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Novel Augmented Reality system for Contract Design Sector

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ABSTRACT

This paper presents a novel transportable and cost-effective Augmented Reality system developed to support interior design activities in the contract design sector. The main functioning principles and technical information about its implementation are provided to show how this system allows overcoming some of the issues related to the use of the Augmented Reality in interior design activities. The effectiveness of this system is verified through two different testing sessions based on a case study, which relates to the contract design sector. The testing sessions involved many interior designers with the intent of demonstrating the possibility of integrating this Augmented Reality system in the "everyday" interior design practice in the specific context of the contract design.

Keywords: augmented reality, interior design, virtual prototyping.

1. INTRODUCTION

Up to date, designers (including product designers, interior designers, etc) use commercial tools to represent, develop and evaluate design solutions. In particular, during the evaluation phase, they need specific tools to present their design solutions to the company or to the final users. Traditional tools are mainly used to produce bi-dimensional representations, such as technical drawings and photorealistic renderings. However, in order to show the actual characteristics of a designed solution, it is necessary, very often, to introduce the usage of real prototypes. Since making real prototypes is an expensive and time-consuming activity, and bi-dimensional representations are not very descriptive, other tools based on Virtual Reality (VR) and, more recently, on Augmented Reality (AR) technologies have been developed to support the evaluation phase [19].

One of the major benefits of using VR and AR tools is the higher users' involvement during the evaluation activities in comparison to the traditional bi-dimensional representations. Besides, if these evaluation tools are compared with the development of real prototypes, we can state that they allow saving design development costs and time, and that they give the possibility of performing a better product evaluation during the whole design process. AR, in particular, allows the user to see these digital prototypes in the real world [3] by maintaining temporal and spatial coherency between digital and real elements. Consequently, the evaluation activities become even more effective, since the designer is able to see the design solutions directly in the real environment.

The research activities presented in this paper aimed at developing a designer-oriented, transportable and cost-effective AR system and demonstrating, through a case study and tests with users, its effectiveness as support for the current interior design practice. This paper presents the technological features of the AR system (architecture, main components, etc.), a real case study in the field of interior design and a testing session with junior interior designers. In particular, the research focuses on the *Contract Design* sector, in which interior designers are in charge of designing interior spaces considered as "standard", repeatable many times (such as, in case of hotel rooms) in different places (as for instance, in case of stores) and to be used and enjoyed by many final users.

2. BACKGROUND

2.1. The Contract Design Context

Within the interior design field, which concerns the design of interior spaces (such as, houses, offices, and so on) [9] and the design of furniture for these spaces,

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exists a specific branch named *Contract Design*. This branch concerns the design of complex structures, in which several interior spaces, usually placed in the same building, have to be specified and designed by using a modular approach. The *Contract Design* sector deals with many different areas, such as hospitality, residential, offices, retails, healthcare, education, art and culture, and so on. The commercial importance of this sector is demonstrated by several market analyses [5,6]. For example, it has represented, in Italy, for the year 2011, more than 38% of the total turnover of the companies that produce furniture [1].

In this design sector, the activities of interior designers need to be organised with a different approach in comparison to those that are traditionally carried out. In fact, in the *Contract Design*, interior designers face with more complex projects and high-level budgets, and are in charge of developing design solutions that integrate different kinds of spaces, such as common spaces (as for instance, the hall of a hotel) and private modular spaces (for example, the hotel rooms) and the needs of different users (e.g., professionals who work in the hotel and visitors) in a common view. Focusing on the *Contract Design* for hospitality or residential, the design process typically starts with a direct request by the buyer to a design studio or, alternatively, by a call for participation open to several design studios, in which many competitors are invited to present one or more design solutions.

In this sector the evaluation phase of the developed design solutions assumes a fundamental importance, because the choices that are taken at this moment will influence the design of many rooms, or serviced apartments, etc. For this reason, the prototypes of the design solutions to use in the evaluation phase have to be realistic, and tools as sketches, technical drawings and bi-dimensional renderings are usually considered as too poor for this purpose. Then, in the *Contract Design* for hospitality and residential, the prototypes of the design solutions are usually real rooms with real furniture. However, the above-described activities are often carried out in parallel to the design and the construction (or renovations) of the building, so as to optimise times and costs, and proceed to the purchasing of the selected furniture as soon as possible. Consequently, the prototyping and evaluation activities present some problems:

- the expensiveness of the setting up of the prototypes, above all in the first stage of the project, in which many and different design solutions have to be presented;
- the need to use a large space, in which setting up the real prototypes of many hotel rooms/serviced apartments (walls, doors, windows, furniture etc.) in order to carry out, at the same time, the evaluation of the developed design solutions;
- the need to manufacture the prototypes of special pieces of furniture designed and developed ad hoc for the specific project.

