Lifecycle Building Card: Toward Paperless and Visual Lifecycle Management Tools

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Keywords: Building Information Model, Augmented Reality, Building Lifecycle, Visual Simulation

Abstract

This paper presents a novel vision of paperless and visual lifecycle building management tools based on the coupling between Building Information Models (BIM) and Augmented Reality (AR) called Lifecycle Building Card. As the use of BIM increases within the architecture, engineering, and construction industries, new opportunities emerge to help stakeholders and maintenance operators to leverage the BIM dataset for lifecycle issues using realtime environments and simulation. In particular, a tighter coupling of BIM with computer vision techniques could enable innovative lifecycle management tools based on AR concepts. In this context, this work explores the possibilities and derives theoretical and practical concepts for the use of BIM enhanced by AR for supporting maintenance activities in buildings. An implementation of a wireless spatially-aware display is presented as a first step toward the stated vision.

1. INTRODUCTION

Society is facing an overwhelming number of urgent issues related to global warming, carbon footprint and energy consumption reductions. The building sector is particularly under pressure as it is one of the biggest consumers of energy, either directly for lighting and thermal comfort (heating and air conditioning) or indirectly from the production of building materials. It also largely contributes to the massive use of critical resources (such as energy, water, materials and space) and is responsible for a large portion of greenhouse gas emissions. For example, in Europe, the construction sector generates up to 25% of the greenhouse gases and uses up to 45% of energy overall. Therefore, any serious strategy aiming to reduce greenhouse gas emissions and deliver energy savings will have to include the construction sector. Thus, the architecture, engineering, and construction (AEC) sector is under significant pressure to reduce its ecological footprint but at the same time, to provide better living and working conditions.

Current business models and working methods are clearly not resulting in sustainable systems and so, new solutions are needed to address these complex and multidisciplinary issues. Improvements needed in the AEC processes relate to:

- Improved architectural and technical design.
- Building components coherent with the design.
- High-performance construction processes.
- Management of the overall lifecycle process i.e. design, construction, operation, maintenance, refurbishment, and destruction with a feedback loop of learned best practice to future projects.
- An operation process that ensures maintenance activities adapted to use and transparent to occupants.
- Systematic inspection of the building envelope.
- Inspection of "weak points" (openings, cabling, electrical plugs) to ensure proper insulation installation.
- Verification of HVAC components (regulation, ventilation, heating) in operation.

A central problem in buildings is the successful implementation of the original design intent. To support continuous improvement after construction, to reach the original design goals, the creation and movement of data, throughout the lifecycle of an AEC project, must be accessible and usable.

