INTEGRATING BUILDING PRODUCT MODELS WITH LIVE VIDEO STREAM

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ABSTRACT: Various Building Information Models (BIMs) are increasingly used for data sharing and communication purposes in real estate and construction sector. This change can be seen as part of more general development where the main target is wide integration infrastructure to handle user interaction, business process, applications and data. Besides of new achievements in BIM technologies the described general development is enabled in an interesting manner by the overall technological integration that is bringing together traditional IT, telecommunication, Internet, TV and radio technologies and entertainment business. The resultant solutions have already changed clearly our working environment, its processes and business, and, more even radical changes are likely to appear. This paper shall present a research project addressing combination of building product models with live video stream applications. The research project named '4D Live' explores hardware, middleware and software platforms for the named purpose whilst the main target is to study emerging new sector specific business processes and changes arising from these solutions. 4D Live project is producing several demonstrative solutions where building models are combined with live video stream from one or several digital video cameras: i) Live internet based 4D, ii) Augmented reality web camera, and iii) Multi-Camera studio for BIM-Human interaction.

KEYWORDS: BIM, building product models, augmented reality, visualizations

1. INTRODUCTION

We have recently been witnesses of diversiform developments in relation to Building Information Modelling technologies. First, data models as an overall approach for organising the identification and classification of data has a very wide acceptance also in industry. This is seen as a strategic avenue for development of the real estate and construction sector towards the next level of improved performance. Second, on the other hand there are obvious limitations concerning multi-purpose and wide-scope BIM standards such as IFC (Amor et al, 2007). IFC is used as an example of BIM standard throughout this paper. In particular the complexity of such standards may seriously hinder their wide industrial usage. It is likely that the development of these standards shall soon have a different form and its objectives are to be changed. Third, industrial BIM solutions are increasingly in place and software companies are providing solutions for these purposes. These solutions can provide functionalities enabled by building information modelling although the solution may provide only rather limited (if any) support based on the actual BIM standards. Rather the software companies are developing these products based on their own vision and data modelling technology that can be clearly different than the overall solution provided by IFC. Thus it seems

probable the wide industrial BIM shall appear on the basis of product specific standards, and, various translators and converters shall be used for the integration and data transfer purposes.

The described general development of BIM technologies is enabled in an interesting manner by the overall technological integration that is bringing together traditional IT, telecommunication, Internet, TV and radio technologies and entertainment business. Now the actual building information models can provide starting point and data source for new fascinating tools that can both increase the total value of building information models and stimulate research community to study such applications. The following examples demonstrate recently emerged research agendas and topics

- *nD modelling*: integration of nth number of design dimensions for portraying the building design from these viewpoints (Aouad et al, 2007)

- *Virtual Reality Technologies*: new interactive communication practices (Leinonen et al, 2003)

- *Internet based telepresence for human-building interaction:* the transmission of interactively controllable live access to remote construction site or building (Quillian, 2005)

- *Augmented reality*: combination of real world and building data (Woodward et al, 2007; Malkawi & Srinivasan, 2005)

- *Mobile technologies*: distributed and mobile work of all real estate and construction practitioners (ENR, 2004)

- *GIS, GPS and RFID Technologies* (Radio Frequency Identification): monitoring the location and condition of building assets (Patel, 2006)

Throughout last two decades VTT has been actively involved in the research and development of RECC-ICT knowledge and solutions (some references included in the listing above). The list above demonstrates how the real estate and construction cluster ICT (RECC-ICT) is nowadays a very diversified field. We are clearly surrounded by numerous research and developments leads. Additionally, many of these efforts can be increasingly characterised with integration challenges where various data sources and streams are to be combined, and, various technology platforms need to operate together for reaching the desired solution.

This paper describes results from on-going research project that is very much in line with the general developments described above. The "4D Live" project aims for integrating building product models with live video stream that can originate from building construction site or from completed building. Complicated technology integration challenges are strongly present in this research project. Hardware for synchronised multi-camera video systems has become affordable and this together with advances of augmented reality (augmentation of live video imagery with virtual digital elements) is providing exciting possibilities for new applications. 4D Live project is targeting *proof-of-concept studies* of several potential solutions where video multi-camera system technologies are combined with BIM technologies. In particular, this paper addresses results from the following studies

  i) Live Internet based 4D – implementation of a lightweight IFC Viewer, running over the network with 4D interaction properties, and live video image of the bulding's real environment displayed in the background;

  ii) Augmented reality web camera – internet server controlling multiple web cameras, including virtual camera angles, with augmented view of the BIM model and 4D interaction properties;

  iii) Multi-Camera studio for BIM-Human interaction – human actor e.g. architect interacting "inside" 4D BIM model using data glasses, while other collaborators see the interaction from "outside view" from virtual camera angles.

It is considered that novelty of the named three studies is in several technological challenges that need to be addressed for gaining improved knowledge. This paper shall discuss those aspects.

2. INDUSTRIAL BIM INTEGRATION PERSPECTIVES

A recent study amongst 20 industrial users of BIM solutions in Finland shows continuously increasing use of BIMs (Fox and Hietanen 2007). On the other hand the researchers identified organizational and technological barriers towards which the individuals' attitudes can be rather different from each other. The overall diffusion of BIMs in real estate and construction sector has perhaps the strongest effect on these attitudes. Gradually increasing use of BIMs means disappearing preventive attitudes. Growth in sales of advanced model based CAD systems (recent growth estimate by Tekla plc. for year 2007 is 20%) is indicating that the buying of such software has build-up.