As a consequence, the *Contract Design* sector strongly needs to introduce new modalities for developing and presenting the design solutions in order to reduce costs and time needed for carrying out the development of the prototypes. In this direction, the AR tools could play an important role, as already demonstrated in other branches of the interior design, and described in the following.

2.2. Augmented Reality for Interior Design

One of the first attempts to use AR techniques for interior design is described in [11], where the authors use AR techniques to move virtual furniture onto a table-top. In this application, the furniture is scaled and there is no merging with the surrounding real environment. In [7] the previous approach has been further developed to intuitively arrange virtual furniture by using a combination of speech and gestures. This application highlights the importance of developing specific interaction techniques to support the interior design activities. In [17] the user can superimpose virtual furniture on some still pictures by means of an interactive Graphical User Interface (GUI). Nevertheless, since the pictures of the environment have been previously taken, the user is not able to interactively move around, but he can only switch from different static points of view. Then, the capacity of the users to evaluate an interior layout is limited by the number of pictures shown. In [22] the use of spherical mirrors allows estimating the position of the light in the real environment, and this information can be used to apply a more realistic illumination to the virtual object. Unfortunately, even if this solution is effective for AR visualization, it does not allow the user to remotely manage the furniture position, which is an important feature to conduct interior design activities. A recent solution is described in [12], where the user can displace virtual objects on the floor by means of a mobile device. However, the user cannot freely move in the room due to the limits of the tracking system developed for the mobile device.

Most of the above-described applications use fiducial markers [10] as main tracking technique, since it is a low-cost tracking technique that allows a quite precise and accurate tracking [2]. However, to correctly visualize a virtual interior layout in a real room, it is necessary to use a system able to track the whole working area. High accuracies in in-door environments are usually achieved by using magnetic, ultrasonic and optical systems, but these typically require the installations of several and expensive devices. Therefore, the use of the marker-based tracking technique seems to be the most suitable solution to

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provide interior designers with a low-cost and easy-to-use AR system. Unfortunately, this tracking approach has still several limitations in wide environments. Practically, the markers have to be always visible during the execution of the AR application. Although there are some techniques allowing the extension of the workspace of the marker-based tracking, by introducing the use of multiple markers [4], this increases the time needed for the setup of the system.

This research aims at overcoming these technical issues, by proposing an AR system for interior design based on an innovative tracking technique. This technique integrates marker-based tracking with the tracking ability of a commercial mobile robot. The robot can be seen as a mobile point of reference, which is automatically controlled by means of the device used to visualize the AR scene. A fiducial marker has been set on the robot that co-works with the user to maintain the marker always traceable. Then, starting from an absolute reference point, the tracking system constantly elaborates the relative position between the robot and the user. The AR system also provides the user with an interactive GUI, which allows the user to easily manage interior layouts directly in the real scene.

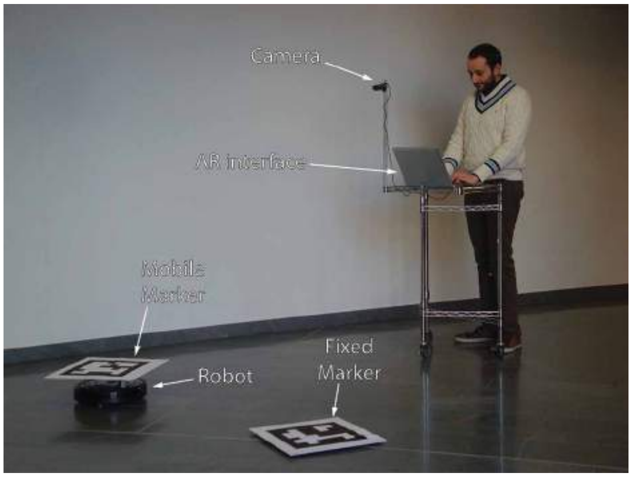

Fig. 1: The main components of the AR system for supporting interior design activities.