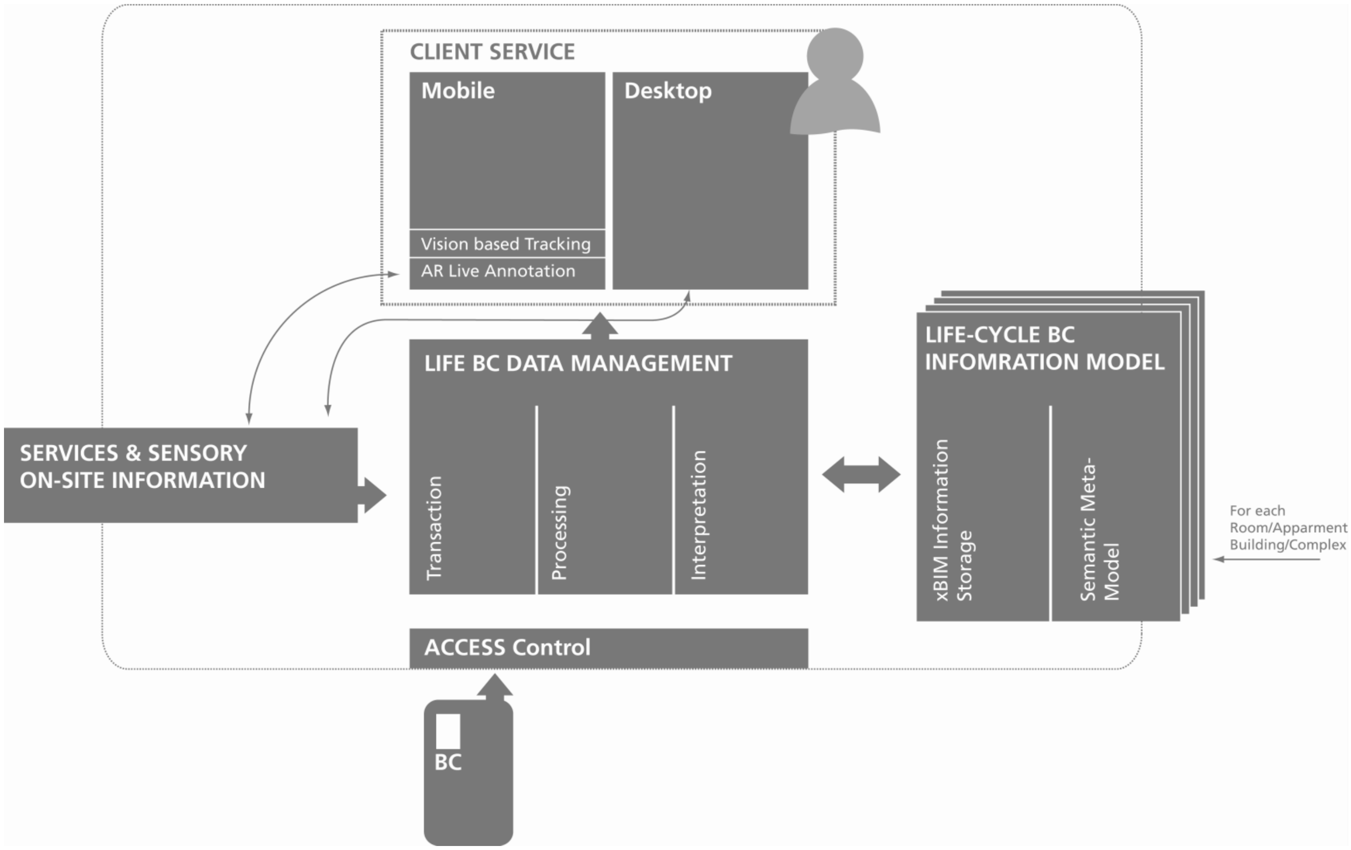

Figure 1. Architectural layout for the visual management of lifecycle building information.

2. LIFECYCLE BUILDING DATA

The majority of the building stock that will be available in 2050 already exists today. The original design intent of these buildings is generally available through the construction drawings but the difference between intent and as-built (the on site condition) is challenging to discover. Surveys (TNO 2010) show that most common complaints, in the area of comfort and high energy consumption, are caused:

- 15% by design errors
- 85% by equipment handover & maintenance problems

This indicates that maintenance and facility management (FM) operations on this existing stock are essential areas of focus for improvements. In particular, the combination of Building Information Modeling (BIM) together with computer vision and tracking technologies would allow future applications to capture and visualize the "as-built" information for "just in time" operation and maintenance tasks. Furthermore, innovative information and communication technologies (ICT) offer potential for the deployment of ubiquitous, anytime anywhere, applications that can be adapted to these needs.

In order to allow a fusion of BIM entities and Augmented Reality a dedicated workflow backbone has to be envisioned for the purpose of an overall lifecycle management of building information. Ideally, it will be a service oriented information system consisting of components which provide an integrated management of BIM data. The planned architecture (see Figure 1) provides a scalable client application interface for the access, retrieval and distribution of enhanced building information model data, its annotation branches and change history. A data management system suits as a service backbone serving different purposes of information processing. The data management system follows a modular service oriented approach in which different services are provided such as transcoding of information models, processing of image data, feature comparison for online tracking, and interpretation modules for the interlinking of semantic information. Users or othe involved persons would be extending the database throughout the operational life of a building by gathering and maintaining the data and versions.

Therefore data in the BIM would be extended reflecting the users need for additional meta-information attached to each object or element. Simple textural information or multiple media elements have to be processed and interlinked to physical and virtual 3D/3D elements. The information model will then be wrapped through a semantic module which would take care of the management of the metadata. A physical token, the Lifecycle Building Card serves as an eCard and will allow access to building information throughout the overall lifecycle of the building.

