INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'09
24 - 27 AUGUST 2009, STANFORD UNIVERSITY, STANFORD, CA, USA

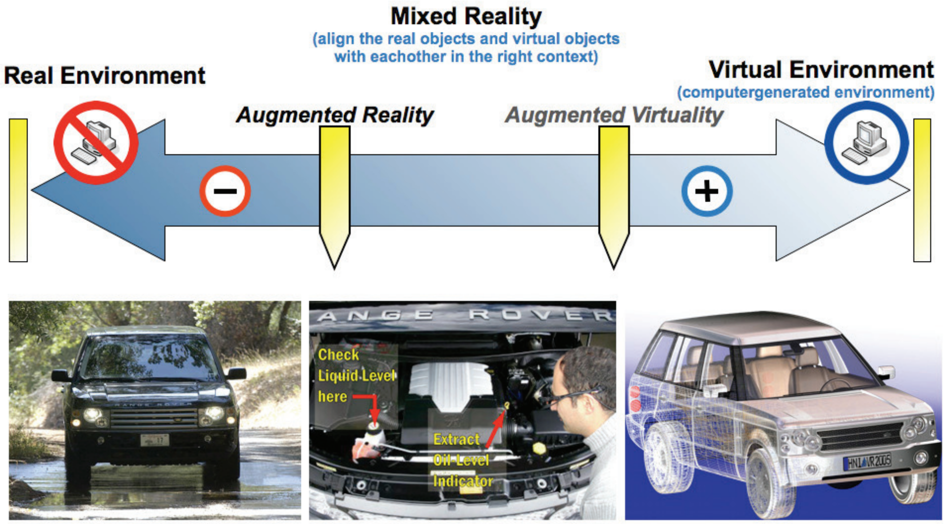
APPLICABILITY OF IMAGE-BASED LIGHTING FOR AN AUGMENTED REALITY-BASED DESIGN REVIEW

Dr.-Ing. Rafael Radkowski[1], Matthias Linnemann[1]
(1) Heinz Nixdorf Institute, University of Paderborn

ABSTRACT
In our paper, we present an Augmented Reality-based (AR) approach for evaluation of the design of virtual cars. For a realistic illumination of those cars, the Image-based Lighting (IBL) method is used. IBL uses images of light sampled from the environment to simulate a realistic illumination. It provides a realistic look of the virtual model and facilitates a seamless integration into the real environment. By this, engineers see a virtual car in a real environment with realistic reflections and shadings. This improves the capability of an AR-based design review. An AR application for design review has been developed and tested by a group of users. The user test should find out, if the illumination and reflections simulated with IBL are appropriate for a design review. The results show that in general AR with IBL is applicable for a design review and allows a realistic evaluation of the car design.

Keywords: Design Review, Vehicle Development, Augmented Reality, Image-based Lighting

1 INTRODUCTION
For the success on the market, appearance and aesthetic of new car models are as important as functionality and engine power. Due to this, the automotive industry spends much afford to evaluate the design, as possible, in the early period of the development.
On method to evaluate the design of a new car model is the so-called design review. At a design review a group of people meet and discus the design and the appearance of the new car model. Normally, engineers, designers and market researchers form a design review group. Common "models" evaluated in design reviews are clay modes, real prototypes, and drafts.
Since several years, Virtual Reality (VR)-based design reviews come on vague [1]. VR facilitates design evaluations in an early stage at the product development process. 3D models of cars can be visualized in a scale of 1:1. Normally, a so-called powerwall is used as output device; a powerwall is a large scaled stereoscopic projection screen. Of course, every known technique of computer graphic can be used to improve the appearance of the virtual car model.
The technology Augmented Reality (AR) facilitates an alternative for design reviews. AR is a human-computer-interface, which superimposes the perception of reality by computer-generated information [2|. The information is shown in the right context and with relation to a real world object. This information can be 3D models, texts or annotations. To see the information, a special viewing device is necessary. A classic viewing device is the head mounted display (HMD), a goggle-like device that uses small displays instead of glasses. The user sees the reality as a video stream inside these displays; the computer-generated information superimposes the video stream.
In order to classify AR, Milgram et al. introduce a mixed reality continuum (Fig. 1) [3]. The "real environment" and the "virtual environment" limit the mixed reality continuum. The real environment is everything that surrounding us, e.g. a real car. The virtual environment is a fully computer generated environment, e.g. a virtual car. Every combination of real and virtual environments is called mixed reality. AR is one case of the mixed reality continuum, where the reality, like the real car, is superimposed by virtual information.
In past, several approaches have been undertaken to use AR for design evaluation. The approaches shown fantastic results but point one challenge: It is difficult to realize a realistic looking virtual car. Two problems are the reflections and illuminations of the virtual car, which differ from those, appear on real parts of the scene or in the environment.



