

An Augmented Reality (AR) CAD System at Construction Sites

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1. Introduction

Augmented Reality (AR) technologies allow computer-generated content to be superimposed over a live camera view of the real world. Although AR is still a very promising technology, currently only a few commercial applications for industrial purposes exploit the potential of adding contextual content to real scenarios. Most of AR applications are oriented to fields such as education or entertainment, where the requirements in terms of repeatability, fault tolerance, reliability and safety are low. Different visualization devices, tracking methods and interaction techniques are described in the literature, establishing a classification between Indoor and Outdoor AR systems. On the one hand, the most common AR developments correspond to Indoor AR systems where environment conditions can be easily controlled. In these systems, AR applications have been oriented traditionally to the visualization of 3D models using markers. On the other hand, outdoor AR developments must face additional difficulties such as the variation on lighting conditions, moving or new objects within the scene, large scale tracking, etc... which hinder the development of new systems in real scenarios.

Although AR technologies could be used as a visual aid to guide current processes in building construction as well as inspection tasks in the execution of construction projects, the special features involving construction site environments must be taken into account. Construction environments can be considered as specially difficult outdoor AR scenarios for several reasons: structures change frequently, additional structures (scaffolding or cranes) cover several visual elements during the simulation, every technological part (sensors, wearable computers, hand held devices) can be easily broken, etc. For this reason, although the capability of AR technologies in construction site environments is a hot-topic research, very few developments have been presented in this area beyond of laboratory studies or ad-hoc prototypes.

In this work, key aspects of AR in construction sites are faced and a construction AR aided inspecting system is proposed and tested. Real world would appear in the background with the construction plans superimposed, allowing users not only to inspect all the visible elements of a given building, but also to guarantee that these elements are built in the correct place and orientation. Besides merging computer-generated information from CAD (Computer Aided Design) plans and real images of the building process, the proposed system allows users to add annotation, comment or errors as the building process is

completed. Since this information is saved in DXF (Drawing Exchange Format) format, a new layer can be added to the original CAD plans including the accomplished modifications. Therefore, users can import original CAD plans to be visualized on real environments, to perform the required modifications using actual image from the current states of the construction site and, finally, to save the final results in the original CAD file. The aim of this new way of working is not to replace the usual CAD applications, but to add a new, more intuitive, faster and reliable stage, in the testing, assessment and modification of plans for construction and reconstruction projects.

2. Background

The term Augmented Reality (AR) is often used to define computer graphic procedures where the real-world view is superimposed by computer-generated objects in real-time (Azuma, 1997). Unlike Virtual Reality, where the user is provided with a completely natural experience in a realistic simulated world, the goal of Augmented Reality is to realistically enhance the user's view of the real-world with visual information provided by virtual objects. AR systems are currently used in numerous applications such as medical, maintenance, scientific visualization, maintenance, cultural heritage and military applications (Cawood & Fiala, 2008).

Besides these contexts, outdoor construction is considered as a suitable application area for AR developments (Thomas et al., 2000), (Klinker et al., 2001; Piekarski & Thomas, 2003; Honkamaa et al., 2007; Izkara et al., 2007; Hunter, 2009; Dunston & Shin, 2009; Hakkarainen et al., 2009). In fact, the development of a construction project includes an important number of three-dimensional activities. Professional traits and work behaviours are all oriented towards the design, understanding, visualization and development of 3D procedures. Workers are used to graphical descriptions such as 2D/3D maps or designs. Moreover, most of this information is already represented and communicated in a graphical form. Therefore, new graphical user interfaces like Augmented Reality could be introduced very naturally into current work practices.

Most of AR applications specifically developed for the construction industry are oriented to outdoor construction processes (Thomas et al., 2000; Klinker et al., 2001; Honkamaa et al., 2007). Initially, the aim of these AR systems was to provide the users with a sense of space and realism about the size and dimensions of the construction tasks developed in outdoor environments (Thomas et al., 2000). Moreover, new approaches based on augmented video sequences, and live video streams of large outdoor scenarios with detailed models of prestigious new architectures (such as TV towers and bridges) were presented (Klinker et al., 2001). Currently, the last developments of AR applications oriented to construction processes not only avoid the use of external markers within the real scene, but also integrate sensors such as GPS devices, rate gyroscopes, digital compasses and tilt orientation elements of the viewer's location (Honkamaa et al., 2007).

Although the marketplace offers several toolkits for the development of AR applications, some of them have been specially oriented towards the necessities of applications in the construction sector (Thomas et al., 2000; Piekarski & Thomas, 2003). In much the same way, the design of TINMITH2 (Piekarski & Thomas, 2003) is based on a highly modular architecture where the software system is split into various modules that communicate with

each other using the connection oriented TCP/IP protocol. Otherwise, the architecture proposed in a similar approach (Piekarski & Thomas, 2003) is optimised to develop mobile AR and other interactive 3D applications on portable platforms with limited resources. This architecture is implemented in C++ with an object-oriented data flow design and manages an object store based on the Unix file system model.