3. SYSTEM DESCRIPTION

The AR system used in this work has been developed to support designers during interior design activities. Hence, some technological issues have been addressed so as to obtain a usable and effective support. These issues were mainly related to the functioning of the AR system in a wide space and its easiness to use for interior designers. A new tracking approach has been developed to overcome the spatial limitations of the above-presented AR techniques. In addition, the system has been designed to provide a simple initialization phase and an interactive GUI that allows an easily visualization and managing of the virtual objects. The AR system grounds on a versatile and cost-effective architecture. The system has been developed by using not encumbrance devices, which are available on the mass market. Consequently, the AR system is quite inexpensive and can be easily transported.

The AR system mainly consists of two parts: the AR Interface and a mobile robot (Fig. 1). The AR Interface provides all the interactive AR tools to support the interior design activities. It consists of a laptop and an external USB camera settled on a trolley. Then, it can be easily moved within the augmented environment, thus reducing the workload of the user. The use of a single camera allows obtaining a satisfactory tracking for interior design purposes, without the need to use more complex tracking systems based on multi markers or multi cameras.

The mobile robot, instead, has a marker used for tracking on its top and manages the position of this one, with the purpose to extend the working area. The system uses a tracking approach that is able to estimate the pose of the AR Interface camera in the environment by merging the data coming from the mobile robot and the ones coming from the marker-based tracking.

The mobile robot used for this work is an iRobot Roomba 560 [8], which is a commercial mobile robot. The choice of this mobile robot was mainly due to its robustness, its availability on the market and the remote-control easiness. The communication between the robot and the laptop has been obtained by using two XBee [21] devices that allow a wirelessly bidirectional transmission of the data coming from the serial port mounted on the top of the robot to the USB port of the laptop and vice versa. Thus, the robot position can be remotely controlled by the user in a manual or in automatic way. In the first case, the robot position is managed by means of a dedicated GUI of the AR Interface. In the second case, the system automatically controls the position of the mobile robot in order to allow the marker placed on its top to be always framed by the camera.

The tracking system used to perform AR in wide spaces relies on a particular approach that can combine two different kinds of data to estimate the camera pose. These two data are the camera pose estimation performed by means of ARToolkit Plus [18] with two square planar markers of 320 mm size and the position of the robot obtained by its own odometric system. One of the two markers used for the tracking is placed on the top of the robot (i.e., mobile marker). In this way, every time the user moves the AR Interface to frame another part of the scene, the marker results to be always visible to the camera. The other marker, instead, is fixedly placed on the floor of the room (i.e., fixed marker) and defines the position of the absolute reference system. Both the data related to the position and the orientation of the

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whole AR environment are based on the fixed marker. The combination of the data is performed only when the mobile marker is visible to the camera. Every time the fixed marker is framed, the AR system performs tracking by only using this marker. In this case, it works by using a standard marker-based approach and it estimates the pose relative to the fixed marker. On the other hand, if only the mobile marker is visible, the system exploits also the odometric data that the robot continuously sends to convey its position. The AR system is able to estimate the camera pose according to the fixed marker even in this condition. In fact, it is possible to describe the pose by a transformation matrix M_{fixed}^{camera} that can be obtained by a linear combination

$$M_{fixed}^{camera} = M^{robot} \cdot M_{mobile}^{camera}, \tag{1}$$

where M^{robot} describes the robot position relative to the fixed marker while M_{mobile}^{camera} describes the camera pose according to the mobile marker.

In order to perform the tracking, calculating the offset between the initial position of the robot and the fixed marker is needed. Once both markers are framed, the offset is calculated by using the tracking data of the two markers. This task takes less than a minute.

The metrological quality of this tracking approach has been evaluated by means of a comparative test in a wide environment, as deeply described in [15]. The obtained results demonstrate that the precision and the accuracy are acceptable for the purpose of this AR system. The test focused on the X and Y position of the camera and its rotation around the Z axis. The other three degrees of freedom are constant since the camera is fixed on the trolley. The results regarding the performances evaluated in the test are shown in Tab. 1.

	Error	Std. Deviation
X [mm]	5.535	7.281
Y [mm]	5.845	7.986
Rot. [deg]	3.419	2.892

Tab. 1: Average and standard deviation error of the camera position and orientation.