At the same time the use of BIMs is taking place in variety of forms in different domains, such as building owners, architects, structural engineering, electricity, HVACE and cost engineering. Interorganizational use of BIMs between these domains is the transformation that is highly desired. It looks obvious that numerous partial solutions shall be presented but shall have merely a specific use; for example, data transfer from architectural BIM to structural engineering one. Domain specific BIMs shall be equipped with functions for serving very focused communication needs. This is the viewpoint that has motivated the research described in this paper.

3. LIVE INTERNET BASED 4D

3.1 Research objective

Managing aspects of modern building project are changing from individual tools towards integrated solutions and enhanced IT tools, such as BIM authoring and advanced 4D tools, are used for capturing as many cross-discipline design aspects as possible. Combination of traditional 3D model and corresponding schedule, the 4D concept, has potential to solve conflicts and prevent problems pro-actively (e.g. McKinney and Fischer 1998, Koo and Fischer 2000, Kamat and Martinez 2002, Kähkönen and Leinonen 2003, Heesom and Mahdjoubi 2004, Jongeling 2006, Porkka and Kähkönen 2007, and Staub-French and Khanzode 2007). In wider context virtual prototyping has become a powerful application field where also 4D functionalities are used effectively.

Messner et. al (2006) enhanced interaction with immersive display technologies. According to 4D, currently proprietory software dominates in the market. Typically these tools operate in closed environment, and online linkage with other applications in runtime is lacking (Rönkkö and Markkanen 2007). Additionally visualizations are often embodied to single coloured background instead of being linked to realistic live environments. "4D Live" project tailors a product model viewer application for visualising information from other applications and integrates augmented and camera systems for delivering live background from the real environment where the virtual model is applied. The process outline is depicted in Figure 1.
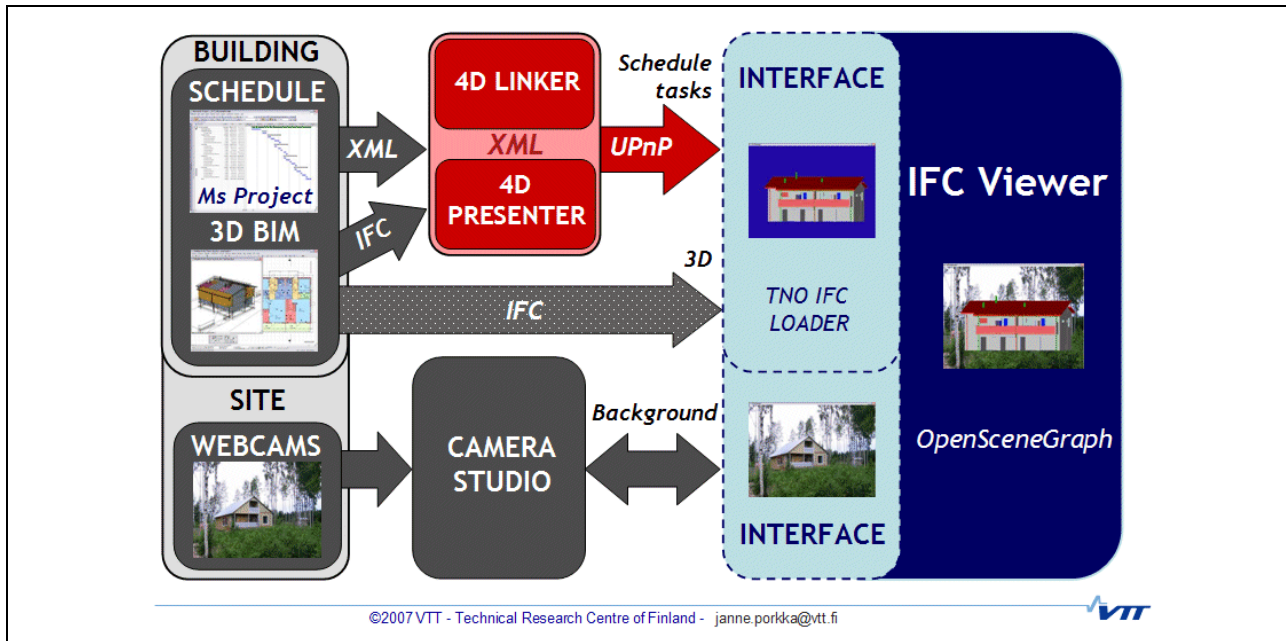
FIG 1: The "4D Live" project process outline for putting together live camera streaming and 4D building models (Modified from Porkka and Kähkönen 2007).

3.2 Resultant solution

The core of our resultant solution *IFC Viewer* is a lightweight model viewer, a visualization client based on OpenSceneGraph open graphics library (OpenSceneGraph 2007). The solution supports IFC data exchange format (IAI 2007) in geometry and Microsoft Project XML in corresponding schedule. The schedule management tool is standard standalone JAVA application, developed in open source environment called Eclipse. The schedule management tool has capabilities for IFC and schedule file import and export.