Mobile computing could offer a suitable hardware platform for the development of AR applications to be executed in construction sites (Piekarski & Thomas, 2003; Honkamaa et al., 2007; Izkara et al., 2007; Hakkarainen et al., 2009). These contributions address a number of problems affecting mobile AR and similar environments related to performance and portability constraints of the equipments (Piekarski & Thomas, 2003). In much the same way, an AR mobile application developed for architectural purposes (Honkamaa et al., 2007) includes a feature tracking for estimating camera motion as the user turns the mobile device and examines the augmented scene. Another approach integrates an RFID reader, a headset and a wristband to be used by workers in order to improve their safety at work place in construction sites (Izkara et al., 2007). A recent work presents an AR system which places the models in geographical coordinates, as well as managing data intensive building information models (BIM) on thin mobile clients (Hakkarainen et al., 2009).

Along with the developments of mobile computing, the technologies based on Augmented Reality exploit a promising field for wearable computers oriented to construction sector (Piekarski & Thomas, 2003; Hunter, 2009). Since the main idea behind wearable computing is the augmentation of human capabilities by wearing devices, these technologies allow construction workers to facilitate critical tasks such as determining the proper excavation for buildings (Dunston & Shin, 2009), visualising conceptual designs in-situ (Piekarski & Thomas, 2003), making modifications on site, and representing construction and engineering data on real-time (Hunter, 2009). In addition to these purposes oriented to the construction sector, the setting out process has been denoted as a challenge when AR technologies are applied to the construction sector (Dunston & Shin, 2009). This process guarantees that components are built in the right position and to the correct level from the location information provided by design plans. Although these technologies could (with a proper visualization device) be used by construction technicians to identify the positions of reference points easily and mark them on the site by simply observing the rendered virtual reference points, from our knowledge all the current approaches are under development and not in commercial use at the present time.

3. AR-CAD, augmenting the traditional CAD

The aim of this work is to introduce AR guidance technologies into the daily tasks performed in construction sites, in order to create a construction control system. For that purpose, instead of creating a new AR system including complex and fragile visualization systems and 3D models, a well-known CAD package (AutoCAD®) and other 2D/3D design tools that export files to a DXF format, have been selected as a base to develop an AR tool that adds new features to the existing ones that CAD users are familiar with. As a result, the common tools for 2D data design such as measuring, annotation, selection, etc. are augmented with tools that allow visualizing these actions over the real image obtained from the current state of the construction site. As a quick walk-through of the construction site, the users can measure the distance between two existing pillars or even the area delimited

by a new concreting area and, therefore, check if the obtained results coincide with the expected data included within the original design plans. In case the user finds differences between the original and the obtained measurements, then some quick notes, draws or pictures denoting these differences can be on the augmented view of the construction site. Therefore, some of the inspection tasks in construction sites can be performed using a computer remotely in the same way that 2D plans are used on-site in the construction zones.

This system manage three different sources of information: background images, AutoCAD DXF as 2D design plans and as-built images. As a result of the merging of these types of data, a new augmented CAD (denoted as AR-CAD) data model is defined, where the common building plans are augmented with both annotation and real images from the current state of the building work. Moreover, the new augmented CAD information can be visualized over the images obtained from the building work. By means of managing this new type of CAD information, both the coherence among 2D design plans and the execution of the construction projects can be easily controlled. Thus, a new link between the traditional CAD information and the on-site tasks in construction works is defined.

Following the same approach and objectives, the next sections describes some software modules oriented to transform classical CAD tools and operations into new versions able to work with real images from the current state of the construction site.

3.1 Scene navigation in AR-CAD

The user can navigate through the augmented construction plans in the same way as he would do it in a conventional 2D CAD plan, by moving the user's view and performing zoom in/out actions. Moreover, a new user's action, denoted as "orbitation", enables the user to move the augmented view around a focus point. In this new mode, the system controls a Pan-Tilt-Zoom (PTZ) camera aiming towards the same focus point of the augmented view, so all the elements around the real camera can be inspected in detail. Figure 1 shows how the PTZ camera, described in Section 4.3, follows the movement indicated by the user and therefore different zones (belonging to the same construction site) can be controlled using a single device. The operation of the PTZ camera is transparent to the user, since the camera movements are calculated automatically depending on the user's action within the augmented view of AR-CAD.

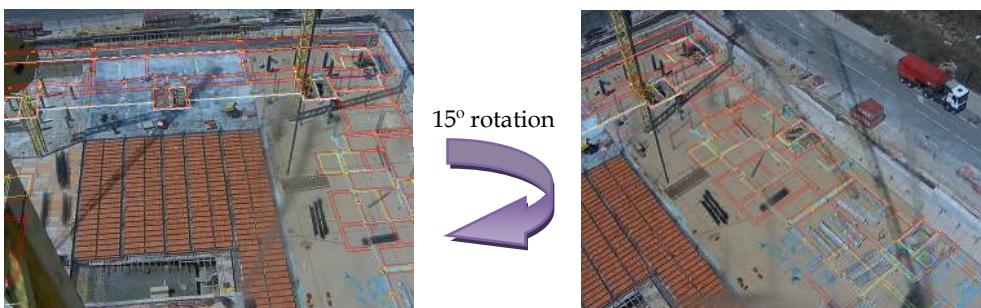


Fig. 1. AR-CAD scene rotation when using the PTZ camera.