Some further corrections have been carried out to improve the tracking quality of the system: in particular, these regard the data coming from the robot and the stability of the visualization. The odometric measurement is normally prone to an error that increases during the use and it affects the data of M^{robot}. Consequently, this error has an impact on the camera pose, which becomes noticeable by the user after a prolonged usage of the mobile robot. In order to correct this error, every time the two markers are framed together, the AR system uses the tracking data of the two markers to automatically rectify the M^{robot} matrix. Another correction relates to the jittery visualization during some movements of the robot or the camera. This issue is also due to noise in the captured image, in particular when the markers are far from the camera (camera resolution problem). For this reason, a Kalman filter [20] has been integrated in order to smooth the tracking data.

The interactive GUI has been designed to support interior design activities, in particular showing the AR environment to the user, allowing him to interact with the virtual models and managing the robot position for tracking purposes. A GUI made up of 4 windows, has been designed to manage these functions; three of them are shown in Fig. 2.

The main window of the GUI allows the user to see the augmented environment through a live video with a resolution of 800x600 pixels and a refresh rate of 30 Hz (Fig. 2a). The visualization exploits the above-described tracking approach in order to have spatial and temporal coherence between the real environment and the virtual objects. By means of the buttons on the right side of the window of the GUI, it is possible to activate other sub-windows.

The GUI has been developed by means of an event-based programming approach and written by using Microsoft .NET framework support. The main thread of the application incorporates the principal loop that manages the robot, the tracking, the AR interaction and the visualization in a sequence that is repeated with a frequency of 30 Hz. All the commands selected by the designer and the asynchronous data coming from the robot are managed in separated secondary threads. Event calls are used to update in real time all the variables and objects of the AR application.

The designer can autonomously manage virtual objects in the real room by means of the dedicated window of the GUI in Fig. 2b. This window shows all the available virtual pieces of furniture, which are stored in a database, by means of a small image preview of 320x240 pixels. Then, the interior designer can switch trough these models and place the selected one in the augmented environment. The virtual object is automatically placed in the scene and visualised in front of the camera point of view, to a distance of 1.80 meters. Afterwards, the designer can move the object to a precise location by means of some buttons. The buttons are six, two for each axis, and they allow the designer to modify the position and the orientation of the virtual pieces of furniture according to a step-by-step value. This value can vary according to the designer needs: in case of position from 1 mm to 1000 mm and in case of orientation from 1° to 10°. In this way, the designer can control the position of the virtual object both for fine and large displacements in a very precise manner.

The typologies of the virtual objects with which the system provides the designer are not limited

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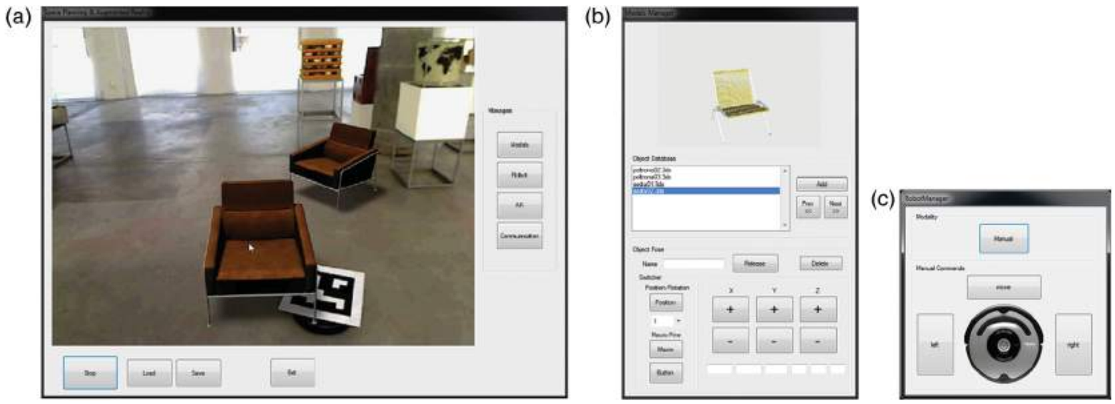

Fig. 2: Windows of the GUI. The main window for AR visualization (a) the interaction panel for managing the virtual object (b) and the robot manager panel.

to pieces of furniture. In fact, the system allows the designer to work also with two other different functionalities. The first one regards the plans of the rooms, in order to provide a further reference for locating the virtual objects in their specific position. These plans are previously prepared by the designer and, once loaded, they are visualised on the floor of the real room. The second functionality regards the virtual light configuration. A correct illumination enhances the coherency between the real and the digital worlds and the level of immersiveness of the augmented environment. In this way, the designer perception of the room is improved and the GUI helps evaluating the aesthetic impact of the furniture in depth. The lights settings are externally designed according the different real illumination of the room and can be loaded within the AR scene to assess the visual impact on the furniture.