A „real" vehicle — *AR-based motor-maintenance: mixing a video image with text generated in a computer* — *VR-model, e.g. derived from CAD-Data*

Figure 1. Mixed reality continuum according to Miller et al. [3]

In this paper, we present an application for an AR-based design review, which has been extended by a simulation of light and reflections. AR is used to visualize a virtual car model in a real environment. We use the Image-based Lighting (IBL) method to simulate the light and reflections. IBL is the process of illuminating virtual objects with images of light from the real world. Therefore, lighting conditions of the environment are extracted from pictures and used to simulate a realistic illumination. As our approach works in real time, changing light conditions immediately results in different reflections and shadings on the virtual model. IBL facilitates a realistic look of the virtual car model and enables a seamless integration into the real world [4], [5].
Furthermore, we determine the applicability of IBL for the simulation of illumination and reflections for design reviews. Therefore, we perform a user study. In this study, several probands compare the appearance of a real car and a virtual car with the appearance of a virtual car, illuminated by IBL. Our main question, we want to answer is: Is an AR application that simulates light and reflections with IBL appropriate for design review? Moreover, does it add any value to the common techniques and to virtual reality?
The paper is structured as following. First, we describe the state of the art from the relevant field. Next the AR-based design review application is explained. It includes the basic principles of IBL and how it is used by AR applications for the realistic illumination. Furthermore, the AR application is described. The user study, the test and its results are presented in section five. The paper closes with an outlook.

2 STATE OF THE ART

Design review is a common technique to evaluate the appearance of a new car model subjectively, especially in the automotive industry [1]. They are carried out by a group of car developers and designers. Normally, real car prototypes, car models (Figure 2) and drafts are used for the evaluation. Models are often made of clay or foam plastic. The participants discuss direct in front of these models or prototypes. In addition to established models, prototypes and drafts, VR- and AR-based design reviews have been introduced to carry out a design review.

2.1 Virtual Reality-based Design Review

VR facilitates design evaluations in every stage at the product development process. A common used device is the so-called powerwall, a high-scaled projection screen (Figure 3a). A powerwall facilitates stereoscopic pictures in a scale of 1:1. One advantage is, that a large group of engineers can use it. The engineers can evaluate the appearance of shapes and colors as well as the location of control elements and readouts. Moreover, ergonomics issues like the reachability of control elements can be proven. In summary, VR-based design reviews save time and money.

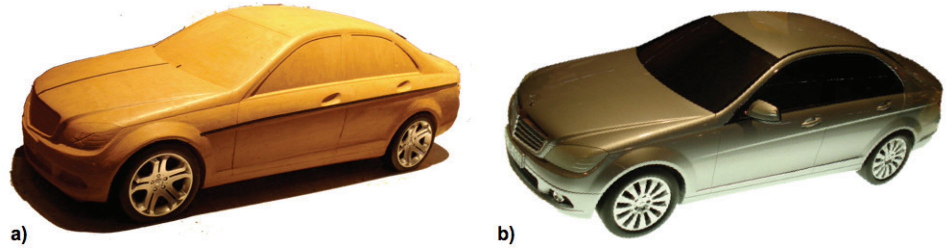


Figure 2. a) Unpainted and b) painted clay model of a car (Ref.: Daimler)

Today, VR is a common technique for design reviews, especially in the automotive industry [1], [6]. For instance, Katzenbach and Haasis introduce in [6] VR tools that are used by Daimler during the product development. Styling and design reviews is one of the task that's accomplishes with VR.
Purschke et al. describe the use of VR at the development process in vehicle styling and design at Volkswagen [7]. Engineers at Volkswagen work in a virtual environment to evaluate CAD models of vehicles and parts of vehicles. At least, this is more efficient than the common way.

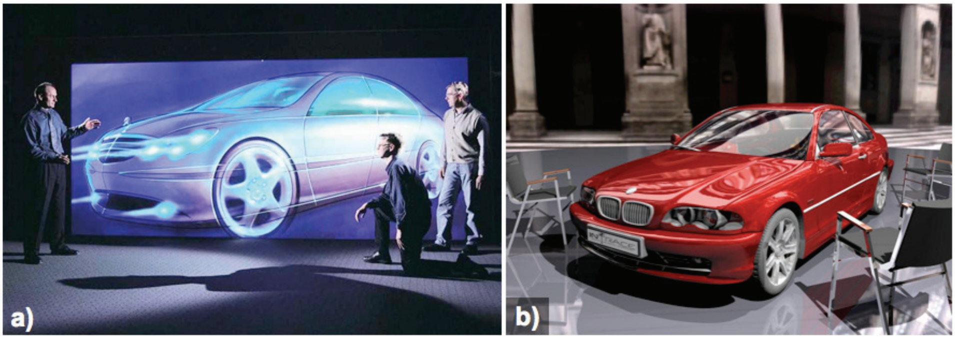


Figure 3. a) VR-based design review (Ref.: Daimler) and b) a car model with shadows and physically correct reflections (Ref.: Slusallek et. al [9]).

Even if VR is still in use, research in this field has been consistent since VR emerges.
Naef et al. [8] introduce a VR system for design review. Their system aimed to provide design review tools for executives, replacing the traditional clay models with virtual prototypes. It provides an immersive visualization to enhance the understanding of form, but also provide basic interaction tools to quickly assess the impact of design changes such as moving or scaling components.
One possibility to simulate realistic illumination in VR applications is ray tracing (Fig. 3b) [9]. Ray tracing is a global illumination based rendering method. It traces rays of light from the eye of a user back into the scene. Then the rays are tested against all objects in the scene to determine if they intersect any objects. If the ray misses all objects, then that pixel is shaded the background color. Ray tracing handles shadows, multiple specular reflections, and texture mapping in a very easy straight-forward manner. A serious disadvantage of ray tracing is performance. The algorithms, necessary to trace the path of light need much computation capacity.