3.2 Dynamical image interaction for AR-CAD

In order to help users in the interaction process of the augmented image in AR-CAD, a magnet-based feature has been developed. This user's action is well-known in some CAD programs such as AutoCAD® or SolidWorks® and snaps the cursor into the correct location more accurately than common mechanism of selection based on grids or grips. In case of AR-CAD, the magnet option make common operations on augmented views -such as scene calibration, note addition, measurement, etc- easier for the user. Following the same approach, an augmented magnet has been developed, so that the user can select lines in the real image in the same way that it would be performed in the 2D design plans, as shown in Figure 2. As a result, when the user tries to measure a distance between two points within the augmented image, the mouse is automatically snapped into the nearest outline instead of expecting a manual positioning of points by the user. In this sense, the user's experience is significantly improved since the users of AR-CAD work with a new but familiar tool because of its similarities to the most common operations in CAD applications. The right picture of Figure 2 shows the results of this feature, which is especially useful when a significant zoom-in operation is performed and the user has to select lines on a blurred image. In addition, a more precise measure can be obtained because the new snap position is calculated using the straight line detected instead a single pixel coordinate, so sub-pixel precision can be obtained.



Fig. 2. AR-CAD line selection. A red line shows the line computed from the blue border pixels detected near the mouse. A white cross and a black pointer show the final pointer position (left). The result of the line selection process for a low resolution augmented image (right).

4. System description

The proposed setting out system for construction sites consists of a hardware platform and an Augmented Reality application. Since one of the main goals of the system is the development of a more affordable alternative than conventional equipment for surveying purposes in construction sites, the hardware platform has been developed using commercial off-the-shelf (COTS) components.

This type of developments is oriented to reduce expenses and to shorten the development time, while maintaining the quality of the final product. Moreover, the AR application has

been designed following a component-based model to enable a continuous increase of functionality and portability.

4.1 Hardware description

The hardware device of the proposed system includes a high performance PTZ network camera, a reliable 3G-WiFi router and an AC voltage stabilizer in a 15-inch watertight box. This box is made of fiberglass and is located at the top of the main crane obtaining a high resolution top view of the overall construction site. Figure 3 shows an image of the final aspect of development as well as the final location of the hardware device when the experiment tests, described in Section 5, were completed.

In order to fulfil the high performance PTZ network camera requirements, a Toshiba IKWB-21A model was selected (see Figure 3). This IP camera includes a 1280x960 resolution CCD camera with a 15x optical zoom lens. In addition, this camera operates as a stand-alone unit with a built-in web server where the AR application connects and obtains top-view images of the construction site in real time.



Fig. 3. PTZ camera (left); installation of the camera on a crane (right).

4.2 Software description

The design of the software application for the proposed system has a software architecture following an “event-driven object-oriented” model. These software designs describe synchronous event-driven architectures composed of a set of components (modules), which are based on a classic object-oriented approach. The modules exchange custom messages that model internal actions or external events captured in real-time. In the case of the proposed application, the software system is composed of 8 independent and interrelated subcomponents, which work concurrently in a real-time manner. Figure 4 shows the diagram view of the architecture that relies on a centralized approach around an AR engine. The kernel of the proposed system, denoted as SICURA Engine, is responsible for launching the application, controlling the user interface, and keeping the coherence among the rest of the modules. The three Data I/O modules manage all the information: construction plans, as-built photos and external camera images, so all this data can be loaded and saved.

Finally, three functionality modules –“Image analyzer”, “Measure & annotation” and “Background calibration”- implement the system functionalities. All these modules are detailed in the next sections.

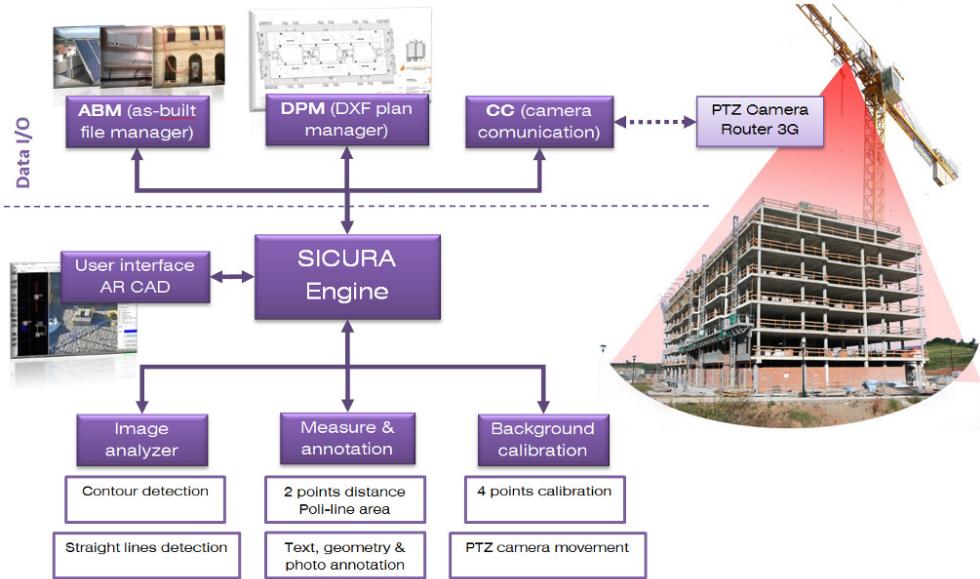


Fig. 4. SICURA software system architecture.

