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Augmented Reality supporting User-Centric Building Information Management

Manuel Olbrich · Holger Graf · Svenja Kahn · Timo Engelke · Jens Keil · Patrick Riess · Sabine Webel · Ulrich Bockholt · Guillaume Picinbono

Abstract The rapid development of geo-referenced information changed the way on how we access and interlink data. Smartphones as enabling devices for information access are main driving factor. Thus, the hash key to information is the actual position registered via camera and sensory of the mobile device. A rising technology in this context is Augmented Reality (AR) as its fuses the real world captured with the smartphone camera with geo-referenced data. The technological building blocks analyse the intrinsic sensor data (camera, GPS, inertial) to derive a detailed pose of the smartphone aiming to align geo-referenced information to our real environment. In particular, this is interesting to applications where 3D models are used in planning and organization processes as e.g. facility management. Here, Building Information Models (BIM) were established in order to hold "as built" information but also to manage the vast amount of additional information coming with the design, such as building components, properties, maintenance logs, documentation, etc. One challenge is to enable stakeholders involved in the overall building lifecycle to get mobile access to the management system within on-site inspections and to automatise feedback of newly generated information into the BIM. This paper describes a new AR framework that offers on-site access to BIM information and user centric annotation mechanism.

M. Olbrich · H. Graf · S. Kahn · T. Engelke · J. Keil · P. Riess · S. Webel · U. Bockholt
Fraunhofer Institute for Computer Graphics Research IGD, Fraunhoferstrasse 5, 64285 Darmstadt
E-mail: {manuel.olbrich, svenja.kahn, holger.graf, timo.engelke, jens.keil, patrick.riess, sabine.webel, ulrich.bockholt}@igd.fraunhofer.de

G. Picinbono
CSTB, Sophia Antipolis, France
E-mail: guillaume.picinbono@cstb.fr

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1 Introduction

Over the last few decades, society has amassed an enormous amount of digital information about the Earth and its inhabitants. However, these archives pale in comparison to the flood of data which is about to engulf us. A new wave of technological innovation is allowing us to capture, store, process, generate through simulations, and display an unprecedented amount of geo-referenced information and a wide variety of environmental and cultural phenomena. Especially the Architectural, Engineering and Construction (AEC) sector is characterised by large efforts for planning, preparation and maintenance. Here, several stakeholders with different interests and backgrounds like facility managers, architects, craftsmen etc. have to cooperate in order to design, plan and maintain new buildings. The inherent diversified tasks cause communication gaps, documentation and planning errors and as consequence losses due to many re-iterations throughout the lifecycle of a building. One major challenge here is to introduce adequate information models that are capable of handling the vast amount of data. Building Information Models (BIM) aim at consolidating and archiving all relevant information related to the building envelope. This implies the management of the overall lifecycle processes spanning design and construction through operation, maintenance, and finally culminating in its destruction. Ideally, the information model should provide structures and mechanism to capture change logs in the same way as "as-built" information fostering a documentation of learned best practices for next gener-

Fig. 1 Our system running on a smartphone. The metal framing for a planned insulation system is superimposed over the camera stream.

ation buildings. While several mature solutions do exist for earlier stages, there is still a lack of supportive management tools within later stages, in which manual paperwork is still predominant. Digital support in order to feedback on-site experiences, change logs or additional information relating building information to a current maintenance status would resolve this bottleneck. This paper presents an AR framework, its interlinking mechanism to BIM and an annotation engine that supports on-site documentation tasks during operational and maintenance phases of the building lifecycle. The presented work explains the architecture and mechanism of the proposed building information integration concept, the coupling of user driven BIM data with mobile AR (as shown in Figure 1), server-client communication using REST (Representational State Transfer) paradigms, user-driven annotation objects and services as well as embedded tracking technologies on smartphone platforms. In order to interlink different instances of collaborative workers we describe in detail the new concepts for BIM exchange that enable user driven annotations for real-time content generation during on-site sessions. Finally, we showcase the use of our system exemplifying on-site application scenarios for documenting and maintaining building related information using our mobile AR framework. Several building blocks are web compliant (HTML5, JavaScript) and standard conform (ISO X3D).