2.2 Augmented Reality-based Design Review

AR for designing and design reviews is more scientific used than as a productive tool at the product development process. But it comes on vogue, how the following works show.
One impressive example is the Fata Morgana system, which was built for BMW [10]. Fata Morgana is a mobile AR system, which allows car designers to evaluate the car design in a scale of 1:1 (Figure

4a). A common problem for the car designers is, to compare a previous developed car with a new designed model. Fata Morgana places a virtual car side-by-side to a real car in a real environment; this way, car developers can compare both cars directly.
Fiorentiono et al. introduces Spacedesign [11], a mixed reality workspace for industrial design. It combines virtual and augmented reality technologies. Designers can materializes ideas in a semi-immersive VR workbench. AR facilitates the review of the designed prototype, when a physical prototype is realized. The both tools are seamless integrated to CAD and downstream applications (FEM, FEA).

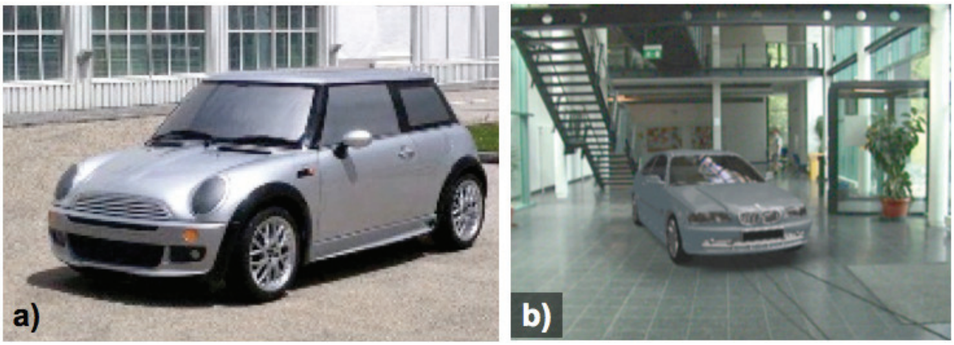


Figure 4. Two virtual cars, visualised in the real environment, a) without realistic illumination [10] and b) with realistic illumination calculated with a ray traycing algorithm [17]

A third AR application in use has been developed in the ARVIKA project [12]. ARVIKA was a leading project for AR in the area of industrial development, production, and service. During that project, AR applications have been developed, which overlay real cars or prototypes with virtual parts, e.g. a virtual light-alloys rim can superimpose a real car. By this, engineers can review the appearance of new parts, like the alloy rims.
These three examples show the possibilities of AR. But for a seamless integration of virtual parts into the real world, and for a realistic appearance, light conditions of the real world must be consider by the AR application. These applications don't do this. However, there has been much research to integrate real light conditions into an AR application.
Kanbara et al. introduce a method for real time light detection [13]. For that purpose, they put a black colored sphere onto a tracking pattern. A camera image of that mirror is sampled and analyzed. The brightness at discreet supporting points is measured, the brightest point is assumed as the point, where is light is coming from. A virtual light source is located at that position and with direction to the model.
Sato et al. estimate the brightness control from shadows [14]. Thereto, they place a know object (color and shape) into the relevant environment. That object casts a shadow. The shadows are detected and analyzed, their color gradient is transferred to virtual objects.
Matsuoka et al. introduce a method for the realistic illumination of virtual objects, which use pictures to simulate the appearance of real objects [15]. The pictures have to be taken prior and from many different directions. During rendering, that picture is mapped to the virtual object, which was taken from the viewing direction of the user. To simulate the current brightness, 13 on a sphere mounted light sensors, sample the light inside the room. A virtual light source is placed at the direction of the highest illuminance.
Suspan et al. have suggested an approach, similar to our approach [16]. They use IBL for realistic illumination of virtual models in AR applications too. A camera samples images from a mirrored sphere inside the scene. The image is used as a sphere map to simulate a realistic appearance. In difference to our approach, they use a different hardware setup and a different method to simulate the illumination of the virtual object.
There also exist some approaches that use ray tracing in AR applications to simulate realistic illumination. One approach is presented in [17]. Figure 4b) shows on of the results. The figure shows a virtual car, visualized in a real environment. As source for the ray traycing algorithm, pictures of the

environment are captured in real time; it is similar to the IBL approach. However, the used a cluster to compute the resulting image and the application is not real time capable and not interactive.
Some other methods for realistic illumination in AR applications are introduced in [18], [19], [20].
Altogether, there are different approaches to use realistic illumination in AR applications. However, until now, it has not been examined, if IBL in an AR application for design reviews add value to the engineering task. Furthermore, it has not been tested, if the results of the simulation are good enough for an evaluation of the design.

3 DESIGN REVIEW WITH REALISTIC ILLUMINATION

Our AR application for design review uses IBL to simulate a realistic illumination and realistic reflections of a virtual car. In our opinion, it has two advantages in different to common VR solutions:

- The design review is performed in a realistic environment. That way, the entire scene (real + virtual) appears more realistic.
- The immediately change of reflections and shadings of the car model surface due to changing environment conditions improve the quality of the virtual model and of the design review results.