In geometry representation IFC format has gained worldwide attention especially due to many building owners demanding its usage, such as GSA in United States and Senate Properties in Finland. While OpenSceneGraph does not directly support IFC, we use TNO's IFC Engine (Bonsma 2007) to create triangle meshes from IFC geometry, and the meshes were converted to OpenSceneGraph format for rendering. The IFC Viewer has also a networking module that opens its geometry visualization services in runtime to other applications, such as specific tools for varied analyses or simulations.

The networking module in the IFC Viewer bases on Universal Plug and Play standard, *UPnP*, allowing other applications automatically configure the network and launch visualization services of the client in runtime. Global unification ids (GUIDs) are used in object management and as starting point both applications, viewer and the utilising application, use the same geometry data. The UPnP communication protocol specification that was developed in our VBE2 project provides access methods for individual and object group hiding/showing, highlighting and changing transparency settings (Hietanen 2006). Figure 2 demonstrates the IFC Viewer's 4D visualising capabilities through UPnP networking module, showing the model at a given point of time in the schedule while rest of the model is made transparent.

Finally, the 4D Live solution increases convergence between virtual and real live environments by communicating model view points and adjusting live camera picture to the model background. Typically product model backgrounds are just single coloured., whereas live environments in most of the research efforts such as Behzadan and Kamat (2005) have been based on one-camera systems. The technological novelty in "4D Live" is exploring multi-camera systems for embedding video streaming behind the product model. There are many technological challenges, mainly related to sufficient image compression and image processing for producing "virtual angles" from multiple camera images; cf. sections 4 and 5.
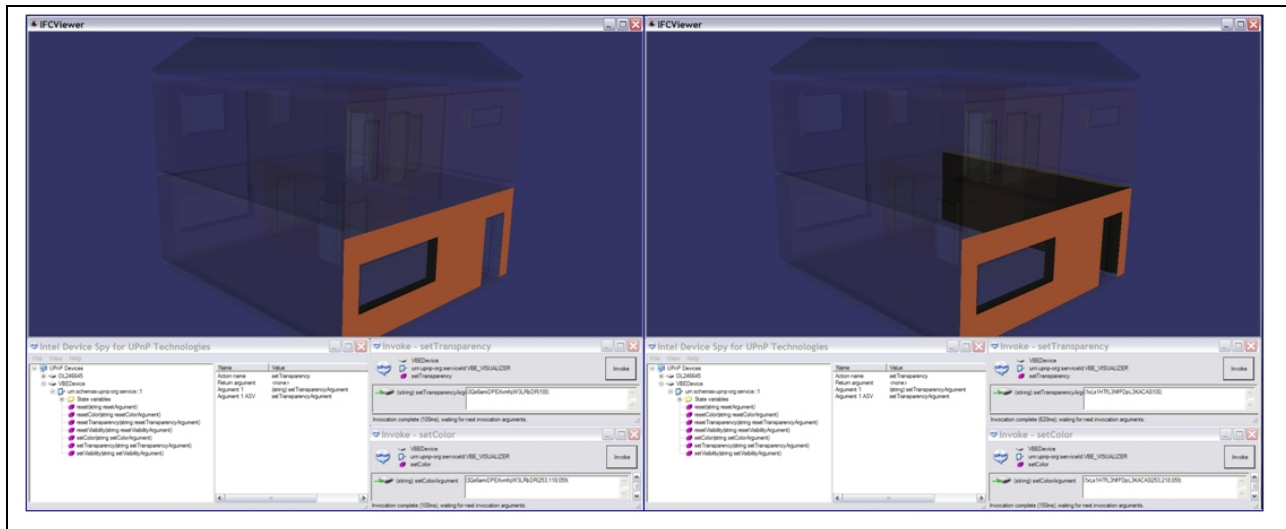
FIG 2: Utilising UPnP for construction schedule 4D presentation.

3.3 Main findings and further work

Early implementation experiences have been positive although various technical challenges have been encountered. It is possible that 4D applications may integrate with other digitalised services in near future (Porkka and Kähkönen 2007). As mentioned earlier, current BIM modelling tools are closed environments. Approach in internet based 4D actually opens doors for third party software developers who want to utilise free viewers instead of expensive in-house visualization clients. New level of design evaluation may include embedding design of a building into live environment. Therefore augmented reality solutions have great potential and may also provide interesting feedback loop to design reviews. Marketing could also be interested in utilising new advanced technologies. In future, we plan to develop further the UPnP networking interface, promote neutral and flexible application integration platform and enhance ways of interaction in real estate and construction sector.

4. AUGMENTED REALITY WEB CAMERA

4.1 Research objective

Visualization of future buildings in real environment helps the architectural modelling, planning of the construction projects and gives added value for selling and marketing. Traditionally visualizations are static 2D images where the building is embedded by hand. With augmented reality techniques the right scale and perspective are computed automatically in real time video; cf. (Azuma 1997, Azuma et al. 2001). Using static cameras on the other hand, VTT has earlier pioneered in implementing augmented reality for an internet web camera; cf. (Woodward et al. 2007).