2 State of the Art

Recent research trends in AR focus on the challenges of high quality rendering, using advanced scene graph technology in combination with fast graphics accelerators (e.g. for occlusion calculations of real/virtual objects) and tracking technology for mobile applications. The registration of position and orientation of virtual objects and its alignment to real objects do make use of several tracking approaches (e.g. [5]). Markerless methods did achieve impressive results (e.g. [20]). In the AEC domain a growing number of technical feasibility studies of AR have shown the potential of this technology during planning and construction phases. [4] establish an animated AR prototype designed to simulate activities in outdoor locations within construction operations. [27] presented an outdoor AR system that augments virtual objects of subsurface utility systems, such as buried pipes and cables, onto the real outdoor environment. [21] created an AR prototype for architectural assembly that provides users with AR guidance for assembling a space-frame structure. [23] identified AR as a technology with a high potential for coordination, interpretation and communication within certain construction, building and inspection tasks. [12] used AR for rapid assessment of earthquake-induced building damage. Their study, nevertheless, question the lack of validation and its proof of suitability for the AEC sector. A good overview if existing AR approaches in the construction area can be found in [9]. However, in view of the management and presentation of building lifecycle data, currently no platform is available that allows the efficient use of mobile AR within the AEC sector [14], nor addresses potential lifecycle stages in which this data might be useful. As mentioned above, there are some fragmented solutions but clearly lack of integration. This is of outmost importance as in the last decade the AEC sector has been inherently using 3D models for the design of new buildings, its simulation and communication. Complying with trends originally pushed by the automotive industry to also capture and interlink correlated information, such as geometry, properties, its documentation, change management, etc. within one information management system, the AEC sector pushed the development of BIM systems. Main aim was to make early on information not only available during the construction phase, but also using this information for the whole lifetime of a building[11][15]. The information model does not only encapsulate building geometry but also its spatial relationships as well as technical installations and building components, such as cables or heating systems. BIM data has proven its high potential for the reduction of costs resulting from inadequate interoperability in construction processes [33]. However, during the lifecycle of a building, additional (user-driven) data has to complement existing data at any stage of the building lifecycle, e.g. by instruction manuals for technical installations, lifecycle documentation, or maintenance plans. In current state-of-the-art processes, this information is processed with facility management systems, e.g. Archibus [1], Nemetcheck [18] or SpeedikonFM [25]. Whereas these systems offer a wide range of functionality for storing and maintaining building related information within the software, the stored data is not easily accessible on-site and (apart from some RFID-based approaches) usually is not linked to real objects. This work contributes to overcome these limitations by integrating user-centric BIM data with Augmented Reality on mobile devices. The processing power of mobile devices has steadily increased in the past years, resulting in the development of first mobile tracking approaches [2][17][30]. However, these approaches do not fulfill the BIM related requirements for AR applications, such as a good scalability for devices with different processing power and the possibility to fuse 3D building models with semantic annotations as well as tracking reference data. There are only very few previous works in which both AR and BIM have been addressed in the same context [14]. However, an overview of the usefulness of AR for the construction and building facility sectors in general was shown in several studies [10][31]. For instance, Shin and Dunston [24] pointed out that Augmented Reality can support work tasks such as inspection, coordination, interpretation and communication on construction sites. Augmented Reality supports labour effective methods by presenting construction information in a way which is easy to perceive.

3 Architectural Design

The architectural (shown in Figure 2 design of the AR framework and the envisaged building information integration is based on a coupling of 6D indoor tracking technologies with Evolutional Building Models. These models merge sensor collected and user annotated data with existent building models available in the BIM in order to establish an evolutional track of the models. Thus, they are able to be updated at any time within the lifecycle. The architectural design is based on a client adapter (enabling a multiple player solution, i.e. VR or AR clients) and a service based infrastructure exposing REST interfaces.

3.1 Client Adapter

The client adapter wraps visualisation, network and tracking access (through REST interfaces), as well as sensory information and synchronisation processes into one building block. We use a fusion of multisensory technologies on mobile computing systems that capture the real environment and register the 6D pose of the mobile device in real-time. The client adapter is able to connect different mobile devices or instances of interactive visualisations, e.g. VR (players solution) with a central backbone holding the building and tracking related information (building cloud). At the same time, if the mobile device allows for resource intensive computations, it might keep an instance of the AR tracking services (i.e. reference models and image based anylsis-by-synthesis techniques) on client site. This enables to also operate maintenance support as stand-alone application without a service backbone. The information model we are using integrates all building related data and enhances the BIM with multiple user captured media data. AR can be used as one front end (but is not restricted to) for the visualization of BIM data. The client adapter might also be realised as a pure VR environment (VR client). This mulitple players solution offers annotations on request, lifecycle documentation and monitoring of building components throughout the deployment phase. Our main focus is on:

- an AR-tool for the documentation of maintenance and service procedures on recent smartphone systems,
- fusing 3D building models with semantic annotations as well as tracking reference data using REST technologies,
- realizing an AR-service based infrastructure that uses the smartphone for environment capturing and AR-visualization on the client while processing content and tracking reference models on the server,
- establishing a web compliant annotation engine that links BIM and multi-media content to building parts supporting real-time content authoring,
- enabling collaborative users to exchange annotations and link those to the building information model database in real-time, and
- downscaling markerless/large-area tracking technologies to smartphone devices and tablet-PCs.

