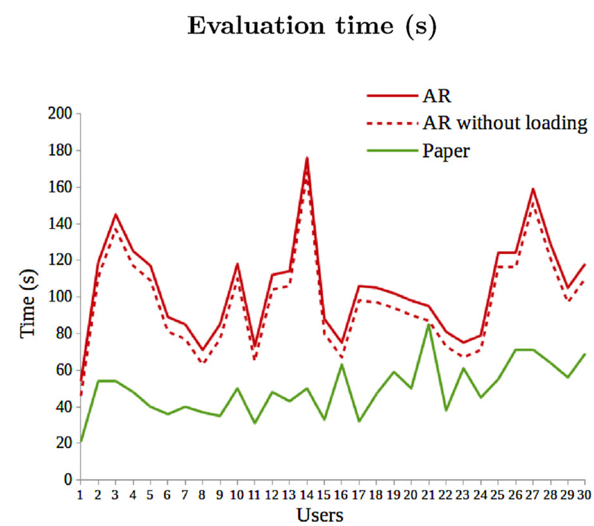
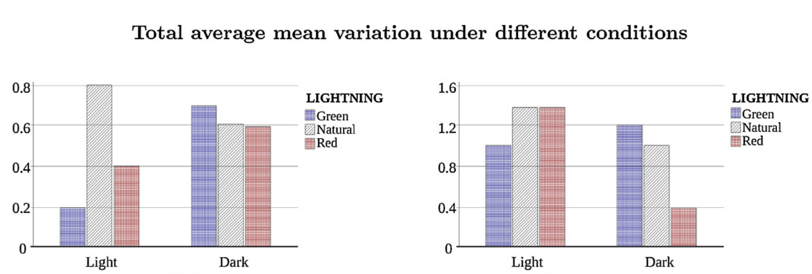


Fig. 14. Measured time of the user in the test. In green the time using a real product and paper. In red using CARE in a tablet computer, in dashed red the time without taking in account the loading of the assets of the application. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

and perceived ease of use.

- Most of the users (60%) expressed that the most remembered event about the use of the application was the product. Therefore, the CARE application could be also used to generate product experiences and to introduce the product to the market.
- The virtual product evaluation using the CARE application was 47% slower than the real one. This could be explained by the difficulty of the users to start the marker recognition since in some cases it was necessary that the user gets farther or closer to the marker. Other factors that could influence the evaluation are regarding the user interfaces or the user novelty that make them interact more with the



(a) Product 1 (b) Product 2

Fig. 13. Total average mean variations of SD evaluation between virtual vs. real product under different lighting and background colors in user experiments.

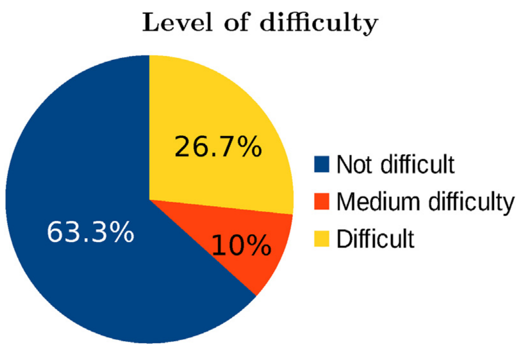


Fig. 15. Level of difficulty of interaction with CARE expressed by the target user after evaluate the concepts.

product. Further research could evaluate different user interfaces.

- The CARE application allows getting a general approximation to the real user product perception with slight variations (0.2–0.8 total average mean of SD points) and a similar pattern under light and context conditions compared to the evaluation with the real product. In this way, the designers are able to get the user's perception in a collaborative way and in early stages of the product design process when there is no interaction with a real product.
- The CARE application would allow getting more data during the product design process in order to analyze in a deeper way the influence of the context, lighting and concept interaction, improving the understanding of the user's perception in different situations.

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