While our first ARwebcam implementation used just one web camera, our current research objective is to generalise this work to multiple cameras, enabling the user to choose among any existing camera angle, zooming and panning with the cameras, as well as obtaining views from virtual camera angles interpolated between the real ones (Figure 3). Furthermore our aim is to provide a 4D view to the construction plans, to visualise how the actual situation at the construction site compares with the original plans. Such a virtualised 4D augmented reality web camera application enables several use scenarios. The constructor of the building may compare the progress with the construction plans. The work safety supervisors may check that required rails, supporting structures etc. are in place. In addition, the system provides the option for viewing the virtual building before construction is finished, so future users, buyers or tenants can see how the building will look and how it fits the real environment and existing surroundings.
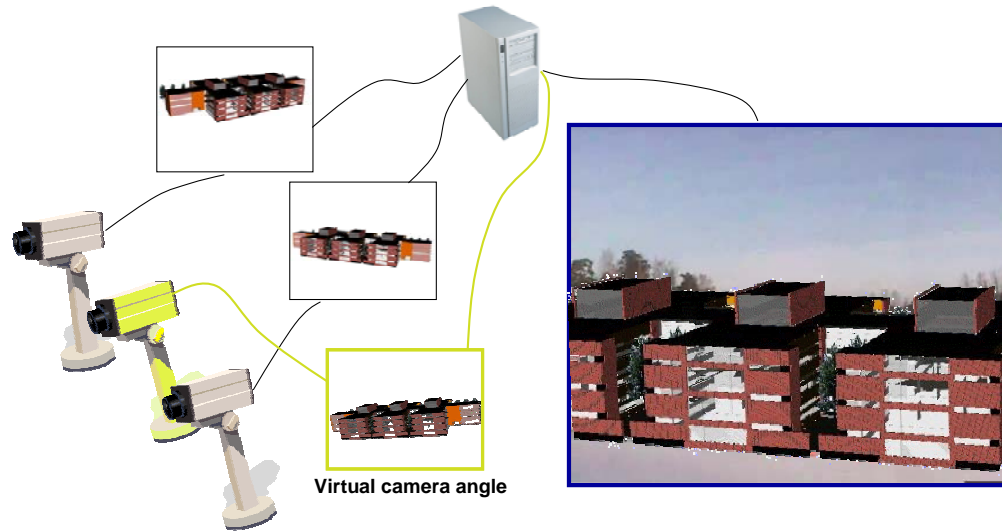
FIG 3: AR web camera combines 3D illustration of a building (from building information model) with the actual view from site.
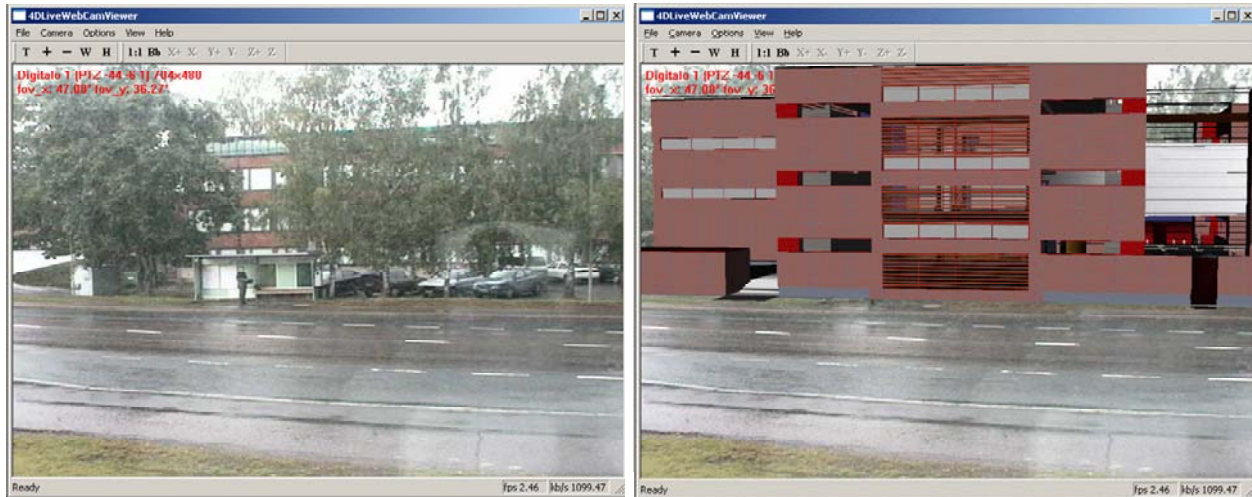
4.2 Resultant solution

The starting point of the work is the single camera ARwebcam system implemented in our previous projects (Woodward et al. 2007). In the former ARwebcam implementation the service was available over a public server. In the current implementation augmentation is instead performed at the client side, e.g. architect's office. Although this does not allow for a public internet service, the benefit is having much higher image quality and faster interaction with the virtual model than if the interactions were performed over the net.

For the viewer we use the IFC Viewer, described in the previous section 3. The IFC Viewer links the 4D (time) information from IFC model to parts of the graphical model, so that real time interaction with the 4D IFC model is made possible. Also, our current ARwebcam application supports general OpenSceneGraph virtual models and support for other formats can be added if required. The visual appearance of a general OSG model is typically better than pure IFC models, as the OSG standard supports textures and different characteristics for materials.