For the AR client we are using advanced image based analysis-by-synthesis techniques (see Chapter V) in order to retrieve significant features and reconstruct their 3D positions being continuously updated and stored within an updated feature map. Furthermore, the 3D feature map holds specific criteria that characterises the features and that allow an identification and classification. An online learning process continuously updates and enhances the 3D feature map used as reference data for the tracking.

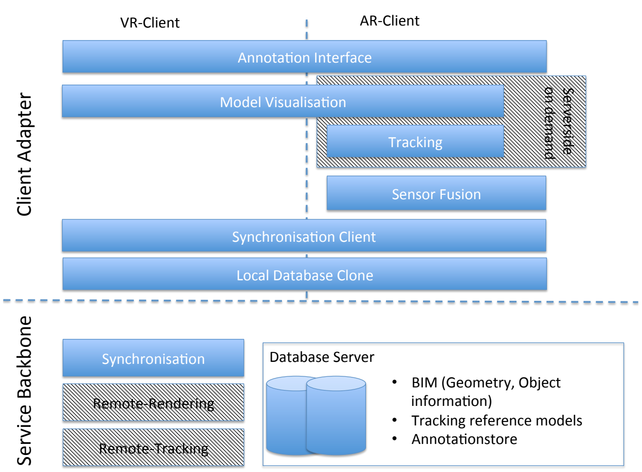

Fig. 2 Architectural Design

Fig. 3 User Interface in AR- (top, with data superimposed to the camera image) and VR-Mode (bottom)

3.2 Service Backbone

Several tracking mechanism can also be (depending on the resource limitations of the client devices) "outsourced" as service in order to achieve the required real-time performance. We are thus able to integrate the captured 3D feature map with the BIM at service level, granting access to the 3D model including relevant infrastructure elements like electrical wires or pipe systems. Thus, the BIM provides the 3D-model as starting point for the tracking reference data. Therefore, our three main contributions are:

- A web based AR framework which accounts for different processing capabilities of mobile devices by combining embedded on-device camera tracking with a server- client approach enabling ressource critical devices to estimate the camera pose.
- An annotation engine which links spatially registered user annotations to corresponding objects in the BIM model.
- An exemplified use case that shows how the integration of BIM and the mobile AR framework in combination with the annotation engine can support building related documentation and maintenance tasks.

4 User-Centric BIM Compliant Annotations

In this section, we describe the annotation mechanism for extending and adding annotations to the BIM data. The main motivation for the annotation engine is to provide means to annotate BIM data directly in-situ, without the need to return to a workstation and manually feedback the changes into the BIM. With our solution, content can be added to the system on-site and on the fly. For example, technicians detecting an issue can directly record the problem where it occurred and do not need to return to their workplace and to insert a description of the issue into the BIM system. Our annotation engine

- uses web technologies ensuring interoperability along platforms
- can be used on arbitrary devices (mobile phones, desktop platforms or workstations)
- supports an AR mode for on-site annotations as well as a VR mode for annotations on workstations can either be used in single-client mode or in multi-client mode (synchronizing several distributed annotation clients)
- spatially registers annotations with the BIM 3D model, which directly links annotations with the correct corresponding object of the BIM 3D model.

The spatial registration of the annotations (which is based on the alignment of the 3D model with the real world) makes the recorded annotations easily accessible later on. When a facility manager inspects a location, the AR system visualizes all the annotations, which were acquired at and linked to the corresponding part of the 3D model. Thus, the user does not need to search a textual database for previously gathered annotations. Instead, he can directly access them via their positions in the building.