Finally, the interior designer can save the solutions in a file during or at the end of the design process. In this way, he can store different configurations and quickly switch from one to another, in order to show the results to customers or keep on working on a previous space plan.

4. CASE STUDY AND TESTING SESSION

This section describes the experimental use of the above-described AR system in a real case study and a subsequent testing session. Target users of the AR system are interior designers, who can use the AR system in their daily design practice. Specifically, the goal of the use of the AR system is to reduce the times and costs associated with the evaluation phase: interior designers can evaluate with the buyer several design solutions, which can be modified in real time at no additional cost.

The case study has concerned the design process for developing a Serviced Apartment (SA) to be used as a "standard model" in the context of a project for the *Contract Design* sector. In order to carry out an experimental case study as closer as possible to the real design practice, it has been defined following the course of a traditionally design process. The results of the case study have been used to verify the actual integration of the proposed AR system in the common interior design practice.

The following testing session has concerned the use of the AR system for arranging pieces of furniture starting from the design solution already defined in the case study. The testing session involved more users and the results have been used to evaluate the overall usability of the system and, in particular, the easiness and the time of the learning activity necessary to properly use the system. Both the case study and the testing session have been used to assess the level of satisfaction of the target users (interior designers unskilled in the use of the AR technology) about the AR system compared with the tools traditionally used for presenting the design solutions to the buyers (photorealistic renderings, technical drawings, etc.).

4.1. Case Study

The case study starts analysing the buyer's request concerning the design of a standard SA to build in a city-centre edifice. The interior designers have the task of defining the dimensions and the layout of the SA, and of choosing the pieces of furniture from catalogues of furniture suppliers. Starting from the buyer's requests and inputs, a design team constituted by two senior interior designers has carried out the following activities:

1. defining the target users of the SA and their possible needs;
2. defining the spatial layout of a single SA;
3. identifying the furniture with which to equip the SA;
4. developing 3D models, by using commercial 3D software, of the SA and of the furniture (if not available from their brand);

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5. processing the 3D models in a file format compatible with the AR application;
6. using the AR system for developing several design solutions, arranging the selected furniture in different layouts or using different materials and colours, and their storage.

The last activity was carried out with the support of one of the AR system developers, who only has contributed to the initial setup and to the training phase. During the case study, quantitative data about the design activities related to the use of the AR system (e.g., the time for the processing of the 3D models of the furniture) have been collected.

Regarding the first activity, the target users have been defined as those people, commonly named as Business Stay Traveller, who must spend a long period of time (at least 6 months, maximum 2 years) far away from their home, on business. The SA to design and equip should be made at minimum of a living room, a kitchen, a bedroom and a bathroom. With this layout, the SA will allow the users to take care of their selves (relaxing, watching TV, by using a wellness area), to prepare and eat their meals at home, to take care of their clothes, to have a space where work and so on.

Starting from these needs, the total dimension of the standard SA has been defined equal to 45 mq (26 mq dedicated to the living room and the kitchen, 9 mq dedicated to the bathroom and other 10 mq dedicated to the bedroom). Then, the style of the SA has been defined as "modern", and consequently furniture to equip the rooms has been selected from the online catalogues of diverse furniture companies. Furthermore, from these catalogues the main dimensions of the selected furniture have been taken and then used to develop the 3D models. Only in few cases, where possible, the 3D models of the furniture have been downloaded and directly integrated into the 3D model of the whole SA. Fig. 3 shows the SA and some renderings of the bathroom, the kitchen and the living room.

Finally, several material textures and colours have been applied to the 3D models of the SA elements (walls, doors, windows) and to the furniture. These have been selected according to the modern design style and the preferences of the interior designer team.

Until this moment, the activities of the interior design team have been carried out similarly to those of a traditional design process, which usually continues with the development of bi-dimensional renderings, technical drawings and, eventually, real prototypes.

On the contrary, in this case study the subsequent activity has been dedicated to the processing of the 3D models of both the apartment and the furniture to make them fully compatible with the AR system. The time dedicated to the processing of the 3D models has been measured considering:

- the time for experimenting and learning about the most appropriate file formats,
- the verification of the accuracy of the size of the 3D models in the different file formats (this type of test was carried out only with the 3D models of piece of furniture - a chair -, and consequently the others 3D models where considered as correct),
- the processing of each specific 3D model (walls, ceiling, doors, windows, kitchen furniture, living room furniture, bathroom furniture, bedroom furniture, accessories).