3. BUILDING INFORMATION MODEL (BIM)

Virtually all of the surveys carried out in the construction industry place interoperability as a key issue for the use of ICT (Wix 2009). The evidence for available cost benefit comes from a study conducted by the U.S. National Institute for Standards Technology (NIST) in which the lack of interoperability was estimated in 2004 to cost U.S. industry more than US$15 billion per year (NIST 2004). However more recent estimates suggest that this figure might be too low.

The key to interoperability is that there must be a common understanding of the building processes and of the information that is needed for, and results from, their execution. This is where BIM plays a key role since it is the term applied to the creation and use of coordinated, consistent, computable information about a building project in design, in construction and in building operation and management. The term has been adopted within the building and construction industries to replace Computer Aided Design (CAD). With CAD, the emphasis was on the creation of a representation of the building geometry, such as walls, windows, and doors, in 2D using basic geometric entities such as lines, arcs, and circles. BIM places the emphasis on the objects from which the building is constructed or that describe the process of construction such as walls and windows, but also abstract concepts such as tasks or approvals. The emphasis is placed on 'information' and 'modelling'. BIM is sometimes referred to as virtual design and construction (VDC) (Kunz 2009) because it can be used for simulation of the real building.

Building Information Modelling is the process of using modern software tools to deliver a 'Building Information Model' which is the collection of objects that describe a constructed item. Both the process and the result use the term BIM. It should be noted that whilst the word 'building' is used, BIM can be applied to any constructed artifact including bridges, roads, process plants and others.

An object represents an instance of 'things' used in construction. These can include:

- physical components (e.g. doors, windows, pipes, valves, beams, light fittings etc.),
- spaces (including rooms, building storeys, buildings, sites and other external spaces),
- processes undertaken during design, construction and operation/maintenance,
- people and organizations involved,
- relationships that exist between objects.

An object is specified by its identity, state and behaviour:

- each object has a unique identifier that makes it distinct from any other object even where they are otherwise exactly the same,
- state is determined by the values given to the data attributes of that object,
- behaviour specifies how the object reacts to operations carried out on them.

Within BIM, the geometric representation of an object is an attribute. This differs from CAD in which geometric representations of objects is critical. A BIM handles objects as though they were real things and not just as a representing shape. Shape is an attribute (or property) of an object in exactly the same way as cost or construction time or the material from which the object is constructed. Quite often, a BIM is discussed as a 3D object model. Use of '3D' makes the attempt to characterize BIM as being geometry driven, similar to usage of the term in CAD. A BIM will often be represented as 3D. However, it could also be represented as an abstract list of objects and relationships, or 2D CAD-like drawings may be extracted from the BIM.

BIM software is typically seen as being the large mainstream applications such as Revit, Bentley, ArchiCAD and similar. Increasingly however, downstream applications such as those used in structural, energy and HVAC applications are becoming BIM applications. The definition of 'what is BIM software' needs to be wider than has been considered in the past. It is possible even that BIM is not one single software application but is the result of multiple software applications working collaboratively.

IFC (Industry Foundation Classes) emerged as the major standard for BIM implementation in the scope of construction industry information exchange [IFC2x3]. Its development is the result of an industry consensus building process over several years and across many countries. IFC contains common agreements on the content, structure and constraints of information to be used and exchanged by several participants in construction and FM projects using different software applications. The result is a single, integrated information model representing the common exchange requirements among software applications used in construction and FM specific processes. It is currently registered with ISO as a Publicly Accessible Specification [ISO16739] with work now proceeding to make it into a full ISO standard.