In the following, the basics of IBL, the AR application for design review and the hardware setup are presented.

3.1 Image-based Lighting

As Image-based Lighting (IBL) the process is denoted, which uses images of light to illuminate virtual objects. IBL facilitates realistic appear 3D models and a seamless integration of them into the real world. Figure 5 shows an overview about the four necessary steps, according to Debevec [3].

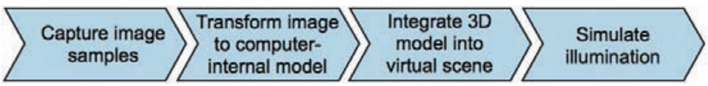


Figure 5. IBL process for the simulation of realistic illumination from sample of images, according to Devevec [3]

In the first step, an image sample of the environment has to be captured with a camera. The image samples are the basic for IBL. The images must fulfill two properties [21]: First, it must shown an omni directional view to the surrounding, second, the numerical values of the colors, defining the image, must be linear to the brightness of the light at the environment. Omni directional images can be taken from a mirrored sphere. To get a linear relation between the numerical values and the brightness, a HDR (High Dynamic Range)-camera is necessary. Furthermore, for AR demands a continuous image stream of the environment is necessary.
In the second step, the image must be transform into a computer-internal model, which represents the real environment. For instance, a sphere map or a cube map can be used. A sphere map represents the environment in a spherical coordinate system, a cube map represent the environment as cube. Every side of a cube shows one spatial direction. We use a cube map to represent the environment.
In the third step, a virtual model like a car must be placed inside the cube map. For a realistic illumination, the virtual model must be located in the center of the cube map.
In the fourth step, the environment model, represented by the cube map, is projected to the virtual model. For that purpose, different approaches exist, which can be found in [21]. In our approach, an adapted Phong illumination model is used, to calculate a certain position, at which a color is read out from the cube map. The color is calculated for every pixel of the car.
The four steps are repeated continuously, until the user stops the application.
Because we are using a Phong illumination model to simulate the behavior of light, the calculation is capable for real time applications. In comparison to a ray tracing approach, only a fraction of the computation capacity is necessary. Moreover, it is easier to use, once integrated into an application, it don’t need much time to prepare the simulation. However, the Phong illumination model is only a rough approximation of the real behavior of illumination. Ray tracing algorithm is much more accurate.

3.2 Augmented Reality Application

For the AR-based design review, an AR application has been developed and IBL has been integrated. Figure 6 shows some results. The figures show, what a user sees by looking through a HMD. The user sees a virtual car with realistic illumination and reflections. The appearance of the entire illumination, shading, and reflections looks realistic. It is possible to move around the virtual car and to evaluate the illumination form every direction. Changing light conditions will immediately affect into different reflections and illuminations of the shape. Furthermore, the virtual shape reflects the environment, like it is reflected in a real car (with a metallic color). The user can move an object along on side of the car and the objected is reflected on the surface of the virtual car.

Figure 6. Different colored virtual cars with realistic illumination

Moreover, the user can evaluate the reflection properties of different chrome-plated parts of the car, for instance the alloy rims or the reflection of the head lights. Figure 7 shows one example. The two figures show the head light of a virtual car model.

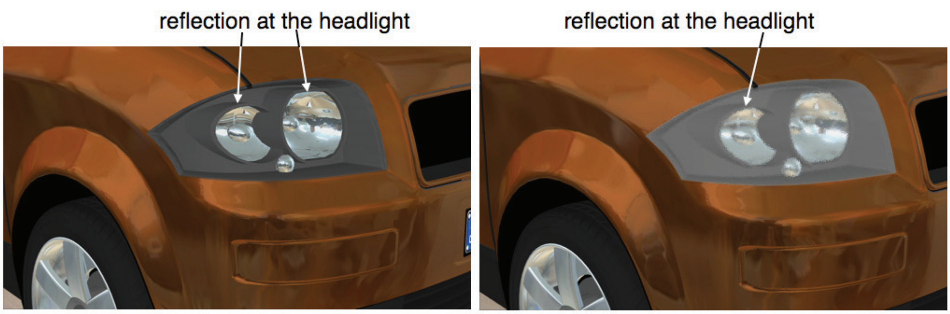


Figure 7. Reflection at the chromed reflector of the headlight

In the left figure, the reflection on the reflector surface can be seen. The glass of the headlight is transparent. Thereby the environment is reflected like in a mirror. In the right figure, a frosted glass is simulated. A frosted glass disperses the light, reflected be the reflector. This effect can be observed, too.

The user can change the color of the virtual car interactively (Figure 8). Therefore, the so-called paddle metaphor is used. An ARToolkit (see [22]) pattern is attached to the end of a paddle; each pattern is related to a certain color. The user recognizes this certain color by a colored sphere, visualized on the pattern. To change the color, the paddle must be moved inside the virtual car. Using the paddle metaphor, up to 15 colors can be offered to the users. To handle more than 15 paddles starts to be stressful during the design review is performed. But for a normal car model in an early design stage, 15 colors are adequate.
In general, a design review group (one user uses a HMD, the others use the wide-screen monitor) can evaluate the different properties of reflection and illumination, which occurs by the shape of the car, and the appearance of different colors.