The total time dedicated to the processing of the 3D models, carried out by the interior designers who performed it for the first time, has been 16 hours.

Finally, the 3D models have been used to develop the augmented environment. Firstly, the bi-dimensional map of the SA has been loaded in the augmented environment: it has been represented on the floor and its position was relative to the fixed marker. Secondly, the main elements of the SA (walls, ceiling, doors and windows) have been loaded and placed according to the map on the floor. Then, each piece of furniture of the rooms has been loaded and correctly placed by using the map, the apartment elements and the other pieces of furniture as reference. For example, in the kitchen a first piece of furniture (the refrigerator) has been placed using the map and the walls as references; consequently, the refrigerator has become a new reference for correctly placing the other pieces of furniture in the kitchen environment. At the end, the whole augmented environment has been stored as first design solution. Subsequently, other two design solutions (with different material

Fig. 3: Floor plan elaborated for the SA and some renderings of the bathroom and the living room.

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textures and colors) have been developed. In this case, interior designers loaded the first solution, deleted selected pieces of furniture, and integrated the new ones with different material textures and colors. The time dedicated to the development of the first design solution was 2 hours, while the time necessary for the development of the other two alternative design solutions was 1 hour in total.

4.2. Testing Session

Starting from the models elaborated in the case study a subsequent testing session has been conducted. It has involved a higher number of interior designers, who were not involved in the case study and who were not skilled in the use of AR technology. The testing session has been carried out by asking to the interior designers to re-arrange in real time some furniture of the already-developed design solutions. This testing session aimed at comparing the remarks and the satisfaction levels of "expert" (interior designers who participated in the case study) and "naïve" users of the AR system.

This testing session has been carried out by involving 20 people, who are students of the Master Degree in Interior Design at the School of Design of Politecnico di Milano. The testing session was organized in the following way:

1. a brief introduction concerning AR techniques in general has been provided and the specific AR system has been presented to the participants;
2. the participants have been asked to fill in a short questionnaire concerning participants' background, possible previous experiences with VR and AR techniques;
3. a free period of time in which each participant, singularly, can experiment the AR system in order to become familiar with its main functionalities. This period, whose maximum duration was 10 minutes, has been timed to add an objective data to the subjective evaluations collected from the testers concerning the intuitiveness of the AR system.

At the end of the training phase, the test proceeded with the arrangement of the following two rooms: the kitchen and the bathroom. In the kitchen, the participants had to complete the kitchen with pieces of furniture present in the database. A pre-defined scene, in which a module of the kitchen furniture was already precisely placed and one of the virtual walls was aligned with a real one, was presented to the tester. The participants have been asked to place as many pieces of furniture as possible, aligning them to the first one initially provided, in a maximum time of 10 minutes. In the second task, which concerns the bathroom environment, a pre-defined virtual scene included the bath, the sink, the washstand and the shower present in the concept. Also, a series of real references that simulate the attachment points on the wall have been supplied. The request to the participants has been to set, in the most accurate way, the toilet blow and the bidet at the attachment points on the wall, and the mirror above the sink. Specifically, for the mirror, no real references have been supplied, and the participants had to set the mirror by using as reference only the other virtual furniture already present in the scene. Also in this case, participants had 10 minutes to complete their task. Fig. 4 shows some screenshots of the augmented environment during the second testing session.

5. EVALUATION

In this section the collected experimental results are reported and discussed with the aim of providing useful information to understand the potentials and the issues of the proposed AR system.

In the case study, which involved the team of two senior interior designers, the time required to the preparation of an entire SA has been about 2 hours. The interior designers considered this time comparable with the time to prepare a similar whole 3D model of the SA by using commercial software. However, they highlighted that during the preparation they could better evaluate the results of their arrangements. The possibility of looking at their project in real scale and contextualized with the real environment has been considered as very useful. In addition, they are convinced that the AR environment can be directly used in preliminary design review sessions with buyers in the *Contract Design* sector. The interior designers expressed their intention to introduce the use of the AR system in their common design activities, also if they asked for some improvements, mainly related to the possibility of automatically identifying and hooking sensitive points of the virtual