4.1 Annotation Interface

The annotation interface is modelled in X3D. On session setup, the user can start or join a session and select a 3D model with previously generated annotations. The annotation interface contains tools for navigating in the model, and for creating, displaying and modifying annotations. Each annotation stores the 3D position of the annotation in the physical building as well as a textual description, a set of attributes and attachments. All annotations are linked with the BIM data by their 3D position in the physical building and by the BIM object which is situated at this physical location. Fig. 3 shows the 3D positions of annotations represented by marker symbols. Each annotation marker provides a first small subset of the annotation information via its colour and ID. Furthermore, it serves as a button to access the full annotation information. The top image in Fig. 3 shows an open annotation on the right side, which contains a textual description as well as an attached image. Taking a snapshot with the camera of the mobile device is a fast and easy way to document the current state of an object in a building. After taking a snapshot, the user can mark or highlight important regions of interestes in the image. When several annotation clients are connected, users can share viewpoints and annotations with the other clients. Mobile users can stream their position in real time to other users. Fig. 5 shows the use of the distributed annotation engine on a mobile tablet PC and on a workstation. Whereas on the workstation the annotation system is a pure VR application, the annotation system on the mobile device uses the mobile AR framework described subsequently to link the pose of the mobile device in the physical building with the corresponding part of the virtual 3D model. In this mode, the camera pose of the real camera is tracked and sets the pose of the virtual camera. When the user moves the tablet PC, the real camera image is augmented with the virtual content. The bottom image in Fig. 3 shows the annotations augmented onto the image captured by the camera of the mobile device.

4.2 Annotation Exchange

We use a new exchange format for annotations in building models in order to transfer geo-located comments between different actors in the design and maintenance process. This format defines a zip container, called BCFZIP [26], which holds information about the annotation in XML files and a snapshot of the surroundings.

Fig. 4 shows the basic structure of an BCFZIP container with its 3 main files:

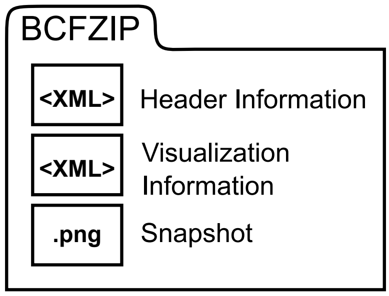

Fig. 4 Structure of an BCFZIP container

Header Information - Contains information about the referenced model, like title, project name, unique id and a date. It also contains information about the annotation: a unique id, a title, a reference (string - can be used to refer to a model part, or ticket in an workflow management system), information about the status of the issue, a reference to the author as well as a free text field to describe the issue.

Visualization Information - Information about the object which is referenced by the annotation and about the camera that was used to capture the issue. The referenced object is identified by its UUID and the system in which the component is originated. The camera is described by its location, orientation and field of view. Additionally, this file can contain positions for markers in 3d which can be used to mark the point of interest.

Snapshot - This image shows the viewpoint which was chosen by the author during the creation of the annotation.

All this data is very similar to the annotations in the system, which allows us the easy export and import of those files.

The Annotation Server shown in Fig. 6 offers a web interface which allows browsing through the annotations in the system. Within this interface, the displayed annotations can be downloaded in the exchange format. Also, files in the format can be uploaded via the web browser and are added to the database.

4.3 Component Architecture

Fig. 6 shows the system architecture of the annotation engine. While it is possible to use only a single client, it is also possible to synchronize several annotation clients through a synchronization service. The first annotation client that initiates the session is used as a hub for data synchronization (synchronization server). Each client consists of three major components: a database, an information server and an X3D browser. The database locally stores the annotations. It is synchronized with the

Fig. 5 Annotation engine on mobile device and on workstation

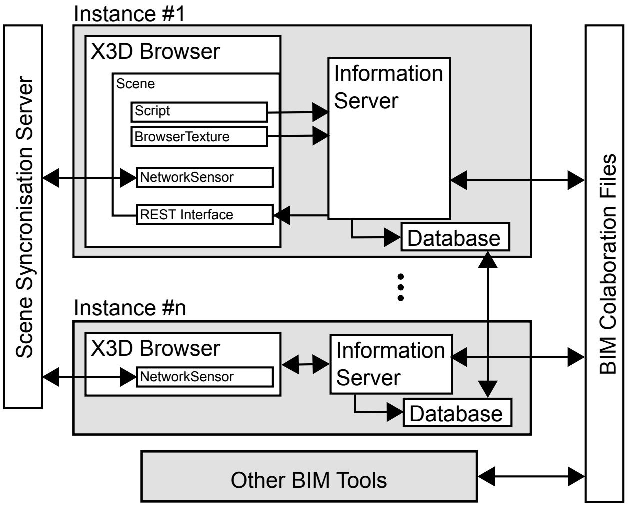

Fig. 6 System architecture of the annotation engine.

databases of the other clients. The information server is responsible for the session setup, for data storage, synchronization and for data representation. The browser displays an X3D scene, that contains the 3D model (from the BIM data), the annotations and the user interface. In addition to the interfaces shown in Fig. 6, the browser is also connected to the mobile AR framework, which provides the position and orientation of the mobile device. The communication between the X3D scene and the information server is HTTP based. A JavaScript node in the X3D scene uses an XMLHttpRequest object to access and to deliver information to the information server, whereas the server uses a REST interface to trigger actions in the X3D application. The information server provides the annotation data as an HTML site. Thereby, the annotations can be accessed through any web browser. They are integrated in the X3D scene with a BrowserTexture X3D extension node that also gives the user the possibility to add data and to modify existing data. When the user clicks on the touch screen of the mobile device to add a new annotation, the system calculates the position of the annotation on the 3D model by intersecting the view ray through the clicked point with the 3D model of the building.

