

# LIGHTWEIGHT 3D IFC VISUALIZATION CLIENT

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*ABSTRACT: We describe a construction product model 3D visualization client software concept that can be used in advanced meeting room, virtual reality and construction site augmented reality applications. Its main target is to improve construction project communication and understanding through visualization. It provides Industry Foundation Classes (IFC) geometry visualization capabilities to existing applications that can incorporate a Universal Plug and Play (UPnP) module to communicate with the visualization client at runtime. To accomplish this we present a software architecture based on UPnP networking standard that allows the visualization client to engage in two way runtime data exchange with existing construction project applications such as project management, cost estimation and quantity calculation applications. The client runs on laptop, desktop and portable tablet PCs. It offers stereoscopic viewing and spacemouse navigation for immersive virtual reality applications and live camera source background as well as external viewpoint control for augmented reality applications. We describe some usage scenarios of this concept, compare it to others and present early results as this work is part of an ongoing effort in Virtual Building Environments project.*

*KEYWORDS: virtual reality, augmented reality, advanced meeting rooms, ubiquitous computing, IFC visualization.*

## 1 INTRODUCTION

Construction projects are multidisciplinary undertakings. Forming a clear picture of what is going to happen in the future stages of a project is essential for a successful project. In project meetings suitable visualization of product information data can help to understand the project. In addition to architectural aspects, visualization can be used for example to help to understand what structures are build at a particular moment in time and in which order and how costs distribute in a building in terms of materials. Visualization can help especially project stakeholders that are not construction industry specialists. The need for communicating construction related data and understanding project data arises in different settings: in project meetings in a meeting room, on-site while observing progress of different working phases and in project sales situations, which can utilize immersive, virtual reality style visualizations.

Another aspect in helping to communicate project data is related to data synchronization between different applications used in project planning meetings. For example when presenting a project schedule in a project management tool, it would be highly beneficial if the visualization of the site at question was shown in a corresponding state simultaneously in the visualization tool and from a relevant viewpoint. This requires that the project management application and the visualization application talk about the same building data as well as that they communicate with each other about the current target of interest within the data. This type of synchronization augmented with data change propagation between applications lessens the need for paper based work, reloading document

data to different applications and the need to navigate to the relevant data source in every single application.

In project planning meetings and project sales situations different pieces of software ideally access data of a particular project via construction information model data exchange technologies such as IFC (IAI 2007). This data can be in a file, or in a model server, which is a computing system and a piece of software that can provide construction project information as a result of database queries. In the future the model servers in addition to managing versioned building data and access control to the data, provide consistent, synchronized project data irrespective of geographical location as well as emit events to listeners when something changes.

CAD applications like ArchiCAD (GraphiSoft 2007) are currently capable of utilizing IFC for data exchange. However, in a communication situation with different project partners these tools are rarely the most suitable tools as they are unnecessarily complex. Therefore there exists a need for more lightweight viewing solutions for construction data that provide intuitive enough navigation techniques and visualization methods. An example of such a tool used in construction projects is JetStream (NavisWorks 2007) visualization software. However, it is typical for these tools that they do not yet provide runtime online linkage to other applications or further product model utilization technologies such as connections to model servers. These applications are also mainly working in standard meeting room environments and do not target, for example mobile, on-site users.

We present our ongoing work with early results in the form of a software concept that enables separate visuali-

zation client software to be used in various usage situations in conjunction with existing construction software. We outline an architecture based on UPnP that allows 3D visualization client software to provide visualization services for external applications and offers further possibilities to develop peer-to-peer networked construction domain “meta-applications” from existing applications. We have implemented a sample implementation of 3D IFC visualization client software that utilizes the presented UPnP architecture. The 3D client software is targeted to operate in advanced meeting room environments together with other applications that may require visualization capabilities. The client software also offers stereoscopic viewing and navigation methods for virtual reality (VR) IFC visualizations. Through incorporating live camera source background and external camera parameter control it assists in developing augmented reality applications for the mobile users operating at construction sites. With our work we aim to provide application developers with a readily usable 3D IFC visualization component for application development.

Several areas of work have connections to our work in the areas of ubiquitous computing and advanced meeting room concepts as well as immersive visualization and on-site augmented visualization of construction data. We present briefly the most relevant related work and point out some of the differences in existing approaches compared to ours. We also present possible usage scenarios for the presented technology in the domains of meeting room, VR and on-site visualizations. The described work is part of an ongoing effort in Virtual Building Environments II (VBE II) nationally funded project.

## 2 RELATED WORK

IFC is a standard for construction product model data exchange. Different CAD packages, such as ArchiCAD (GraphiSoft 2007) can operate with IFC files. The idea of IFC is that different domain applications can have their data described by IFC standard specification and they can communicate by identifying objects with a global IFC identifier (GUID) and by utilizing common structural mechanism to describe data. Not all of the data has any natural geometrical presentation; rather the data may be other numerical or textual information required by a construction project. As CAD packages themselves are rather complex pieces of software to use, a set of simple IFC viewers have emerged. An example of this is an IFC viewer made by TNO Building and Construction (TNO 2007) and a programmers’ development kit that can be used to implement IFC file reading to ones’ own application. TNO’s viewer can be incorporated as part of another application as an OCX component. TNO viewer and its counterparts are not designed to operate in virtual reality setups, nor in augmented reality, on site applications. The embedding mechanism does not allow the formation of application networks to be applicable in advanced meeting room concepts.