4.3 Data Input/Output modules

The software architecture designed for the proposed system includes three input-output data modules denoted as *AS-Built Manager (ABM)*, *DXF-Plan Manager (DPM)* and *Camera Communication (CC)*. The ABM module manages the AS-Built images, obtained from relevant areas of the construction site, and inserts additional information into the images using the EXIF fields. The EXIF format was created by the Japan Electronic Industry Development Association and is referenced as the preferred image format for digital cameras in ISO 12234-1 (Gulbins & Steinmueller, 2010). Basically, this format defines a header, which is stored into an "application segment" of a JPEG file, or as privately defined tags in a TIFF file. As a result, the resulting JPEG or TIFF images keep a standard format readable by applications that are ignorant of EXIF information. In the proposed system, the EXIF fields save information related to the exact point of the construction site where the picture was taken, additional comments, relevant elements included within the picture, etc. The DPM module opens, reads and writes the 2D design plans of the construction site exported in DXF format. Moreover, this module accesses to the different layers, which are commonly included in the plans. These layers are defined by the architects or draftsmen and allow to organize information about the setting out, structure, pipelines, etc. The properties, comments and measurements related to each layer are also accessible and modifiable by the DPM module. Finally, the CC module provides the communication with the IP-camera,

receives images from it and produces basic commands to modify the orientation, zoom and image resolution of the camera. This module makes the camera communication transparent to the rest of the system, so different IP cameras could be used simply modifying the CC module.

4.4 The user's interface in AR-CAD

The user's interface module integrates the graphical user interface (commonly denoted as GUI module) defining a single point of communication to the user within the entire application. This module controls the 2D design plan user's view, the configuration dialogs and shows as many augmented views of the construction zone as the user defines. The pictures used as background images within the augmented views can be selected as real-time video images, static images and compound images.

The option corresponding to the real-time video images seems the most appropriate choice because they make the most of the features of the PTZ camera located at the top of the main crane of the construction site. Otherwise, the static image is useful in scenarios where it is not possible to properly locate a camera in the top of a crane to cover the main surface of the construction site. In those cases, aerial pictures taken from helicopters, helium balloons or specialized small planes can be used as input to the module for defining the background of the augmented view of the scene. Finally, the compound images are a special type of background, which is generated automatically from the images of the augmented views, regardless if they were real-time video images or static images. The compound image is located under the 2D design plan and can be hidden depending of the user's preferences. Section 5 shows some examples of different scenarios and types of background images.

The GUI module of the proposed AR system has been developed under Microsoft Windows Xp/Vista/7 operative systems as a .NET Windows Forms application in C++ using Microsoft Visual Studio 2010. All the windows handled by the application are dockable windows so the workspace is completely configurable. This dock feature is very useful due to the important amount of augmented views that a user can create for the same construction site. Figure 5 shows different views of the user's interface of the system.

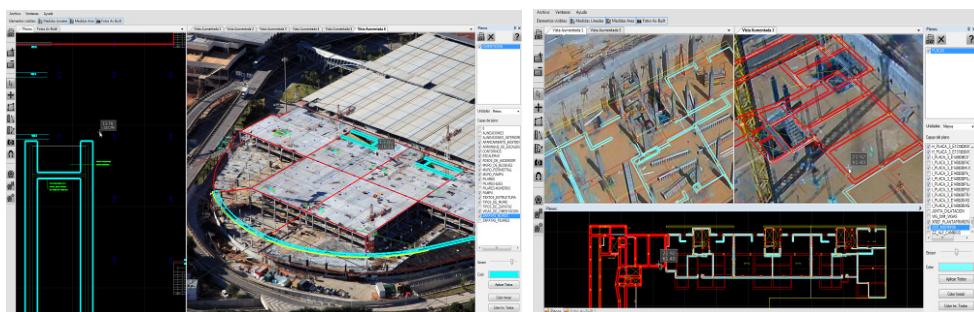


Fig. 5. Distintas vistas del interfaz de usuario.

In order to properly represent and to visualize the augmented view of the construction site, OpenSceneGraph has been selected as a high performance graphics library (Burns &

Osfield, 2004). OpenSceneGraph is an OpenGL-based high performance 3D graphics toolkit for visual simulation, games, virtual reality, scientific visualization, and modeling. Basically, this toolkit is a scene graph-based open source graphics library, which provides all the functions required for representing three-dimensional models in virtual environments. Besides the common features included in OpenSceneGraph, the library has been extended (with a so-called NodeKit) by means of an own development incorporating not only AR features, but also configurable graphic windows oriented to AR content. This interface allows users to show, to hide and to modify layers included in the original DXF design plans, to visualize and to edit measurements and annotations. Moreover, the interface can be used to adjust common image parameters, such as brightness, contrast and saturation, for each one of the background images of the augmented views, separately. This feature allows to represent images in black and white or gray scale in order to bring out the color images of the design plans, when they are superimposed to real images from the camera in the augmented views. Since this feature generates a computational intensive operation when the real-time video image is selected as background of the augmented views, a shader has been defined to perform this operation into the GPU.



Fig. 6. Examples of the modification of brightness, contrast and saturation of the background images in the augmented views.