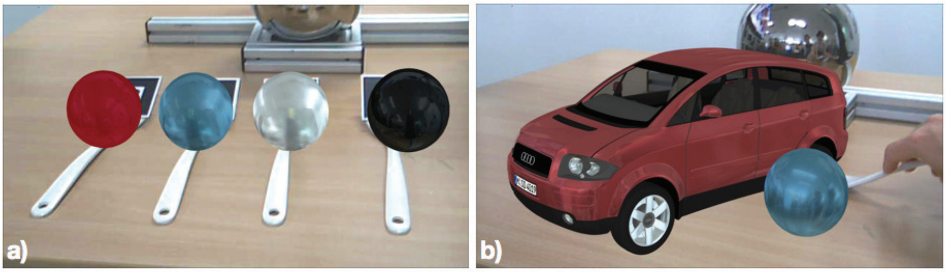


Figure 8. a) AR paddles are used to change the color, b) in order to change the color, the user has to navigate a paddle into the virtual car.

3.3 System Setup
Figure 9a) shows a schematic overview of the system setup. For IBL, images from the light distribution in the environment are necessary. To get these image samples, we use a mirrored sphere. A camera assembled above the sphere samples the images. The sphere has a diameter of 25cm, the camera is mounted 75 cm above the sphere (Figure 9b).

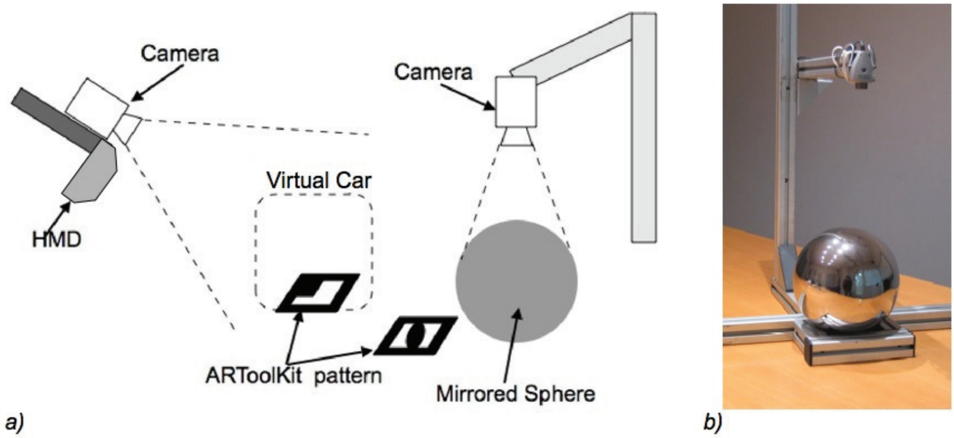


Figure 9. Schematic overview of the hardware setup

To use AR, a special viewing device is necessary. We use a head mounted display (HMD); a Canon VH-2002, with two integrated cameras. If a users looks through the HMD, he sees the environment in a video stream. Virtual objects superimpose that video stream. Inside this HMD, two small video cameras are integrated. They capture images for the AR application.
In addition to the HMD, a 40”-LCD-Display (16:9) is used to facilitate the work in groups. Therefore, one camera is directed to the ARToolkit pattern, the augmented scene is visualized on the LCD-Display.

For a perspective correct view to the scene, the AR application must know, where the users head is located and to which direction he is looking. To get this information, we use the ARToolkit tracking system [22]. It's a pattern based tracking system. If a pattern is in the field of view of a camera, an image-processing algorithm calculates the user's view to the scene.

4 USER STUDY

To evaluate the usefulness of the AR-based design review, we run a user study. Aim of the user study was to evaluate, the two in section three mentioned points. Therefore, 32 users tested the application and have compared a real car with a VR application and the AR application. The users have been students from the department of mechanical engineering, from the department of computer science, as well as design students. To get the results from them, a questionnaire has been used.

4.1 Test Scenario

To test the AR-based design review the probands have compared the reflections and the illumination of a real car with the reflections and illumination of a virtual car. To show the virtual car, two kinds of applications have been used: the AR application and a VR application. Both used IBL, but the VR application provides only a static picture to simulate the environment light conditions.
The test procedural method was as following:

1. First, one test user has been shown images of a real car with real reflections.
2. In the second step, the user should compare the real reflections and illumination with the reflections and illumination on the virtual model, shown in the AR application.
3. In the third step, the user should compare the previous reflections and illumination with the reflection and illumination on a virtual model, shown in the VR application.

These three steps have been repeated three times. Each time, some other objects have been placed inside the environment. First time, a bright light illuminate the car, the second time, a text has been placed next to the car, followed by a building, than a person have been placed inside the scene, and last, a taped pattern (square). Task of the user was to compare the reflections of the different objects.
The bright light results in a characteristic illumination on the surface of the car body. Furthermore a light spot appear on one side of the car. The test persons should compare the position of the light spot.
In the second test, the test persons should read the text in the reflections. In addition, it was mirror-inverted, too.
Next, a building was shown. Aim of the test was to count the windows, visible in the building.
In the fourth test, the proband should identify some characteristic feature of a person, seeing only their reflections. For instance, a characteristic feature is the length of the hairs.
At last, a geometrical object should be identified. It was a box, taped on a sheet of paper. The reflection distorts this box. This test should clarify, if it is possible to identify the object.
The probands could change the color of the virtual car model. They could choice between three colors: red, blue, and silver. To view the virtual scenes of the AR application, they could select an HMD or a 40"-LCD display. They could also change there viewing position, from that they are looking towards the virtual car model. For this test, the virtual car models itself could not be rotated or moved.
A person guided the tests, which guided the focus of the test persons to important properties.