4. AUGMENTED REALITY (AR)

A comprehensive overview of Augmented Reality within the AEC sector can be found in Wang (2009) and Graf (2010). Most research in AR focuses 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. Nevertheless, within the architectural domain one of the most obvious applications is visualisation of buildings on site. In this context, Dunston et al. (2002) use AR technology for visualising AEC designs. An obvious extension of onsite visualisation is being able to design onsite as well. Hence, another application area has been studied in aiding the design and construction process. Shin and Dunston (2008) showed that AR is a potential technology that can aid several work tasks on a construction site for building and inspection, coordination, interpretation and communication. By presenting construction information in a way that is easier to perceive, AR is expected to provide more cost and labor effective methods to perform the work tasks. The potential benefits deploying user studies for AR in construction have been suggested or demonstrated e.g. excavation information (Roberts et al. 2002) or steel column inspection (Shin and Dunston 2009). Since that time the processors in mobile phones have become fast enough to also support AR applications (Möhring et al. 2004, Henryssen and Ollila 2004, Stricker et al. 2009). The mobile phone is an ideal AR platform because the current phones have full colour displays, integrated cameras, fast processors, and even dedicated 3D graphics chips. Wagner (2007) identifies several advantages for PDA and mobile phone AR such as low per-unit costs, compact form factor, low weight allowing comfortable single-handed use, and touch screens for intuitive user interfaces. However, in view of the management and presentation of building lifecycle data, currently no platform is available that allows the efficient use of AR within the AEC sector, nor addresses potential application areas in which this data might be useful. As mentioned above, there are some fragmented solutions but clearly lack of integration. In order to make use of this technology and create sustainable impact on the AEC sector, one of the key issues is to establish a robust and markerless tracking system that is adapted to the use of BIM. Furthermore, it should allow capturing and tracking of changes to the building envelop due to maintenance tasks in the context of lifecycle management of building information. Thus there is a need to establish feedback channels from the real environment into extended user-defined BIM structures.

5. TRACKING

The localization of the user on the site represents a key issue of augmented reality. While several mobile devices provide a global positioning service (GPS) receiver and an internal digital compass, only coarse positioning information is available and even then, primarily in an outdoor setting. Furthermore, such sensors are too slow and not accurate enough to allow proper superposition of virtual views onto images of the surroundings in real-time. Vision-based sensors can provide additional data but when looking at a white surface such as a wall, for example, to see what may be inside the wall, further data is needed to differentiate which floor the user may be on and which wall may be in view. Many approaches have been developed, the main issue being reliability and accuracy (no jitter). Difficult lighting conditions of indoor and outdoor environments further complicate matters. Within the envisioned work, we intend to deploy a markerless robust tracking workflow that comprises two major steps: first, establishing and initialisation of a feature map without a priori information that allows for an optimal transformation and alignment using a small subset of known feature points. Secondly, the fusion of the reconstructed map and the obtained on-site image sequence, in order to train a feature classifier for subsequent tracking. This establishes frame-to-frame 3D tracking and a retrieval of 3D/3D-correspondeces between a small subset of reconstructed points and their true anchors within the CAD part of the BIM model.

5.1. Initialisation Step

The initialisation is a major challenge in order to obtain a first estimate of the scene's 3D geometry. Typically Kanade-Lucas-Tomasi features (KLT) (Bleser et al. 2006; Baker et al., 2004) are initialized with a corner detector (Rosten et al. 2006) in the first frame and tracked in 2D throughout the following frames. Several tracks of the features are stored back into a database for later recall. The idea is to establish a structure from motion analysis with a synthesis mechanism that allows retrieval of 2D point correspondences of two subsequent images. This mechanism delivers a matrix that can be decomposed into a rotational matrix and a translation vector. This vector can be used to triangulate 3D positions of the points. However, there are situations in which this procedure fails, i.e. when the matrix is not well defined. This can happen when the translation vector is not available, which means there is no translational move within the camera's motion. In this case, a homography-based reconstruction method must be used (Faugeras et al. 1988).

The following steps have to extend the initial found feature map incrementally while moving the camera. Several features will traverse different states in which their contribution to the overall reconstruction process changes gradually: points which are only passively triangulated at the beginning may serve later actively for pose estimation of the camera (Bleser et al. 2009). When the pose of the camera is valid, new features are initialized with a corner detector at locations in the image, where the feature density is low. Therefore, we rasterise the image into grid cells and apply the corner detector with non-maxima suppression. We then classify a feature as initialized if the corresponding image cell does not contain a maximum number of successfully tracked features. After initialization and the successful tracking of a feature in a second frame, an initial 3D location estimate can be obtained through triangulation (see above). If the feature's 3D-position is considered to be sufficiently accurate it may serve for pose estimation. Otherwise a smoothing step using Kalman filtering has to be applied.