One of the main problems concerning to the development of the interface was that OpenGL (a low level graphics interface supporting OpenSceneGraph) cannot properly render irregular 4-vertex textured polygons. The left and center images of Figure 7 show the deformation effect of the texturing process performed by OpenGL for a regular (left)

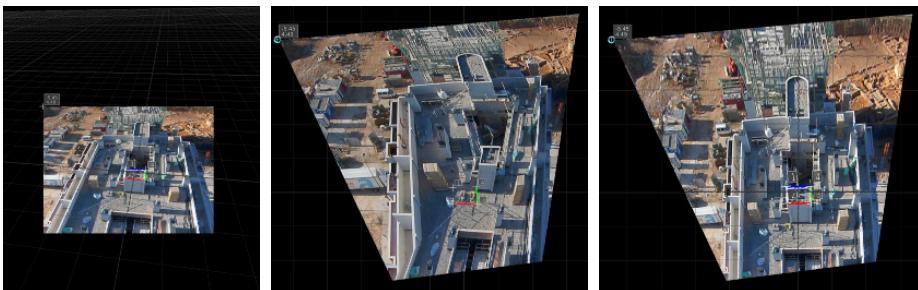


Fig. 7. 4-vertex regular textured polygon (left); OpenGL problem on 4-vertex irregular textured polygon (center); 4-vertex irregular textured polygon using our correction shader.

and irregular polygon (center). In order to solve this OpenGL visualization problem, a two-step software correction has been developed. In the first step, a correspondence matrix between the irregular polygon and the square texture is calculated, obtaining a 3×3 homography matrix. Next, in a second step, a *fragment shader* computes the proper texture coordinates for each pixel of the irregular polygon, using the pixel coordinates and the homography matrix. Figure 7 shows the differences between the original texture on a regular polygon (left), the distortion effect on an irregular polygon (center) and the result of the developed two-step solution.

4.5 Image analyzer

The Image Analyzer module (IA) analyzes the image in order to obtain supporting data as input for the magnet-based feature for lines in the augmented view. This module examines the static images (or even the real-time video image), extracts contours, finds the nearest contour points from the cursor and calculates the corresponding straight line (when possible), all these in real time. Since there are several moving objects in a construction site environment, as well as objects not related to the construction process of the building, a lot of unnecessary information is computed if the whole process is performed for each new image. In order not to evaluate unnecessary information and to result in an interactive system for the users, this operation should be performed as quickly as possible, so the tasks related to the interaction process with lines have been divided into two decoupled steps. In the first step, the contour points are identified each time the background image changes (Fig. 8 left). Next, in a second step, the closest contour points to the current position of the cursor are obtained, and, finally (starting with these points) the straight line is computed. This second step is only executed when the user moves the mouse cursor and therefore a significant computation time is saved decoupling this process. In this sense and for the purposes of the magnet tool, it is only necessary to obtain the straight line among the closest zone to the place where the user is working on. Figure 8 (left) shows the total obtained contour points in a 1440x920 pixels image and the straight line (right) obtained from the current cursor position. The blue pixels in the right picture of Figure 8 correspond to the selected contour points and the red pixels of this figure define the obtained line. In addition, a white cursor has been included to show the initial position of the cursors for the IA module and the black cursor indicates the position of this element obtained by the two-step process.

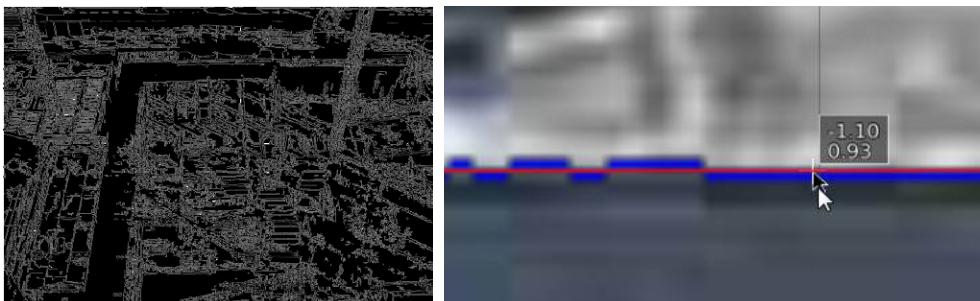


Fig. 8. Contour mask extracted from the background image (left); straight line computed (red line) and pixels selected (blue) from the initial white cursor position to obtain the final black cursor position (right).

4.6 Measure & annotation tools

The proposed system includes a module oriented to directly add measurements and annotations to the original 2D design plans. In this sense, this module allows the user to quantify and to draw the deviations of the execution of the construction project, as well as to save them with the original plans in a unified manner. The development loop is closed by means of this module since the original 2D design plans are made by a commercial CAD application. Then, these plans are completed with measurements and geometry showing the reality of the execution of the construction project and, finally, the last version of these updated plans is generated following the same format in which they were initially created. The aim of this module is not to replace the drawing and design features of current CAD commercial application (such as Autocad®, Intellcad®, MicroStation®, etc.), but to include a reduced set of tools in a AR development to edit directly and efficiently construction plans.

The measurement functions include two different options denoted as lineal or area estimations. The option for lineal measurements obtains an estimation of the distance between two points, while the option for area estimations infers the area surface in a polyline. In both cases, the user uses the mouse to select the different points on the 2D original map, or in the augmented view, and the result of the measurement appears on the selected zone.