4.2 Questionnaire and Results

To get the results of the tests, a questionnaire was used. The test persons don't see the questionnaire before or during the test runs. The users have to answer 36 questions. An assistant has explained the questions. The questions are listed in table 1. In the first and second column, the number of the question and the question itself are listed (The original questionnaires language is German). Questions 5 to 21 have been asked three times. At each question, the test object has changed. For instance, to answer question 5, the virtual model has been shown to the user. To answer question 13, the real car has been shown to the user.
The third column of table 1 shows the result of the questioning to the virtual prototype. Questions 1,2, and 4 have been answered with a scale from one to five, where one means "very good / very realistic" and five means "bad /unrealistic". At question 3 the probands have to choice their preferred viewing device. They could select between the HMD and the LCD display. The other questions could be answered by calling a number. At these questions, the probands have to count different objects. Therefore, they can answer a right or a wrong number. The percentage indicates, how many probands

answered to those questions correctly. The standard deviation to this answer is shown in the fifth column.
The fourth column shows the results to the questions that have been answered after an evaluation of the real car and its reflections. As in the third column, the percentage shows the number of correctly answered questions. The sixth column shows the standard deviation of the answers.
One important value is shown in the seventh column. The percentage shows the difference between column three and column four. Thereby, the results in column four are assumed as correct, because the have been gathered by an evaluation of real reflections. That's why they are the basic to the calculation of the difference. It is an indicator for the error that has been made by probands, and an indicator for the quality of the reflections.

Table 1: Questions and results of the user study

Nr.	Question	Result AR/VR	Result Real	Standard Deviation AR/VR	Standard Deviation AR/ VR	Difference AR/VR to Real
1	How realistic are the illumination and the reflections reproduced by the AR application?	1,95		0,75		
2	Compare the color of the real car and the virtual car. How realistic the color appears?	3,5		0,88		
4	In comparison to the real image: Do you think the light spot are at the same position?	1,9		0,70		
5,13	How many windows of the building can you count in the reflection (8m)?	4%	56%	2,14	3,39	93%
6, 14	How many windows of the building can you count in the reflection (5m)?	100%	86%	0,0	0,24	16%
7, 15	How many windows of the building can you count in the reflection (1,5m)?	97%	96%	0,968	0,968	1,0%
8, 16	Can you identify the called characteristic feature of the person (8m) ?	15%	0%	0,463	0,0	100%
9, 17	Can you identify the called characteristic feature of the person (5m) ?	59%	50%	0,29	0,5	18%
10, 18	Can you identify the called characteristic feature of the person (1,5m)	100%	93%	0,0	0,242	8%
11, 19	Which shape does the reflection shows in the reflection?	87%	100%	0,33	0,0	13%
12, 20	Are you able to read the entire text in the reflection (all five lines)?	0%	52%	0,0	1,27	100%
		HMD	**LCD**			
3	Do you prefer a HMD or a 40°-LCD display?	11%	89%			

The answers to the evaluation of the virtual car model that has been shown in the AR and the VR application have been analyzed together. This decision emerges during the observations of the test itself and the analysis of the questionnaires. To answer the questions or to evaluate the entire model, the probands chose a perspective, which show the virtual car only. The background / the environment has been cut off. That's why no differentiate analysis is arguable.
The answers to question 1 show that the simulated illumination and reflections meet the real ones. The users recognize the same distribution of light. The shown illumination meets their experiences. It was difficult to recognize errors without anything that allows a direct comparison between real and virtual. However, some of the users mist details, e.g. reflections at the mirrors, reflections at the edges, and highlights like they should occur on the window.
Question 2 shows that the color of the virtual car model doesn't meet the real one. First, we assume that the color influence the reflections and their perception negatively. But the probands told us the color shade doesn't match a real automotive paint. Anyway it appears realistic.
Question 4 shows, that the reflections, shown on the two virtual cars, meet the location of the real reflection. This question has been asked as a kind of control question. It should prove whether the geometry of the simulation of light is correct.
Figure 10 shows the answers to questions 5 to 20. The blue bar shows the results of the evaluation of the virtual prototype; the yellow bar shows the similar evaluation of the real car. In our opinion, if two

similar questions reach the same value, real and virtual reflections and shadings cannot be distinguished. The red box indicates the error between the similar questions. As shown, counting window (6, 14 / 7, 15) and recognize people (9, 17 / 10, 18) from a close and mid distance is possible. It is also possible to identify different geometries (11, 19). In summary, if the distances to the virtual and real vehicles are close, the results are comparable.