5 Mobile Camera Tracking

In this section, we present a scalable mobile AR framework that provides the technological basis for supporting BIM with mobile AR applications and that accounts for the hardware capacities of different mobile devices:

– If adequate computational power of the mobile system is available, the 6D tracking is performed in real-time on the device itself (parallelizing tracking and 3D-reconstruction).
– If the mobile system is limited in computational power, the captured data is transmitted to the central backbone. The tracking is performed on the server. After processing, enhanced data including relevant information is retransmitted to the mobile system.

The proposed approach enables us to use all tracking methods on all devices, independent of the processing capabilities of the mobile devices. Our Augmented Reality framework InstantVision [3], available markerless camera tracking technologies encompass (among others) point-based and edge-based camera tracking [34], model-based analysis-by-synthesis methods [35], the reconstruction and alignment of 3D feature maps [32] as well as visual-inertial structure from motion [6][7]. Furthermore the tracking and initialization methods comprise BAG of visual words [8][16] and HIPs [28]. Several methods can be used on mobile phones as well.

5.1 Reconstruction Pose and Orientation using Analysis-by-Synthesis Methods

This section describes the key concepts for supporting BIM data with mobile Augmented Reality applications on mobile devices which are powerful enough to calculate the camera pose directly on the mobile device itself. While other state-of-the-art approaches are based on device specific solutions, our approach consistently builds on above mentioned web technologies:

– AR applications are declared using HTML5 and JavaScript.
– Perspective 3D and 2D content is embedded deploying X3D.
– The user specifies the desired tracking algorithms through XML configuration files. The tracking algorithms are executed by a platform independent and scalable computer vision engine [3].
– Data scalability is ensured by the combination of a distributed database with local storage on the mobile device.

A major advantage of our mobile tracking framework based on open standards is the reusability of its components. For example, tracking algorithms can be replaced without the need to adapt the other parts of the application. Previous approaches such as PhoneGap [19] provided either only a small subset of rather simple functions or were limited to specific tracking technologies, for example marker based tracking [22]. Furthermore, in contrast to previous approaches, our mobile tracking framework is able to interface several multithreaded engines which are executed in background processes. The main components of our mobile AR architecture are shown in Fig. 7. In order to unify the mentioned building blocks, we have created a uniform viewer for the mobile iOS and Android platforms. Special JS interfaces allow to access and connect data of the render engine and the computer vision engine InstantVision [3]. Our framework layers a transparent Web-Kit implementation over an X3D render engine, which directly communicates with the computer vision engine. By specifying abstractions in form of JS interfaces, the developer is able to load, modify, replace, and remove parts of the descriptions and thus to dynamically generate applications. Callbacks can be configured using AJAX services. With these interfaces, it is possible to access real-time information about the current tracking status, to process and to exchange data between the JS-Engine and the other processors in the backend. The lightweight mobile X3D render engine can render a subset of the standardized X3D nodes. In order to display the camera image in the background of the scene for the AR applications, we have extended X3D by an additional PolygonBackground rendering node [13]. To ensure data scalability, we combine a distributed server-based database with a hierarchical local database on the mobile device. The server-based database is a CouchDB database [29]. The CouchDB database stores the building related information, the configuration of the AR Application and the tracking data. The tracking data covers for example reconstructed 3D feature maps and device specific calibration data, such as the intrinsic camera parameters. It is possible to transfer partial or full tracking data via a network to and from a server infrastructure with XMLHttpRequests. The camera pose is calculated directly on the mobile device by the platform independent computer vision framework InstantVision [3]. Table I shows the tracking frame rate (frames per second) for three different mobile devices. The image width and height is the size of the image used for the camera pose estimation. In the sparse mode of the Lucas-Kanade feature tracker (KLT), approximately 15-30 features (Recon. Low) of a reconstructed 3D feature map were tracked in each frame. In the dense KLT mode, at least 50 features were tracked in each frame (Recon. High). The tracking accuracy is permanently observed by the system. If the accuracy of the vision based tracking is not sufficient (for example, if there are only few distinguishable features in the current camera image) or if the pose needs to be (re-)initialized, the pose is coarsely estimated from the built-in sensors (accelerometer, gyro or GPS if available).