According to the selected approach the 4D feature is a result of combining data from several graphical models, representing the state of the construction project at different points of time. Thus, the model representing a state closest to the current moment is augmented first in the camera view, and the situation at other moments in time can be chosen interactively. The system also supports geometric interactions with the virtual model, such as clipping planes for viewing inside to the model.

Managing of multiple web cameras, as well as calculating virtual angles between the real camera views, is performed with the Multi-camera studio software as described in the next section 5. The main difference between the studio situation is that we assume the web cameras allow also PTZ (pan, tilt and zoom) operations;. Implementation of true, i.e. analog instead of. digital, PTZ interaction with virtual cameras remains an issue for future work. On the other hand, the web camera applications do not necessarily have to involve real time video; for most applications it is sufficient to display just still images of the real environment in the camera view, to be augmented with the virtual 4D BIM model for real time interactions.

The augmentation systems gets the information concerning camera state from 4D Live server and thus the augmentation is always adapted to the camera pose and zoom value. The virtual model is augmented on view but if desired the user may select to see only the original video image without augmentation and swap freely between these two stages. The user may also save images from camera with or without augmentation. The user may select which camera to use through a simple user interface. We indicate in the user interface whether the camera is real or virtual one. However, from the interaction point of view the virtual and real cameras do not differ from each other; a virtual camera is operated just like a normal camera.

| The actual view | Augmented view |

FIG 4: Example of the use of AR web camera in Espoo, Finland.

4.3 Main findings and further work

One of the future technical challenges is remote calibration of existing cameras. It is possible to complete the virtual augmentation in the right scale and perspective only if we know the exact the location and the direction (external parameters) of the camera in the relation to the environment. In addition, the optical characteristics of the camera (internal parameters) need to be made available. The challenge is develop a system that finds out both internal and external camera parameters remotely based only on the camera image.

In the current implementation the access to the webcam is restricted, but if the cameras are publicly available, legal issues come into consideration. For privacy protection reasons workers are not allowed to be identifiable from the images. Either the cameras need to be far enough so that people appear small enough to be unidentifiable, or the system needs to manipulate the video in such a way that no humans are recognizable. There are several image processing and computer vision techniques to handle this requirement; for example we can blur the image or reduce the image resolution in places where we detect people, or the detected people can be erased from the image. However, detecting humans from a video material is not 100% reliable even with state-of-the art detectors and further work is required in such "diminished reality" research.

5. MULTI-CAMERA STUDIO FOR BIM-HUMAN INTERACTION

5.1 Research objective

One of the main targets in this study is to construct a multi-camera studio for interaction and visualization purposes. A human, say an architect or a structural engineer, who is located in the studio is virtualized and converted into a real-time 3D model which can be transferred over the network and inserted into a virtual world where also BIM is visualized at the same time. This way the architect can be seen similar way as so called synthetic avatar in computer games. This enables direct real time interaction between the architect/constructor and other parties; as the one giving comments can be inside the virtual model examining it and pointing out objects within it, while the others are able to see the scale model of the same building and the one acting inside it. The view point over the scene is arbitrary selectable by the viewers.

5.2 Resultant solution

In the set up under study a person in the studio is converted into a 3D model using Video Based Rendering (VBR) technique. This technique can provide good and realistic rendering results nowadays (Gross et al, 2003; Zitnick et al, 2004). However, several system design issues must be taken into consideration before the quality reaches adequate

level. First of all, a good multi-camera image acquisition environment is required. The actor's movement in the studio makes the scene dynamic and thus camera synchronization is absolutely necessary to make sure the images from multiple cameras are captured and processed correctly. The studio premises should also be roomy enough. If this is not the case the cameras must be installed very close to the actor which means poor image quality due to e.g. *a)* strong pixel size variations around the model and *b)* image distortion as wide-angle lens must be used. An example of wide angle lens effect while capturing a volume of 3 x 3 x 3 meters from the corner of the cube are shown in figure 5.

FIG 5: Example of wide angle lens effect to the resultant picture.

For the capturing devices IEEE 1394 digital cameras are used that are capable of capturing colour images of resolution 1024 x 768 pixels at 30 fps. The cameras are rotated 90 degrees and the full resolution is used in order to exploit as many pixels as possible from the captured scene, see examples in figure 6. These cameras can be synchronized by using an external electronic trigger signal which will result in more accurate synchronization than just a software signal initiated by a capturing PC.
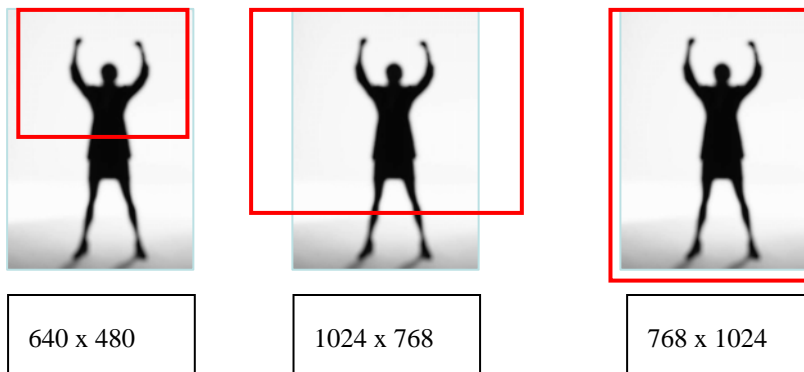

| 640 x 480 | 1024 x 768 | 768 x 1024 |

FIG 6:   When cameras are rotated 90 degrees the target object can be captured with highest resolution.