5.2. 3D/3D Correspondances and Frame-to-Frame Tracking

The establishment of the 3D/3D correspondances can be obtained in different ways, either interactively using a dedicated workflow tool, that allows to interactively manipulate a CAD reference model from our BIM or using a text field in order to fill in the coordinates. This has to be done only for few relevant features as the following tracking exploits the relative position to the remaining intialised features of the feature map (see Figure 2).

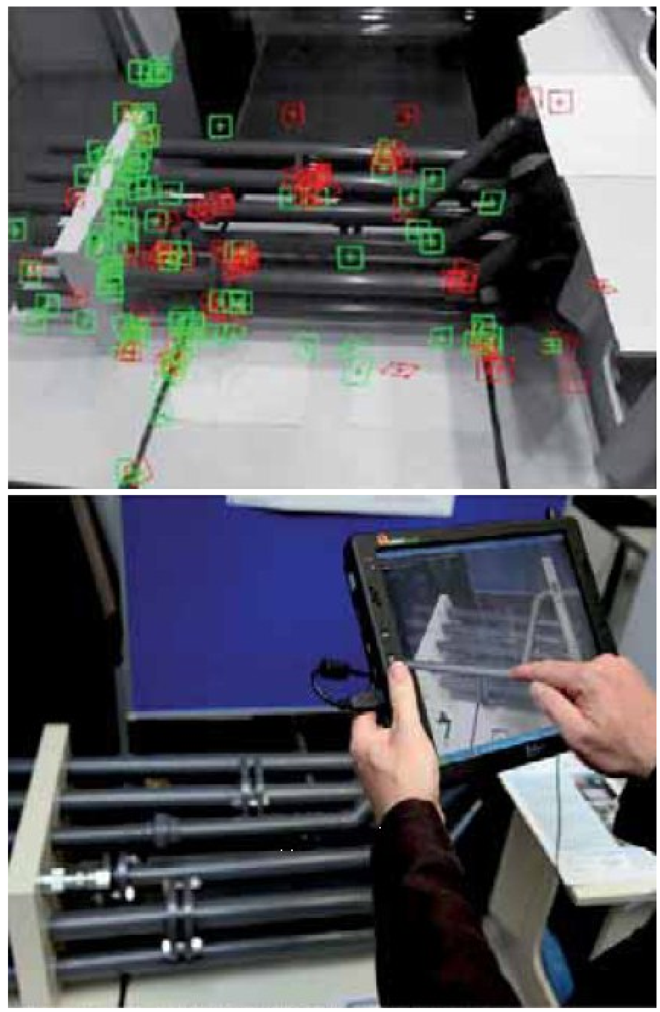

Figure 2. Example of initalised features (top) and its mapping to 3D virtual objects modeled using a CAD model (bottom).

Alternatively, it is also possible to take into account a list of known points given at the beginning (e.g. coordinates of markers or salient points on a known object within the real environment). It is now possible to calculate an optimal transformation based on rotational **R***, translational **t*** and scale **s*** entities for the reconstructed feature map based on a least square optimization. A minimum number of three 3D/3D-correspondences is needed (which should not be collinear). Up to 10 points are usually sufficient depending on how far the selected anchor points are spread along the scene.

5.3. Line Model Tracking

A complementary approach which could support the robustness of the above mentioned way is the use of an online line model tracking algorithm as presented in (Wuest et al. 2007). The algorithm creates a view-dependent 3D line model based on a prediction of the camera pose and exploiting an edge map by analyzing discontinuities in the z-buffer and the normal-buffer. Here, two types of edges are used which either correspond to a partially occluded surface or crease edges which are the locations of two adjacent surfaces with different orientation. Finally, the tracking is established using an extraction of 3D-lines out of the edge map based on a Canny like edge extraction algorithm. This results in a 3D contour within the world coordinate system by un-projecting every pixel in the edge map to the information stored in the z-buffer. During the contour following of the edges in the edge map 3D control points and their 3D direction are generated directly and used as the input for the tracking step. The real time edge detector allows 2D edge information being registered with edges obtained from the CAD model within the BIM (see Figure 3).