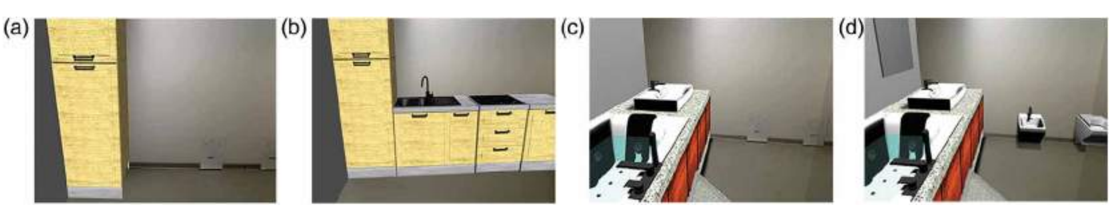

Fig. 4: Screenshots of the augmented environment during the execution of the testing session.

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environment and furniture (such as an edge) to place quickly and more precisely the new virtual objects.

Besides these comments, which were collected during the execution of the case study, interior designers had to fill a questionnaire to numerically express their opinion in relation to specific issues. They were asked to express remarks and give assessments, on a scale ranging from “0” -bad- to “5”-excellent – points, to some characteristics of the AR system. The assessments provided by the interior designers are reported in Tab. 2.

Assessments	Average values
A1. Easiness of using	4.0
A2. Learnability	4.5
A3. Easiness and intuitiveness of the GUI	3.5
A4. Effectiveness for layout evaluation	3.5
A5. Effectiveness for preliminary design review	4.0
A6. Effectiveness for final review	2.5

Tab. 2: Assessments expressed by the team of two senior interior designers.

The interior designers really appreciated the use of this AR system for the development of the prototypes of the design solutions. In a first instance, they expressed high appreciation concerning the easiness of use of the AR interface (A1 = 4). Moreover, they considered the time necessary for learning the main characteristics of the AR system very short and not impacting on the daily design practice (A2 = 4.5). They considered the possibility to make modifications in real-time and to use the augmented environment in the first evaluation activities, in which many design solutions have to be presented to the buyer, as very valuable (A5 = 4). A very good ranking (A4 = 3.5) has been assigned to the possibility of presenting different solutions in the same space and to the comparison between the time used for developing the augmented environment with that used for developing bi-dimensional renderings. However, they pointed out that the AR support would be probably not fully effective in the final evaluation activities (A6 = 2.5), in which buyers could prefer to use the real prototypes of the final design solutions, among which to select the one that will be used in the entire SA.

Concerning the subsequent testing session, the collected data mainly relates to the easiness and time of the learning activity necessary to properly use the AR system. In particular, it was assessed whether all the functionalities provided by the AR system have been intuitively implemented and are easy to learn. All the testers have asserted that they have not encountered any difficulties in learning the use of the AR system. This was also confirmed by the time required by each tester at the beginning of the testing session. Each tester had available 10 minutes at maximum. The average time, taken by the junior interior designers, was about 4 minutes, with a maximum of 7’30"and a minimum of 1’30". At the end of the testing session the junior interior designers had to fill a questionnaire to numerically express their opinion in relation to the overall usability of the AR system. They were asked to express remarks and give assessments, on a scale ranging from “0” -bad- to “5”-excellent – points. The assessments provided by the junior interior designers are reported in Tab. 3.

Assessments	Average values	Standard deviation
B1. Learnability of the AR system	4.3	0.56
B2. Learnability of the positioning methodology	4.3	0.71
B3. Easiness and intuitiveness of the GUI	3.5	0.87
B4. Overall comfort	3.8	1.17
B5. Satisfaction in using the AR system	4.3	0.78
B6. Overall appreciation	3.7	1.05

Tab. 3: Assessments expressed by the junior interior designers.

The assessments provided by the junior designers demonstrated the high learnability of the system in general (B1 = 4.3), and also in relation to the interactive methodology implemented to set the position of the furniture (B2 = 4.3). The easiness and intuitiveness of the GUI have been considered as very good, also if their average assessments have been quite penalised (B3 = 3.5) since some testers would prefer a single windows to control whole application. The results of the overall comfort (B4 = 3.8) was penalised by the very low judgment of a single tester who has considered the workstation (laptop over the trolley) as not very ergonomic. The same tester influenced negatively the high ratings of the other testers about the overall appreciation of the AR system (B6 = 3.7). Contrarily, most of testers have been very satisfied by the work carried out (B5 = 4.3) and considered the AR system a useful tool to rapidly and interactively make several interior layouts.