The total amount of image data in these kinds of multi-camera systems easily becomes massive. For example 10 cameras capturing at 30 fps 24-bit RGB colour images with resolution 1024 x 768 amounts to approximately 700 Mbytes/s of data which would require 10 Gbit/s network. Thus, we selected our cameras so that we can access the original raw 8-bit-per-pixel Bayer stippled image data instead of camera processed RGB data. Of course, the Bayer data must be converted (interpolated) to colour image outside the camera, i.e. inside the capturing PC but in its entirety this is more effective as the bottleneck in our case is the channel between the cameras and the image

processing algorithms. In addition, the cameras were distributed between five different IEEE-1394 400 Mbit/s buses and the frame-rate was slowed down to below 20 fps. A system utilizing directly connected GigE network cameras would have been more elegant solution, although much more expensive.

Five relative modern off-the-shelf Windows XP computers are connected together with Gigabit Ethernet and in addition one of them is also connected to LAN/Internet. The communication between the computers is based on very simple yet effective client/server architecture. More advanced middleware software layer, such as The Internet Communications Engine, Ice (http://www.zeroc.com/ice.html) wasn't necessary even though the capturing and rendering software is distributed between the computers over the network (Figure 7).
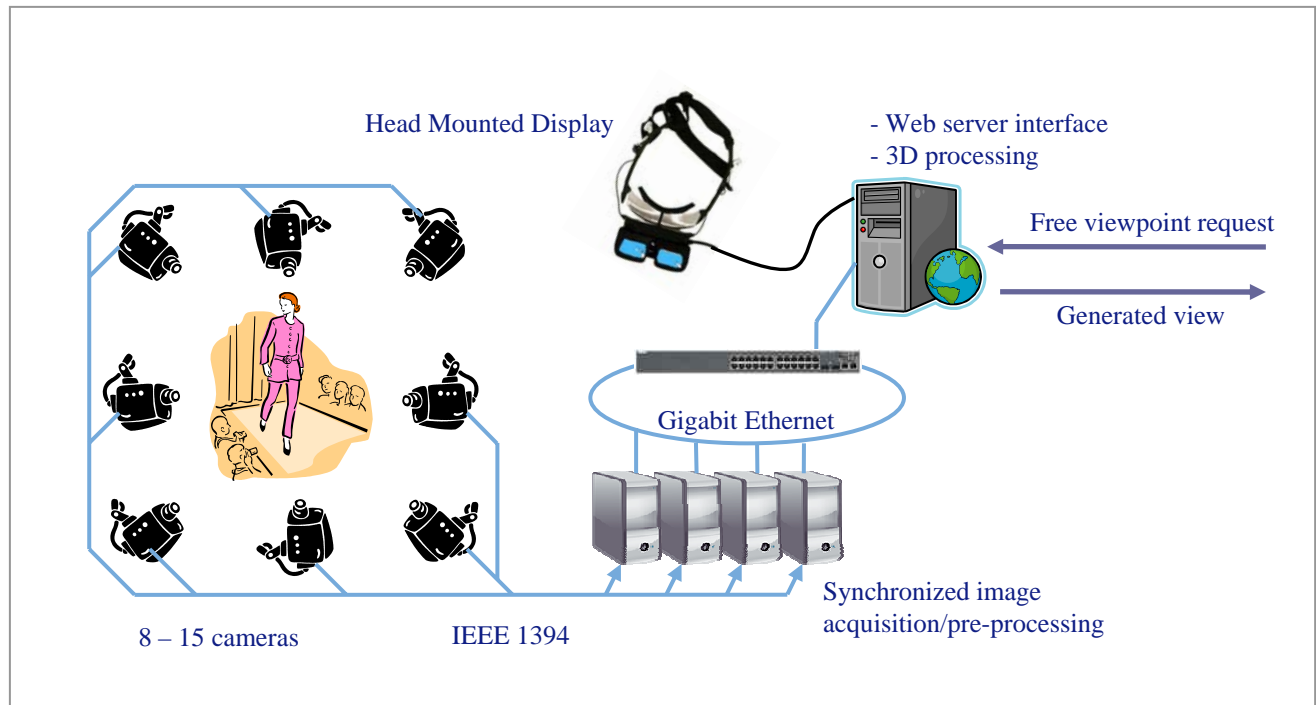

FIG 7: The architecture of multi-camera studio

Walls in the multi camera studio are coated with a retro-reflective fabric and the cameras are equipped with LED ring lighting. This way some of the typical image artifacts due to e.g. shadows and colour leaking are diminished even before the software starts to process video images. A current physical arrangement of multi-camera studio under development is shown in Figure 8.

FIG 8: Current physical arrangement of the multi-camera studio

5.3 Main findings and further work

In this phase of the project only initial results concerning overall quality and usability of the studio are available.