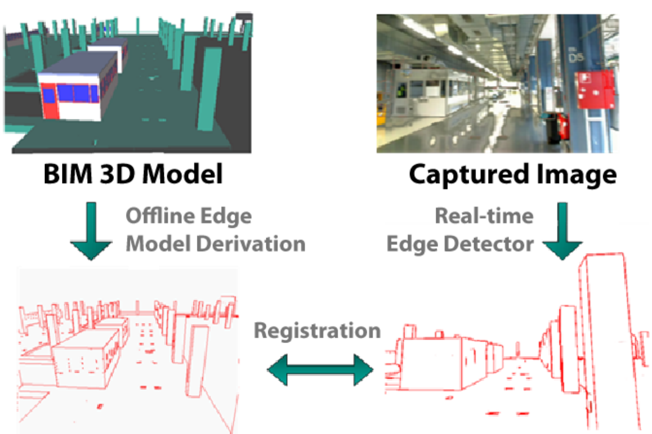

Figure 3. Model based tracking using BIM data.

6. PROTOTYPE APPLICATION

Mobile devices will be used in order to present “as built” information to the owner, landlords or persons in charge of maintenance. Users will be able to browse through historically grown information spaces in which changes done throughout the lifecycle of the building can be monitored, visualised at a certain level of detail, explode geometries retrieving higher resolution of the information space and to capture changes made to certain built in elements such as pipes, electrical wires, cabeling, etc. (see Figure 4). Moreover, the envisioned system will investigate several possibilities to feedback real-time multidimensional data and multimedia annotations in order to enhance the BIM. A semantification module will make them accessible to experts, timestamp those and record the historic evolvement of the quality of the building status. A physical access token will grant access at different levels of information ensuring privacy and security enabling adequate filtering mechanism within the Life BC management system.

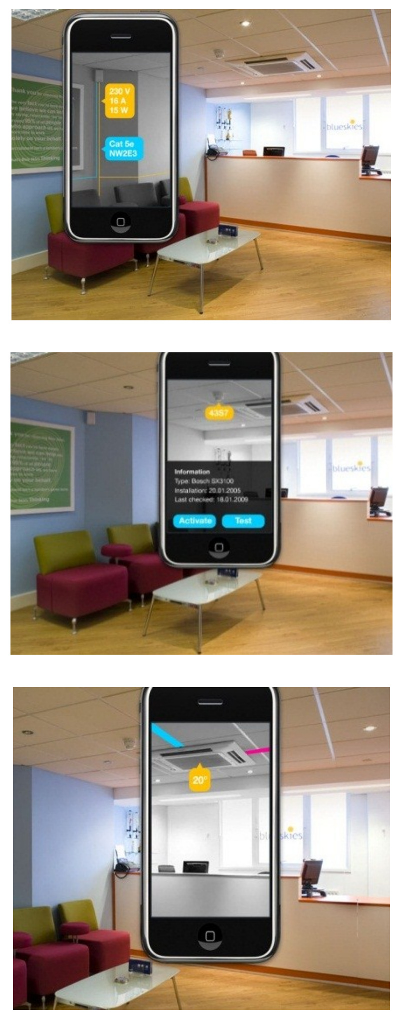

Figure 4. Application scenario of maintenance activities; “visualize the invisible”.

In order to prototype a mobile application, an existing BIM viewer called goBIM (Keough 2009) was enhanced as a proof of concept. Using special markers for in-situ calibration, the goBIM application is able to overlay live camera data and display overlayed, locally cached BIM data. Future prototypes will add tracking and remote data base capabilities.

Figure 5. Registering at calibration tag (top). Inspecting HVAC above ceiling (middle). Image shown on mobile device screen (bottom).

6.1. Using Markers towards a markerless system

Regardless of the quality and accuracy of feature based tracking, the need for calibration and verification of tracker accuracy is a fundamental requirement of any such system. In order to test and prototype a markelss system, the use of markers and fiduciary symbols is a proven technique employed in previous approaches (Zhou et al. 2008).