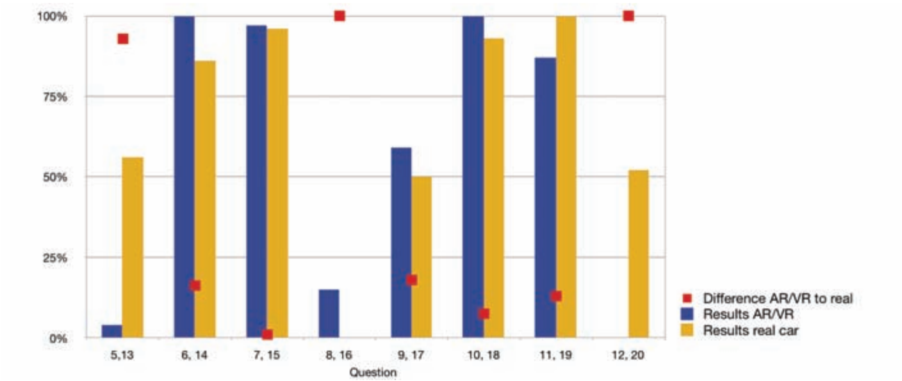


Figure 10. Results of the user study (questions 5 to 20)

Furthermore, most of the test users have used a wide-screen display for the test, because it facilitates an overall view to the virtual car.

4.3 Discussion

We think that the results shows, that an AR-based design review with realistic illumination is a suitable complement for the common VR-based design review and to the common used clay models and drafts. There are two reasons, why we think so.

First, all the probands were the opinion that the illumination of the virtual car and the reflections of the car model look realistic. The shape of the reflections, lights and shadows meet the reflections of the real one. The answers to questions 5 to 20 indicate that the quality of the reflection and illumination is comparable with the real one in a near and mid distance to the car model. The probands are able to identify all the objects on the virtual surface, like they do it on a real surface covered by a reflective metallic paint. Thereby we assume, that the approximation of the physical behavior of light by the Phong illumination model is accurate for this task.

Second, one assumption is that realistic reflections and a realistic shading improve the quality and the perception of a virtual car model. The illumination and the reflections on the surface of the virtual car model are in interaction with the real environment. This effect lets the entire model appear more realistic. The answer to question 1 shows us that the proband have evaluated the appearance of the virtual car as good. It seams to be realistic. In addition, the shown reflections are caused from objects in the environment of the user. The user recognize objects at the surface of the car model, they would be recognize in a real car, too. This behavior of the virtual model meets the experiences of the user. The users know, how a reflection in a car should look. This facilitates an better evaluation of the design.

However, there is one serious problem: The entire virtual model cannot be evaluated in a scale of 1:1. The HMD Display technology as well as the camera technology doesn‘t provide the necessary field of view to see a model in a scale of 1:1. Primarily, in the later development stage it is indispensable to evaluate a car in a scale of 1.1. That’s while the engineers and designers want to see details of the car, something like the distance between cracks and the curve of the body. To use the application in the later development stage, the AR display technology has to be improved. In the early design stages, models made of clay and foam plastic are used. These models are often downscaled; a regular scale is 1:4. A downscaled virtual model can be seen completely with the AR application and an evaluation of this model is possible.

Moreover, the color of the virtual car doesn’t meet the color of the real car. The color should simulate an automotive painting. This objective could not be reached. Because the color is important for a

design review, this limited the possible review tasks. But the Phong illumination model and not the IBL approach cause this problem. Other illumination models should provide better results.
In summary, the user study show, that IBL is a suitable technique to simulate a realistic illumination, a realistic shading, and reflection. Together with the technology AR, it is an appropriate complement to the well-known techniques. On advantage is the dynamic changing of lighting and reflections and the interaction of the shape to the real environment. VR-based design reviews are limited to a static limited world without any interactions to the real world. Furthermore, designers, engineers etc. can move around the model, take a look from different viewing positions and behave, how they would behave in front of real prototype or clay model. Thereby they can stand face to face like in a real design review. Standing face to face has a positive effect to every discussion. This has been shown for AR applications in [23]. Standing in front of a powerwall demands an observation of a screen, which has a negative effect to a discussion.

5 SUMMARY

In this paper, we present an AR-based design review approach. We use IBL to improve the quality of reflections and illuminations, which should in summary improve the appearance of a virtual car model and should make it more realistic. Furthermore IBL facilitate a seamless integration of the virtual car model into the real environment. We have developed an application for that purpose. In our opinion, the seamless integration of the virtual model should improve the quality of evaluation, because the entire scene appears more realistic. Furthermore, the immediate change of reflections should improve the grade of realism, too, because it is an effect, every users knows from a real car: If a user stands in front or next to a real car, he see a mirrored picture of himself (depends of the quality of the cars surface). To test these statements, we run a user study, where the user should compare the AR application with a VR application and a real car. The results show, that an AR-based design review can be used for a design review. The reflections and the illuminations improve the realism of the virtual car model. One problem is the scale of the model. Due to the limited field of view of an HMD and the limited field of view of a camera, model must be scaled down, to see the entire model. A small model doesn't appear realistic. But in general, AR-based design reviews that use IBL-based simulations of illumination are an addition to VR-based design reviews as well as clay models and drafts.