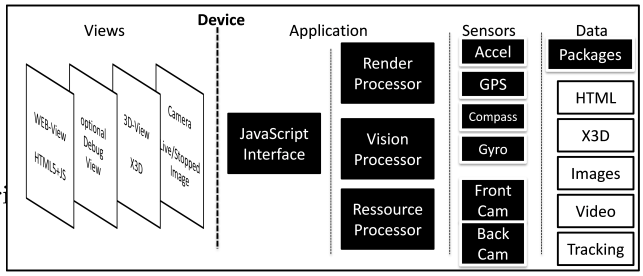

Fig. 7 Generic AR architecture for mobile devices. A JavaScript interface allows steering and connecting render-, vision-processor and other resources

Device	iPhone4		iPad2		Nexus-S	
Input Width	320	640	320	640	320	640
Input Height	240	480	240	480	240	480
Marker	30	18	30	19	30	17
Poster	19	14	30	30	17	10
Recon. (Low)	12	9	25	17	11	8
Recon. (High)	6	4	14	8	5	3

Table 1 Tracking performance(fps) for different resolutions on different hardware profiles and reconstructions of low/high density 3D feature maps

5.2 AR Service Infrastructure - Client and Server

In order to outsource resource intensive tasks we base our AR processing on a client-server infrastructure. Here, we can distribute processing on different backends allowing resource limited devices to perform minimal application processing rather than tracking and image processing tasks. Despite the fact that individual processing power is steadily increasing, it is still notably smaller than the processing power of custom desktop computers. The application layer of the AR client-server infrastructure complies with the REST paradigm exposing HTTP requests. The Transmission Control Protocol (TCP) is used as transport layer to transfer data from the client to the server and vice versa. The carrier is a typical wireless network. Our infrastructure is set up in a way that the clients send HTTP requests to the server. These requests usually encode and contain the currently captured camera image together with additional application related data. Afterwards, the received data is processed by an instance of the computer vision module on the server and the result is sent back to the client. If the processing speed of the client is significantly lower than the processing speed of the server, a smooth AR application can nevertheless be ensured by minimizing the calculations on the client and by shifting most calculations to the server. In this case, only the image acquisition of the camera on the mobile device and the visualization of the augmented image is processed on the client. All other calculations (image processing, camera tracking and the calculations needed for the AR application) are processed on the server. This approach has the advantage that the feasible complexities of the image analysis, the camera tracking module and the application are only restricted by the processing capabilities of the server. This is advantageous for complex applications because the processing speed and the available memory of the server can be upgraded more easily than the processor, the working storage or the graphics card of the mobile device. Thus the entire range of markerless camera tracking approaches can be used for Augmented Reality applications on mobile devices as well, independent of the used processor. On a mobile Nexus-S device, this client-server approach runs with a framerate of 12 frames per second and with a latency of 180ms if the captured camera image has a resolution of 640x480 pixel and if the output (screen) resolution has a resolution of 800x480 pixel. The framerate is independent of the tracking method applied on the server. A further advantage of the proposed approach is that it is also possible to augment the image with augmentations which cannot be rendered on the mobile phone itself, for example complex and large 3D models in arbitrary data formats.

6 Application Scenarios

In this section, we propose exemplified scenarios which show how the integration of BIM with AR and the mobile AR framework in combination with the annotation engine can support building related documentation and maintenance tasks. Based on a requirements analysis with experts, one of the major building related issues still is an integrated process chain from identifying damages during an inspection phase, followed by its documentation, up to finally solving the incidents. In current workflows envisioned changes or detected damages first need to be documented manually on-site (for example on a sheet of paper). This information can only be added to the facility management system after the building manager has returned to a workstation, where he has to document the relevant information anew. The same accounts for information from the BIM database, which has to be printed on paper before it can be used on-site. Therefore, we first present a use case which illustrates how BIM based AR can support the different steps of a building related process chain. An integrated demonstrator for a similar process chain was realized for the CSTB premises in Sophia Antipolis, for which a detailed BIM model exists, which models the whole building. The CSTB BIM/AR demonstrator uses the server-client infrastructure for AR based on-site analysis. The camera pose is estimated by tracking the 3D features of a reconstructed 3D feature map [32]. The service backbone hosts an instance of our realisation of the BIM system (EVE-BIM). A mobile phone was used for the on-site analysis and a tablet PC for the annotations.

6.1 Scenario - Installation of a Ventilation System

Our first use case illustrates how BIM based AR can support the different steps required for the installation of a ventilation system. The exemplary application scenario for a ventilation system includes the technical planning, the technical installation and the documentation of the performed operations.