Fiduciary symbols by themselves provide easily identifiable features for tracking but generally, do not encode complex or structured information. QR tags (Denso Wave) provide unique, machine identifiable markers and also have the capability to store slightly more than 4 kBytes of information. The information stored can take the form of custom structured information or remote tags and identifiers like URLs or GUIDs. BIM models lend themselves well to the generation of QR tags for the labeling of real world objects as they map to their digital representations in a BIM.

Accelerometer and feature based tracking often requires calibration and tracking. Using GUIDs or BIM camera positions embedded into QR tags authored by the BIM application, we can easily identify and locate objects in the real world for verifying and calibrating markerless sytems. Towards that end, our prototype system uses QR tags to embed both the unique BIM identifier as well as the camera position. Our prototype uses accelerometers within the mobile device for local navigation of the immediately surrounding area while overlaying BIM data with the current camera feed for the given view as seen in Figure 5.

6.2. BIM Annotations

Separately creating and maintaining calibration markers for a BIM can be error prone and problematic. To reduce this effect, we propose a method for annotating a BIM based on authoring calibration markers as part of the BIM authoring process. To create the calibration markers used in our prototype, a custom written addin automatically generates a QR tag and stores it as a BIM annotation in the form of an image or texture. In this fashion, tags can be authored and centrally maintained using existing software. Open BIM datamodels, such as IFC, provide various mechanisms for annotation so that tags are portable and maintainable. IFC entities such as IfcAnnotation derived classes as well as IfcSurfaceTextures and IfcImageTextures provide the mechanism for storing the QR image. IfcAnnotation classes contain representations for lines, curves, fill areas, symbols, text and even general 3D geometry which can be used to create physical geometry annotations like blocks for the QR markers to be pasted on. Using Image and surface textures we can then attach the tags to the custom surfaces via IfcSurfaceAnnotations to provide physical proxies of the tags in 3D.

7. CONCLUSION

The presented work explored the possibilities and derived theoretical and practical concepts for the use of BIM in combination with real-time visual presentation systems such as Augmented Reality. It further on provides advanced concepts for the BIM and AR technology being integrated based on a scalable, service driven architecture in wich tasks for the transcoding of BIM models and their use for registration with real world environments are supported. A first prototypical implementation was shown to help discover potential difficulties. Finally, we hope to efficiently be able to support maintenance activities in the future.

Acknowledgements

The endeavours for a Lifecycle Building Card are supported by the Inter-Carnot Programme of ANR (France) and BMBF (Germany).

References

BAKER, S., MATTHEWS, I. (2004) LUCAS-KANADE 20 YEARS ON: A UNIFYING FRAMEWORK. INT. J. OF COMPUTER VISION, 56(3):221–255.

BLESER, G., STRICKER, D. (2009) ADVANCED TRACKING THROUGH EFFICIENT IMAGE PROCESSING AND VISUAL-INERTIAL SENSOR FUSION. COMPUTER & GRAPHICS (C&G), 33(1):59–72.

BLESER, G., WUEST, H., STRICKER, D. (2006) ONLINE CAMERA POSE ESTIMATION IN PARTIALLY KNOWN & DYNAMIC SCENES. ISMAR, 56-65.

DENSO WAVE. WWW.DENSO-WAVE.COM/QRCODE/ABOUTQR-E.HTML

DUNSTON, P.S., WANG, X., BILLINGHURST, M., HAMPSON, M., (2002). MIXED REALITY BENEFITS FOR DESIGN PERCEPTION, PROC. THE 19TH INTERNATIONAL SYMPOSIUM ON AUTOMATION AND ROBOTICS IN CONSTRUCTION, PP.191–196.

FAUGERAS O. AND LUSTMAN, F. (1988) MOTION AND STRUCTURE FROM MOTION IN A PIECEWISE PLANAR ENVIRONMENT. INT. J. OF PATTERN RECOGNITION AND ARTIFICIAL INTELLIGENCE, 2:485–508.

GRAF, H. AND SANTOS, P. (2010). AUGMENTED REALITY FRAMEWORK SUPPORTING CONCEPTUAL URBAN PLANNING AND ENHANCING THE AWARENESS FOR ENVIRONMENTAL IMPACT. SIMAUD'10, PP. 142-149.