For the case of the annotations, three types of tagging elements, denoted as text marks, geometric marks and AS-BUILT images have been developed. The text annotations consist of a reduced text describing a situation or a problem detected. The central image of the Figure 9 shows an example how these annotations are placed together with a 2D reference indicating the beginning of the position of the text mark within the plan. The geometric annotations follow the same procedure that was developed for the area measurements in polylines since the objective of this module is not to replace a CAD commercial application, but to include some common drawing and labeling features. The last type of annotation corresponds to the AS-BUILT images and assigns pictures, showing the current state of the construction site, to the place where they were taken. Usually, these pictures are managed by the construction site manager who has to organize and classify them into several criteria as well as creating the construction site delivery document, denoted also as CSDD. The developed system not only lets users to organize, categorize and classify the AS-BUILT



Fig. 9. Lineal and area measure (left); text and geometric annotations (center); as-built photo annotation (right).

images, but also allows these images to be inserted into exact points within the 2D original plans and the augmented views of the construction site. The right image of Figure 9 shows an example of the result of these features. This annotation method is especially useful for the construction site manager in the last stages of the construction process, where it is necessary to control and review the task performed by outsourced work-teams such as carpenters, electricians, etc.

4.7 Background calibration

This module computes the correspondence between the background image of the augmented views and the computer-generated information. This correspondence is a key aspect of the system because all the geometrical information (including measures) is computed using this correspondence. The accuracy of the system proposed depends directly on the precision of the calibration performed for each augmented view. Due to the importance of the calibration process, an easy-to-use calibration tool has been developed. Using this tool the user defines the points of correspondence between the real background images and the 2D design plans. This action can be performed using the magnet-based feature for lines and its augmented version if a higher degree of accuracy is desirable. When this correspondence has been established, the system obtains the position and orientation of the camera, which collected the image. The user can modify the calibration points and watch the result in real time, so it is possible to improve the initial estimation only moving each point to its correct place. This process needs to know the intrinsic parameters of the camera, in terms of camera geometry, in order to complete the calibration successfully.

Moreover, this module obtains the proper movements from controlling the PTZ camera according to the CAD augmented view when the orbital mode is selected. In this sense, the corresponding values for the pan, tilt and zoom parameters that the system needs to point the camera at any given position are obtained from the initial calibration of the augmented view. In the cases where the desired point to monitor is physically unreachable because of the camera placement, the system locates the camera pointing at the closest zone to the desired point, always within the eye camera field-of-view. Using this correspondence, the orbital mode is automatically restricted to the feasible zoom and camera operations that can be performed by the system camera.

5. Experiments and results

Different experiments have been conducted in actual construction sites in order to evaluate the system performance of the proposed approach. This section shows the description and the obtained results in the three more representative cases corresponding to the construction of a building of apartments, the enlargement of a parking area and the tasks for the rehabilitation of an old building.

5.1 A low-height construction site building

The first performed evaluation corresponds to the use of the system in the monitoring processes for the construction of a seven-floor building for apartments. The size of the construction size is roughly 6840 (95x72) square meters. In this experiment, a Toshiba IKWBA-21A camera, described in Section 4.1, has been used. This camera was located at top

of a tower crane of 50 meters high. Using this configuration, it was impossible to obtain a high resolution top view of the overall construction site in a single snapshot of the camera. To improve this situation, an augmented view of the system was configured including three different views of the same construction site. Figure 10 shows the configuration of the three different views of the scene as well as the obtained results.

In this first experiment, the construction site manager used the system to verify the setting out of pillars in the building. This process has to be completed in order to guarantee that the pillars belonging to the building are constructed in the right position and level from the location information provided by the 2D design plans. Although the construction of pillars should be a very accurately tasks, some errors can occur because bad interpretations of the plans, or even because of non-commented last-moment modifications performed by the topographers. These mistakes are especially dangerous if they are not detected in the early stages of the construction site process, since sometimes they cannot be solved and involve modifying the original design plans.

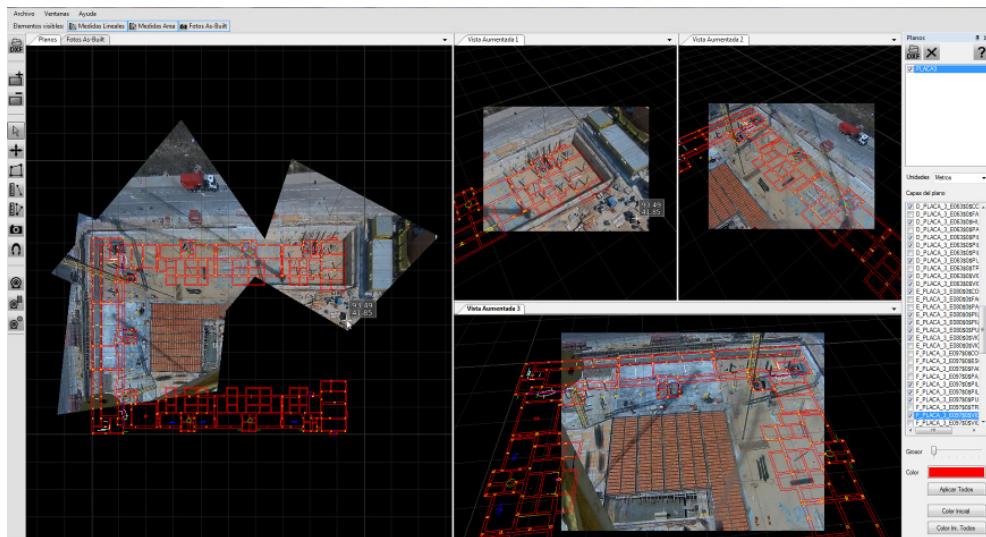


Fig. 10. Example of the use of the system in a construction site for a 7-floor building; three augmented views(right) and composed background mixed with 2D plan (left).