As already introduced, the testing session has been carried out also with the aim of measuring the accuracy with which testers are able to place the virtual objects in the scene, both with virtual and/or real references. In the first experience (kitchen) the average error of positioning furniture has been quite low, and results mainly from a lack of attention by the testers and also from the non-use of the data in the GUI. The maximum errors have been verified, in

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fact, in relation to the rotation parameters: sometimes testers placed the furniture "at a glance", not considering the data in the GUI. In the case of the second experience (bathroom), in which the positioning of the furniture was done on the basis of real points of reference, the average error was higher (up to 10%), but also in this case it depended on the different parameters used (for the lateral translations the average error was about 2%, for the vertical translations and the rotations was up to 10%). In the following image this error is particularly evident: in this case the tester had even not used the first furniture (already precisely placed in the virtual scene by the authors) for aligning the other objects.

Two main factors have influenced the error: the first one consisted in the dynamism of the shadows of the pieces of furniture, and the second one was related to the previous experiences of testers in using AR applications and environments.

Concerning the dynamism of the shadows, the testers have been asked to not modify the height parameters of the furniture in both the experiences (kitchen and bathroom), because these were already set-up at the correct height (floor level in the first case, +20 cm from the floor level for the toilet blow and the bidet). However, in the case of the bathroom, this request has not been complied with. Such imprecision can be referred to the not-understanding of the shadow of reference: in fact, while for the unwanted rotations the testers tried to correct their errors (made visible by the fact that the furniture "penetrating" in the wall), this has been not verified for the position in height. However, 83% of the testers considered as essential the presence of the shadow, though not dynamic.

Concerning the previous experiences of testers with AR environments, even if they were free to move within the augmented scene, they tended to stay in the position assigned at the beginning of the test. For each tester the test began in a default position. In the majority of the cases the tester has not moved much from his/her initial position until he/she was forced, for example during the insertion of the mirror, placed on a different wall. But, even in the case of the mirror, some testers have attempted to place it starting from the initial position, placing the mirror in a totally wrong way. On the contrary, the testers who used the application for a longer time (during the first testing session), moved a lot in the augmented scene and the positioning errors were lower. This demonstrates that it is important to look at the piece of furniture from different points of view to better define its position in relation to the real and the virtual objects within the scene. Further system improvements will be needed to manage better the positioning issue through the use of the AR system.

Globally, it can be stated that the level of satisfaction of the users has been quite positive in the testers participating in the case study as well as in those participating in the testing session. This demonstrates that the functionalities of the proposed AR system can become an effective support in the context of the interior design and, specifically, could help interior designers to better and rapidly evaluate the quality of the developed design solutions.

6. CONCLUSION

The research activities presented in this paper aimed at developing a designer-oriented Augmented Reality (AR) system for supporting the space planning and the evaluation of design solutions in the area of interior design, and at demonstrating its effectiveness through a case study and a testing session with interior designers.

Firstly, the paper presented the description of the background on which this research grounded, concerning both the *Contract Design* sector, which is a specific branch of the interior design, and the state of the art in the use of AR techniques for interior design. Then, the AR system specifically developed by the authors has been presented, and its main functioning features have been described.

Subsequently, a case study in the field of *Contract Design* has been presented: it consists in the setting-up and the carrying out of a traditional design process concerning a SA, supported by the use of the AR system for the representation and evaluation activities. Also, in a subsequent testing session some interior designers not skilled in the use of AR techniques were asked to use the AR system for performing space planning tasks based on rooms and furniture of the SA. In both cases, the interior designers were asked to express remarks and assessments about some features of the AR system, and the collected data demonstrated the following:

- a high level of appreciation concerning the intuitiveness and easiness-to-use of the AR system and its interface;
- short time necessary for learning the AR system main features;
- a high level of appreciation of the immersiveness obtained by the use of the AR system for representing the developed design solutions;
- a high interest in the possibility of introducing the AR system in their design and evaluation activities.

Also, interior designers expressed some remarks about specific features that are still not present in the AR system. These remarks mainly concern the AR interface, and specifically the possibility of automatically identifying and hooking sensitive points of the virtual environment and furniture to place quickly and more precisely the new virtual objects, and to integrate in the augmented environment dynamic shadows of the pieces of furniture, which can be used as visual reference for the furniture placement.

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In addition, measurement tools will be implemented to allow users to objectively evaluate distances and dimensions during the furniture arrangement. The authors of this work consider these remarks as the starting point for carrying out further experimental research activities.

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