REFERENCES

[1] Gausemeier, J.; Ebbesmeyer, P.; Kallmeyer, F.: Produktinnovation - Strategiesches Planen und Entwickeln der Produkte von morgen. Carl Hanser Verlag, München, 2001

[2] Azuma, R.: A survey of augmented reality. In Teleoperators and Virtual Environments 6, 1997

[3] Milgram, P.,Takemura, H.: Augmented Reality: A class of displys on the reality-virtuality continuum, SPIE: Telemanipulator and Telepresence Technologies, Boston, MA, 1994

[4] Debevec, P.: Image-based Lighting. IEEE Computer Graphics and Applications, März/April 2002

[5] Debevec P.: Estimating surface reflectance properties of a complex scene under captured natural illumination. Technical Report ICT-TR-06.2004, University of Southern California Institute for Creative Technologies Graphics Laboratory, June 2004

[6] Katzenbach, A.; Haasis, S.: Virtual and Mixed Reality in a SOA Based Engineering Environment. In: Design Synthesis, CIRP Design Conference, April, 7-9, 2008, Enschede (NL), 2008

[7] Purschke, F.; Schulze, M.; Zimmermann, P.: Virtual reality-new methods for improving and accelerating the development process in vehicle styling and design. Computer Graphics International, 1998

[8] Naef, M; Payne, J: AutoEval mkII - Interaction Design for a VR Design Review System. In: IEEE Symposium on 3D User Interfaces, March 10-11, 2007, Charlotte, North Carolina, USA, 2007

[9] Ingo Wald, Timothy J. Purcell, Jörg Schmittler, Carsten Benthin and Philipp Slusallek: Realtime Ray Tracing and its use for Interactive Global Illumination, Eurographics State of the Art Reports, 2003

[10] Klinker, G, Dutoit, A, Bauer, M, Bayer, J, Novak, V: Fata Morgana - A Presentation System for Product Design. In: Proceedings of the International Symposium on Mixed and Augmented Reality (ISMAR 2002), 2002
[11] Fiorentino, M, de Amicis, R, Monno, G, Stork, A: Spacedesign: A Mixed Reality Workspace for Aesthetic Industrial Design. In: Proceedings of the International Symposium on Mixed and Augmented Reality (ISMAR'02), 2002
[12] Wolfgang Friedrich: ARVIKA-Augmented Reality for Development, Production and Service. In: Proceedings of the International Status Conference HCI, 2001
[13] Kanbara, M.; Yokoya, N.: Real-time estimation of light source environment for photorealistic augmented reality. Proceedings of the Pattern Recognition, 17th Int. Conference on (ICPR'04), 2:911 – 914, 2004
[14] Sato, I., Sato, Y., and Ikeuchi, K.: Illumination distribution from shadows. In Proceedings: CVPR99, 1999
[15] Matsuoka, H; Onozawa, A.; Hosoya, E.: Environment mapping for objects in the real world: a trial using artoolkit. Augmented Reality Toolkit, 1th IEEE Int. Workshop, Darmstadt, Germany, Aug 2002
[16] Supan, P.; Stuppacher, I.: Interactive image based lighting in augmented reality. Central European Seminar on Proc. of Computer Graphics for students, page 8, March 2006
[17] Pomi, A.; Marmitt, G.; Wald, I.; Slusallek, P.: Streaming Video Textures for Mixed Reality Applications in Interactive Ray Tracing Environments. in Ertl, Girod, Greiner, Niemann, Seidel, Steinbach, Westermann (Eds.): Vision, Modeling and Visualization (VMV) 2003, Munich, Germany, November 19-21, 2003
[18] Agusanto, K; Li, Li; Chuangui, Z.; Sing, N. W.: Photorealistic rendering for augmented reality using environment illumination. In: Proceedings of the Second IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR '03)
[19] Madsen, Claus B.; Jensen, Tommy; Andersen, Mikkel S.: Real-Time Image-Based Lighting for Outdoor Augmented Reality under Dynamically Changing Illumination Conditions. In: Proceedings: International Conference on Graphics Theory and Applications, Setubal, Portugal, s. 364-371, 2006.
[20] Korn, Matthias; Stange, Maik; von Arb, Andreas, Blum, et al.: Interactive Augmentation of Live Images using a HDR Stereo Camera. Journal of Virtual Reality and Broadcasting. Vol. 12 (4) , 2008
[21] Reinhard, E.; Ward, G.; Pattanaik, S.; Debevec, P.: High Dynamik Range Imaging – Acquisition, Display, and Image-based Lighting. Morgan Kaufmann Publisher, 2006
[22] Kato, H.; Billinghurst, M.: Marker Tracking and HMD Calibration for a Video-based Augmented Reality Conferencing System. In Proceedings of the 2nd International Workshop on Augmented Reality, 1999
[23] Schmalstieg, D.; Fuhrmann, A.; Szalavari, Z.; Gervautz, M.: Studierstube - An Environment for Collaboration in Augmented Reality. (CVE'96), 19-20th Sep. 1996, Nottingham, UK, 1996

Contact: Dr.-Ing. Rafael Radkowski
Heinz Nixdorf Institute, University of Paderborn
Product Engineering
Fürstenallee 11
33102 Paderborn, Germany
Phone: +49 5251 606228
Fax: +49 5251 606267
E-Mail: Rafael.Radkowski@hni.uni-paderborn.de
URL: http://web.me.com/rafael.radkowski