The construction site manager (an expert AutoCAD © user) learnt easily the main features and operations of the system, following a two-hour tutorial, and worked with the system for a period of 3 months, until the end of the setting out tasks in the construction site. For this period of time, the main problems were caused by the unexpected low performance of the wireless connection to the system camera, caused by the radio magnetic interferences generated by the surveillance equipment of a very near military building. As a result of the use of the system, the manager showed a high level of satisfaction and emphasized the ease of the system to check the setting out tasks at a glance, when testing pillars, elevator holes, stairs, etc. Moreover, the resulting accuracy of these verifications was enough to measure the

length and width of pillars remotely because of the optical zoom provided by the PTZ camera.

5.2 Construction and enlargement of a parking area

In this experiment, the system was evaluated to monitor the construction and enlargement of a three-floor parking lot with an area of 19.800 (165x120) square meters. Because not only by the large surface of the construction site, but also by the low height of the installed tower cranes, the system worked with aerial images obtained by an air company specialized in this type of services. Figure 11 shows an example of the use of the system using this type of pictures, which were obtained every two weeks providing a complete evolution of execution of the construction project. Since aerial pictures are not usually taken with conventional digital cameras, it was necessary to calculate the intrinsic parameters of the camera along with the distortions at a predefined number of measured points of focus and zoom. In order to complete this tuning process, a set of different 50 pictures corresponding to a calibration pattern for this professional camera was provided by the air company.

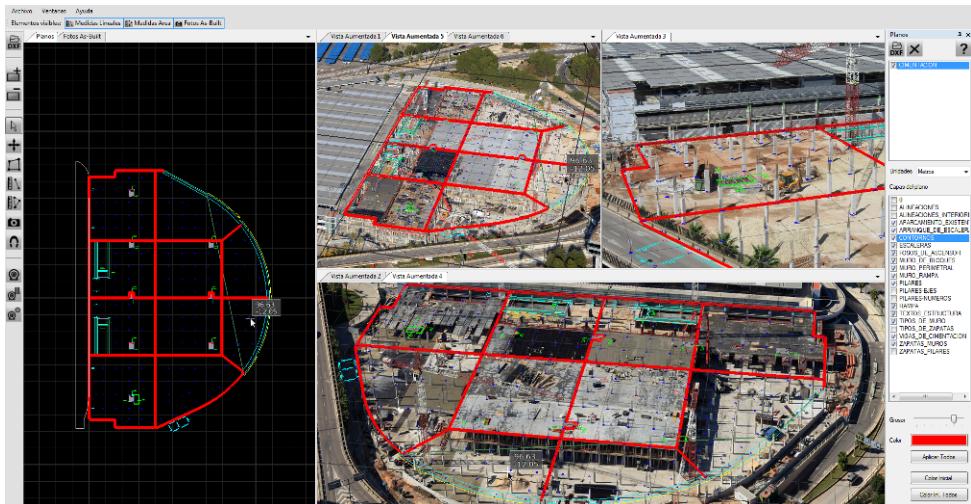


Fig. 11. Image of the system in the construction of a parking area using aerial images as background for the augmented views.

As in the previous experiment, the construction site manager was trained in a one-day course and evaluated the performance of the system, which was used for eleven months. In this case, the most profitable feature by the manager was the measurement of irregular areas. This measurement is significantly important in the development of the daily tasks in a construction site environment, since it sets the amount of money to be paid to outsourcers (concrete company, companies providing metallic framework, etc...) as they complete their tasks. In most cases, the measurements of areas (which are finished by the subcontractors) are obtained from either the initial 2D design plans, or a topographic service. Both solutions, or could be erroneous, because the differences between the scheduled and the executed

tasks, or even are difficult to perform in all the cases since. Concretely, some completed elements in a construction work cannot be measured by a topographic service, because the occlusions problems in a classical construction process.

5.3 Restoration of a building (Nou de Octubre)

The last presented experiment corresponds to the use of SICURA for the restoration tasks of an old building converted into an office building with communal services. The three-floor building covers an area of roughly 4.340 (70x62) square meters. In this project a Sony DSCF828, 8MP compact digital camera, was used as input device for the images inserted into the background of the augmented views.

One of the main features of the building restoration projects is the important amount of work related to the review, estimation and updating of the 2D original plans with the restoration actions to be performed. The restoration actions assign information about material, task description, estimated time, etc. to different points of the 2D original plans. These actions require several visits to the construction site to review measurement, estimations and tasks to be performed.