Step 1 Technical planning
: For the reduction of energy, a new ventilation system should be installed in an existing office building. The engineer who is responsible for the planning of the technical installations in the company enters the technical room with his mobile computing system. With the smartphone integrated video

camera he captures the room. Using the annotation tool he can scribble in an overlay to the captured pictures where the main components of the service installation should be placed. After finishing the annotations, the room planer connects to the service backbone. He transmits his planning data to the enhanced BIM. His planning data is included into the BIM related database and is geo-referenced within the 3D-model of the building.

Step 2 Technical organization
The BIM is accessible via a workstation (e.g. Multi-Touch PC). Here the building manager reviews the technical planning; he distributes the tasks resulting from the technical planning to different craftsmen that can solve the task. The craftsman responsible for a specific task receives his tasks including all related information of the BIM as an action assignment on his mobile computing system and enters the relevant part of the building. In an augmented reality set-up he receives the planning data as superimposition to his captured camera pictures.

Step 3 Technical installation
Before installing the ventilation system, the technician has to control if the available pipes and electrical cables can be used for the service installation. Therefore he connects to the service backbone. Here the BIM data of the complete building complex is put together. On basis of the 6D pose tracking, data relevant for the area to be operated is selected and transmitted to the mobile device of the technician. The technician uses his mobile system to visualize all these information related to his order to install the new ventilation system. Thereby, the information is geo-referenced and is linked to the addressed building components. Via the multi-sensory semantic-based tracking, the annotations made by the engineer are overlaid with augmented reality visualizations. The technician also gets the information about existing cables and pipes all over the building so that he can check, whether he can use them or plan new pipes and cables, if he needs them. Based on the information of the engineer and his own plans, he can install the ventilation system.

Step 4 Technical documentation
For the documentation, the technician scribbles the cables and pipes he has renewed and completes the information about the service installation and their integration. After finishing his work, he connects to the service backbone and transmits the information to it.

6.2 Scenario - Meeting Room

Step 1 The architect checks the project using BIM (c.f. Figure 8) The geometrical container of the BIM model used within this scenario represents exactly the meeting room within the CSTB-Building. Thereby the model includes information about joints, the isolation material included cables etc., the model includes also a planned audio installation that will be included within the meeting room.

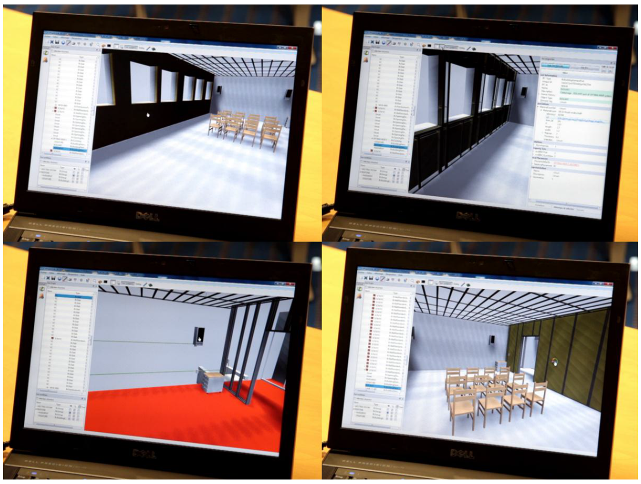

Fig. 8 Visualisation of the meeting room within our prototypical BIM system

Thereby the architect focuses on the meeting room (near the projection screen) in order to install a new video/sound system and he checks the composition of the wall (various layers) and the existing electrical cabling.

Step 2 The architect is performing an on-site analysis using Augmented Reality on his smartphone (c.f. Figure 9) The smartphone integrated camera is used to capture the meeting room. In real-time the captured images are transferred to the service backbone. On the service backbone the pose of the smartphone is registered and according to this captured pose the filtered informations of the BIM model are rendered in superimposition to the captured camera images. In real-time the rendered images are streamed back to the smartphone and are rendered within the Web-Browser. Also touch interactions executed on the smartphone are registered and transferred to the service backbone, thus the user can select different components of the BIM data to be visualized within AR client.