Increasing the image acquisition resolution from typical 640 x 480 per camera to 768 x 1024 per camera clearly increased the amount of usable image pixels without a need to add excessive amount of capturing hardware. The rotated camera image is applicable to our case where the actor is assumed to be standing human. As for the frame-rate, it is further assumed that this human isn't moving very rapidly in current configuration. The camera installations are done using flexible arm mounting brackets in case the object to be virtualized, say a dog, would prefer non-rotated images. However, it would require further work to be insured the implemented studio is truly adaptable to different use scenarios.

Head Mounted Display (HMD) which is used as a main display for architect/constructor/designer in the studio would definitely require lots of improvements in this application area; connected wires are annoying, the display resolution (max 800 x 600 in our case) is not very good for viewing 3D models if at the same time the other parties are looking at the same model with 1920 x 1200 resolution. HMD will also become part of the generated 3D model of the actor and thus the masked face of the actor will hinder the communication between the parties instead of improving it.

Software-only camera synchronization will be studied more thoroughly in the future as this would extend the list of suitable cameras greatly.

Needless to say, the overall quality, system latency/speed and interaction possibilities require attention in the further work.

6. DISCUSSION

Structurally the described applications include two different elements: 1) 4D building model (*design object*), and 2) Image of site and/or human(s) (*locational and situational context*). This combination together with interactive functions provides a promising starting point for meeting successfully various key communication needs in building projects. These key communication needs are relating to collaborative working practice where a dialogue between

different partners, who even can be geographically dispersed, is continuously facilitated for developing their commitment further and for taking full advantage of their knowledge. Possible applications and the use of them are as first stage based on speculative thinking but during the second stage the research is culminating with a proof-of-concept study of potential industrial innovations. This study comprises i) use scenarios with experts from industry based on demonstrational software, and ii) market test of use scenarios and their applications. Whether passing the market test shall take place it can indicate that the constructions of this research provide added value to the end users. For this testing purpose a method termed weak market test is to be applied. In this test the willingness of actual and economically responsible managers to accept the constructions for trials in real situations shall be evaluated (Kasanen et al., 1993). Strong market test, which is out of the scope of the research effort presented here, is another more comprehensive method where the innovations are in place at actual business operations and the resulting change can be measured.

The following list describes possible targets for applications of technologies under development in 4D Live projects. These are to be used as a thinking starting points for use scenarios during the second stage of research. In all scenarios a building or its part is combined with a live image of real world.

Project development; Collaborative building concept testing and its further development with client, end users and other key stakeholders. This is particularly addressing commercial construction and capital construction projects.

Screening (pre-bid); Collaborative consultations with potential customers e.g. house or apartment buyers

Co-design; Presentation of designs in their actual context aids to approach various stakeholders for design reviews, approvals and other needed decision making.

Co-planning; Construction animations (4D) are superimposed on the live site image to be shown to stakeholders who are influenced by the plans and whose knowledge is needed for developing the plans further.

Commencing site activities; Ensure knowledgeable site resources for each activity by presenting plans interactively in real site context. Motivation: sufficiently qualified resources have turned out to the most serious risk in modern construction business (Zelle, 2006).

Monitor the progress; The actual site image is combined with as-planned status of the building (according 4D model) for realizing deviations.

7. CONCLUSIONS

This paper has presented the current results of an on-going research project *4D Live*. Various software development challenges are approached in this effort where interactive viewing of building information models is to be combined with live video stream from multi camera systems. It is expected that this research can provide improved understanding of i) the nature of challenges, i.e. are they fundamental ones or can they be rather easily overcome, and ii) the possible solution that are reachable using the current technology. Examples of software challenges that are occupying the people involved in this project are: interfaces and interplay between BIM/interactive 3D viewer/over Internet, camera calibration, on-line and sufficiently accurate augmentation of building visualizations with video picture, management of enormous video data streams in multi camera environments. The current work is focusing on proof of concept demonstrations.

8. REFERENCES

Amor, R., Jiang, Y. and Chen, X. (2007) Bim in 2007 - Are we there yet? *Proceedings of 24th CIB W78 Conference* "Bringing ITC knowledge to work", Maribor, June 26-29, Slovenia, pp. 159-162.

Aouad, G., Lee, A. and Wu, S. (2007) *Constructing the Future - nD Modelling*, Taylor & Francis, UK.

Azuma R., (1997). A survey of augmented reality. *Presence: Teleoperators and Virtual Environments 6, 4 (Aug 1997)*, pp. 355 - 385.

Azuma R., Baillot Y., Behringer R., Feiner S., Julier S., MacIntyre B. (2001). Recent advances in augmented reality. *IEEE Computer Graphics and Applications 21, 6 (Nov/Dec 2001)*, pp. 34-47.

Behzadan, A., and Kamat, V. (2005). Visualization of Construction Graphics in Outdoor Augmented Reality. Department of Civil and Environmental Engineering, University of Michigan U.S.A.. in Proceedings of the *2005 Winter Simulation Conference*. M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines, eds.

Bonsma, P. (2007). IFC Engine Viewer specification, *available at web site*: http://www.ifcbrowser.com/

ENR, (2004) 10 Electronic Technologies That Changed Construction, Engineering News Record, June 21, pp. 24-33.

Fox, S. and Hietanen, J. (2007) Interorganizational use of building information models: potential for automational, informational and transformational effects, *Journal of Construction Management and Economics* 25(January-March 2007), pp. 289-296.