HENRYSSON, A., OLLILA, M. (2004) UMAR: UBIQUITOUS MOBILE AUGMENTED REALITY. PROCEEDINGS OF THE 3RD INTERNATIONAL CONFERENCE ON MOBILE AND UBIQUITOUS MULTIMEDIA, PP. 41-45.

KEOUGH, I. (2009). GOBIM: BIM REVIEW FOR THE IPHONE. ACADIA '09. PP. 273-277.

KUNZ, J., FISCHER, M. (2009). VIRTUAL DESIGN AND CONSTRUCTION: THEMES, CASE STUDIES AND IMPLEMENTATION SUGGESTIONS, CIFE WORKING PAPER #097, VERSION 9: JANUARY 2009.

MÖHRING, M., LESSIG, C., BIMBER, O. (2004). VIDEO SEE-THROUGH AR ON CONSUMER CELL PHONES, ISMAR'04. PP. 252–253.

NIST (2004). WWW.BFRL.NIST.GOV/OAE/PUBLICATIONS/GCRS/04867.PDF. [LAST VISITED JULY 2010]

ROSTEN, E., DRUMMOND, T. (2006) MACHINE LEARNING FOR HIGH-SPEED CORNER DETECTION. LNCS PROC. EUROPEAN CONF. ON COMPUTER VISION (ECCV), VOLUME 1, PP. 430–443.

ROBERTS, G., EVANS, A., DODSON, A., DENBY, B., COOPER, S., HOLLANDS, R. (2002) THE USE OF AUGMENTED REALITY, GPS AND INS FOR SUBSURFACE DATA VISUALISATION. PROC. FIG XXII INTERNATIONAL CONGRESS, TS5.13 INTEGRATION OF TECHNIQUES.

SHIN, D., DUNSTON, P.S. (2008) IDENTIFICATION OF APPLICATION AREAS FOR AUGMENTED REALITY IN INDUSTRIAL CONSTRUCTION BASED ON THE SUITABILITY. AUTOMATION IN CONSTRUCTION 17(7):882-894.

SHIN, D., DUNSTON, P.S. (2009) EVALUATION OF AUGMENTED REALITY IN STEEL COLUMN INSPECTION. AUTOMATION IN CONSTRUCTION 18(2):118-129.

STRICKER, D., PAGANI, A., ZÖLLNER, M. (2009). IN-SITU VISUALIZATION FOR CULTURAL HERITAGE SITES USING NOVEL AUGMENTED REALITY TECHNOLOGIES, INTERNATIONAL MEETING ON GRAPHIC ARCHEOLOGY AND INFORMATICS, CULTURAL HERITAGE AND INNOVATION (ARQUEOLÓGICA 2.0)

BORSBOOM, W. (2010). TNO - BU BUILDINGS AND SYSTEMS. SEMINAR AT ENVIRONMENTAL ENERGY TECHNOLOGIES DIVISION, LAWRENCE BERKELEY NATIONAL LABORATORY

WAGNER, D. (2007). HANDHELD AUGMENTED REALITY, PH.D., INSTITUTE FOR COMPUTER GRAPHICS AND VISION, GRAZ UNIVERSITY OF TECHNOLOGY.

WANG, X., SCHNABEL, M.A. (2009). MIXED REALITY IN ARCHITECTURE, DESIGN AND CONSTRUCTION. SPRINGER. PP. 157–170

WIX, J. (2009). IMPROVING INFORMATION DELIVERY IN COLLABORATIVE CONSTRUCTION INFORMATION MANAGEMENT. TAYLOR AND FRANCIS. PP. 156-165.

WUEST, H., WIENTAPPER, F., STRICKER, D. (2007) ADAPTABLE MODEL-BASED TRACKING USING ANALYSIS-BY-SYNTHESIS TECHNIQUES. CAIP'07. PP. 20-27.

ZHOU F., DUH H., BILLINGHURST M. (2008). TRENDS IN AUGMENTED REALITY TRACKING, INTERACTION AND DISPLAY: A REVIEW OF TEN YEARS OF ISMAR. ISMAR 2008. PP. 193-202.