Step 3 The architect then uses scribbling tool to mark new positions of the cabling to be installed (c.f. Figure 10) While capturing the room the architect is

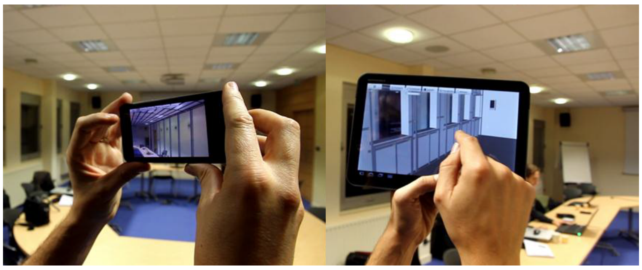

Fig. 9 AR Visualisation of the BIM data in superimposition to the captured meeting room

performing some changes of the planning. Therefore he wants to change the planned cabling. Using his AR client device the architect is setting an annotation. The annotation is linked to the BIM model of the meeting room. On a captured snapshot the architect is scribbling his changed cable plan. Via HTTP the scribbling is transferred to the CouchDB and linked to the BIM model.

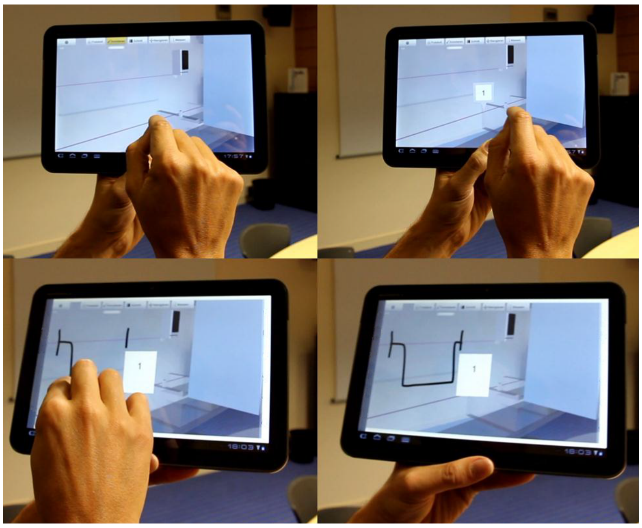

Fig. 10 AR scribbling for documentation of the planning process

Step 4 The scribbling is transferred to http accessible DB and then added to the BIM server in order to be used by other stakeholders (c.f. Figure 11) From the AR client adaptor the annotation is retransferred to the service backbone. Thereby, the tracked position of the annotation is used to establish a geolocated reference within the BIM model. The annotation can also be used by different stakeholders that are working on the building with the BIM data.

Fig. 11 Transmission of the onsite annotations into the BIM model

6.3 Scenario - Building Envelop

From the integration point of view this scenario is similar to the indoor scenario. But here the mobile AR system is used outdoor (c.f. Figure 12). This outdoor scenario is very challenging in the context of tracking as feature point based tracking methods are difficult to use (because of unstable illuminations and wandering shadows). Therefore, we mainly use contour based tracking methods as described above in order to stabilise the outcome of the vision based tracking.

7 Conclusion

We have presented a mobile AR framework as well as an annotation engine, which provide the basis for mobile AR applications that support the building life cycle by integrating virtual information with the real environment. One of the main contributions of the presented system is its flexibility and scalability, as a result of which the distributed BIM AR applications can be realized on arbitrary devices. The presented mobile AR framework supports markerless tracking technologies on mobile devices with different processing powers, both by a client-server based AR infrastructure and by a generic tracking framework for mobile devices whose processing power is fast enough to handle the necessary calculations themselves. The thorough use of standardized interfaces such as HMTL5, X3D (both for the AR framework and for the annotation engine) and REST paradigms ensures a maximal interoperability. The proposed system provides the technological basis for the creation of mobile AR applications which fuse 3D building models with semantic annotations. In addition to the mobile AR framework and the annotation engine,

Fig. 12 Use of the AR client adaptor in our outdoor scenario

we have provided use cases which show how these technologies could support the building lifecycle management. The combination of BIM with AR offers building related data directly on-site and provides the basis for mobile on-site documentation. When presenting the developed technologies, we have received positive feedback. For example, maintenance employees stated that such a system would remarkably simplify their work because they would not need to carry on heavy, printed manuals anymore and that they would not need to tediously search the required information in the paperwork any longer. In future work, it will be interesting to conduct studies which quantitatively evaluate the effects of AR support for building related maintenance and documentation tasks. We expect that the combination of BIM data with AR will be particularly evident when it comes to the visualization of hidden objects which are part of the BIM data, but not visible in the real world. With mobile AR it becomes possible to see what was built inside a wall, for example the position of water pipes or electrical cables. Due to the steadily increasing availability of building related data, in the future BIM data will not only be accessible for facility managers but also for building inhabitants or house owners. For this new market, markerless augmented reality applications offer a large potential, as they integrate BIM data with the real world and thereby make hidden information intuitively visible.

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