Gross, M., Wuermlin, S., Naef, M., Lamboray, E., Spagno, C., Kunz, A., Koller-Meier, E., Svoboda, T., Van Gool, L., Lang, S., Strehlke, K., Vande Moere, A., and Staadt, O. (2003). "blue-c: A Spatially Immersive Display and 3D Video Portal for Telepresence" In Proc. SIGGRAPH 2003, 819-827.

Heesom, D. and Mahdjoubi, L. (2004). Trends of 4D CAD applications for construction planning. *Construction Management and Economics*, Volume 22, Number 2, February 2004, pp. 171-182(12).

Hietanen, J., Rönkkö, J., Markkanen, J., Lehtinen, S., and Ylä-Mella, T.(2006). Interactive 3D visualization UPnP methods specification. UPnP implementation guidelines from *VBE2, project report*, November 9th ,2006.

IAI (2007). The documentation of the IFC data exchange standard for architecture, engineering, construction and facilities management is administrated by *International Alliance of Interoperability* (IAI). 1) IAI web page: http://www.iai- international.org/ 2) Latest IFC standard specification: http://www.iai-international.org/Model/IFC(ifcXML)Specs.html . (Accessed March 15th, 2007)

Jongeling, R. (2006). A Process Model for Work-Flow - Combined Use of Location-based Scheduling and 4D CAD. Doctoral thesis, Luleå University of Technology, Sweden. Publication 2006:47, ISBN 978-91-85685- 02-8.

Kamat, V. R., and Martinez, J. C. (2002). Comparison of Simulation-driven Construction Operations Visualization and 4D CAD. *Proceedings of the 2002 Winter Simulation Conference*. E. Yücesan, C.-H. Chen, J. L. Snowdon, and J. M. Charnes, eds.

Kasanen, E., K. Lukka & A. Siitonen (1993): 'The Constructive Approach in Management Accounting Research', Journal of Management Accounting Research, volume 5, Fall, pp. 243-264Koo, B., and Fischer, M. (2000). Feasibility Study of 4D CAD in Commercial Construction. *Journal of Construction Engineering and Management*, Vol. 126, No. 4, July/August 2000, pp. 251-260.

Kähkönen, K., and Leinonen, J. (2003). Visual product Chronology as a Solution for Accessing Building Product Model Data. Published in *CIB W78 2003 conference in Auckland*, New Zealand.

Leinonen, J., Kähkönen, K., Hemiö, T., Retik, A. and Layden, A. 2003 New Construction Management Practice based on the Virtual Reality Technology, in 4D CAD and Visualization in Construction by Issa, R.R.A., Flood, I. and O'Brien, W.J. (editors), A.A. Balkema Publishers, pp. 75-99.

Malkawi, A.M. and Srinivasan, R.S. (2005) A new paradigm for Human-Building Interaction: the use of CFD and Augmented Reality, Automation in Construction, 14(1), pp. 71-84.

McKinney, K., and Fischer, M. (1998). Generating, evaluating and visualizing construction with 4D-CAD. *Automation in Construction*, 7(1998), 433-447.

Messner, J., Riley, D. and Moeck, M. (2006). Virtual Facility Prototyping for Sustainable Project Delivery. *Journal of Information Technology in Construction*. ITcon Vol. 11 (2006), pp 723-738 (www.itcon.org).

OpenSceneGraph (2007). Available in web at: http://www.openscenegraph.com

Patel, D. (2006) An Introduction to RFID in Construction, The Construction Industry Computing Association (CICA) and The RFID Centre form Press Release.

Porkka, J. and Kähkönen, K. (2007). SOFTWARE DEVELOPMENT APPROACHES AND CHALLENGES OF 4D PRODUCT MODELS. Published in *CIB W78 2007 conference in Maribor*, Slovenia.

Quillian, J. (2005) The Connected Building, IEEE Review, April 2005, pp. 44-47.

Rönkkö, J. and Markkanen, J. (2007). LIGHTWEIGHT 3D IFC VISUALIZATION CLIENT. Published in *CIB W78 2007 conference in Maribor*, Slovenia.

Staub-French, S., and Khanzode, A. (2007). 3D and 4D MODELING FOR DESIGN AND CONSTRUCTION COORDINATION: ISSUES AND LESSONS LEARNED. *Journal of Information Technology in Construction*. ITcon Vol. 12 (2007), pp 381-407 (www.itcon.org).

Woodward, C., Lahti, J., Rönkkö, J., Honkamaa, P., Hakkarainen, M., Jäppinen, J., Rainio, K., Siltanen, S. and Hyväkkä, J. (2007) Case Digitalo - A range of virtual and augmented reality solutions in construction application, *Proceedings of 24th CIB W78 Conference* "Bringing ITC knowledge to work", Maribor, June 26-29, Slovenia, pp. 529-540.

Zelle, W. (2006) Determining Customer's Requirements, Communicate Risks and Manage Customer Expectations, presentation at The Project Risk Symposium 2006 by PMI and IIR, May 22-25, Houston, Texas, USA

Zitnick, C., Kang, S., Uyttendaele, M., Winder, S., and Szeliski, R. (2004). "High-quality video view interpolation using a layered representation." In Proc. SIGGRAPH 2004, 600-608.