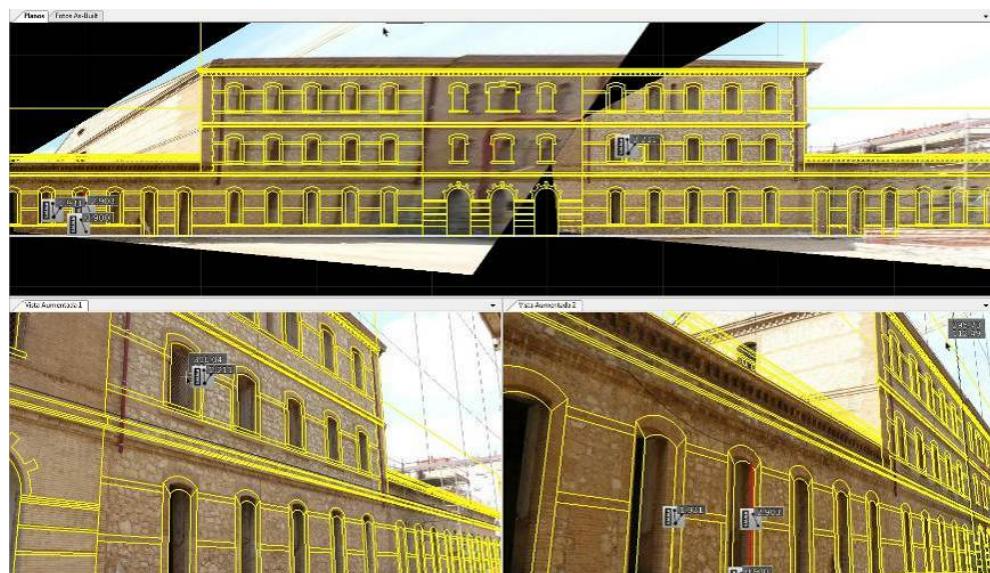


Fig. 12. Example of the restoration process using compound images.

In this case, the system was evaluated by two restoration building technicians, who use the system in the restoration tasks corresponding to the building facades. As in the previous experiments, the users were considered as experts AutoCAD® and passed a one-day training season. After an evaluation of two-month of duration, the users stressed the speed of the annotation operations since they were performed on actual pictures of the building under restoration.

In this sense, SICURA was also considered as valuable new way of inspection and planning for construction purposes. The reasons of these considerations are not only the time and costs savings in the measurement of facades, but also the speed in the annotation tasks for the cataloguing processes. Figures 12 and 13 show some results of the use of SICURA for restoration purposes in an actual building restoration project. As a result, the restoration technicians could update and add measurements and restoration tasks to be performed regardless the topography department of the construction company. Moreover, all the new or updated measurement and annotations were exported into an AutoCAD® format to generate the final restoration project for the building.

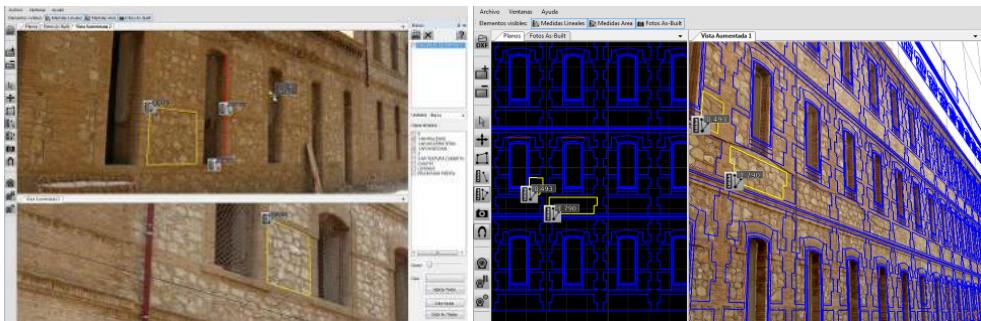


Fig. 13. Snapshots of the system in the restoration process of an old building. Area and lineal measurements over the real image (left); plane and measures superimposed the real image (right).

6. Conclusions

In this paper, we have proposed a new system based on Augmented Reality technologies for the area of building construction. The system is devised to the improvement in the building control process performed by the construction responsible in building areas. The system has been designed and created with current CAD tools (widespread used in this area) in mind, in order to minimize the learning curve for the final users and to guarantee a good level of acceptance of the new functionalities included in our system.

With the SICURA system we have been able to merge three different information sources into the building control process: AS-BUILT photographs, CAD planes and background images from different sources. The SICURA system becomes, thus, an enhanced CAD system, that we call AR CAD. The system is able to combine in a coherent an accurate way these different sources offering an interesting framework for the indicated supervision task.

To show the potentialities of the system three different scenarios of use have been tested. The selection of the scenarios has been based on different types of building area, building heights and the kind of construction tasks required in each case. In all of them, the system worked properly, with only a few issues in the wireless camera connection, due to frequency inhibitors placed in a close building.

After the tests, interviews were performed with the supervisors of each building area. All users showed a good degree of acceptance of the system. We think that this is because of

two main reasons: on the one hand, the appearance of the software with the same look and feel and the same interaction present in current CAD systems, so they feel quite familiarized with the use of the system. On the other hand, the extra functionalities included in the system were very appreciated because with non-extra 3D models or physics models they were able to compare real images with CAD designs in an accurate way, being able to even make measurements and quite precise estimations of deviations from initial designs without even being physically in the building area.

However there are still some minor issues to improve in order to make easier the actual introduction of this system in the daily control of the building process. In this way, the main drawback that users found using the system was the calibration method. Although all the users understood why this process was necessary, the most of the users suggested a more automatic calibration process, instead of placing the control points, which can be sometimes confusing. So, these are the kind of considerations we are using to drive our work to obtain a more usable system.

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