Model servers are databases systems, which allow remote access to IFC model data over a network. This type of a repository that keeps a large amount of IFC model data

consistently stored is potentially a huge step in concurrent design processes over file based data access. In principle model servers could offer efficient partial model retrieval, versioning and triggers that tell if some data has changed to event listening applications. However, according to our experience, for the time being, the model servers available are often rather primitive systems in these respects with relatively poor performance regarding geometry data retrieval. Despite this we see the utilization of more and more advanced product model server systems a very likely step in the future to handle increasing amounts of product data due to the growing complexity of construction projects.

Ubiquitous computing refers to devices and systems that can assist human tasks in a transparent way, they can be embedded in the surroundings and made non-obtrusive (Weiser 1991). Stanford iRoom is an advanced meeting room concept with ubiquitous techniques that has been used in construction project planning (Johanson et. al. 2002). It utilizes multiple large touch screens for simultaneously presenting different types of information through synchronized applications that communicate via iROS meta-operating system. The iRoom system offers meeting participants flexible ways to move data between their own personal digital assistants and laptops to a common interactive workspace. The iRoom also offers facilities for application control so that every user can access all the devices available. An important part of the iROS system is an event passing mechanism called Event Heap that stores and forwards messages. The messages are a collection of name-type-value fields. All applications participating in the interactive workspace can post events and read events from the Event Heap using either web, JAVA or C++ programming interfaces. iROS uses a central control server based structure. iRoom is a general purpose meeting room system that has been extended towards construction product model utilization (Schreyer et. al. 2005). The iRoom concept concentrates mostly on dedicated project room installation type environments and does not address needs related to on-site information nor VR visualization. However, a lighter weight system for more mobile meetings has evolved from dedicated iRoom installations; the system has been integrated to a portable video projector system (Barton et. al. 2003).

Universal Plug and Play (UPnP, 2007) is a standard protocol that works over lower level standard protocols like TCP/IP. UPnP offers pervasive peer-to-peer network connectivity of PCs of all form factors, intelligent appliances, and wireless devices via Ethernet, infra red link, Bluetooth or wireless local area network. UPnP is operating system independent and targets home networks, proximity networks, and networks in small businesses and commercial buildings.

The UPnP architecture supports zero-configuration networking and automatic discovery of services through Simple Service Discovery Protocol. The UPnP architecture includes software units called control points, which can control software units called devices. In an UPnP network a device can dynamically join a network, obtain an IP address, announce its name and convey its capabilities upon request through an XML description. Similarly control points can enter UPnP network and learn about UPnP devices through Simple Service Discovery Protocol

and about their capabilities through device XML descriptions. UPnP devices can have one to many services. These services have state information. The changes in states can be listened by control points through receiving events. A device can leave a network automatically without leaving any unwanted state information behind. While iRoom is central control server based technology, UPnP is oriented towards peer-to-peer type networking. A central server is a single point of potential failure. However, if the server does not fail, it maintains relevant state information in the networked environment. On the other hand when an UPnP device fails, its state information is lost, which makes it more difficult to re-enter the situation as it was before the failure. UPnP is a natural candidate for ubiquitous meeting room systems with its zero-configuring networking and it is already supported by many operating systems.

In the field of VR different types of setups have been used for building walkthroughs to communicate design ideas in the areas of architecture, acoustics, thermal design, ergonomics etc. (Savioja et al. 2003). The applicability of meeting room setups and immersive viewing installations differs; meeting room setups allow natural presentation of also 2D information for planning meetings – like Excel cost sheets – while immersive viewing can offer better sense of overall feeling of the observed space. This is especially important for project stakeholders that do not have construction industry background. The use of augmented reality is an emerging area that can offer interesting tools for on-site project progress observation and communication of project plan issues (Kuladinithi 2004).

### 3 IFC VISUALIZATION CLIENT

We have developed client software that provides building geometry and space visualization from IFC data. Its UPnP (Universal Plug and Play) standard based communication mechanism allows other applications to utilize its visualization functions. In addition to this the visualization client can be used in several different types of usage scenarios and hardware systems. For instance the client can be used in a construction site in portable devices equipped with a camera to provide augmented reality view to the site with IFC data combined with the live camera feed from the site. Another possibility is to use the client to visualize geometry in a virtual reality system e.g. for illustrating future workspaces for building users.

As a third option it is possible to use the visualization client in a project meeting setting in an advanced meeting room environment. In this setting the visualization client can communicate with other project software and provides synchronized 3D views and easy navigation to the particular IFC model of interest. With a simple interface cost estimation, project planning and other IFC capable construction software can access the visualization methods for geometry data.

It is possible to launch application networks, in which selecting an item in the 3D viewer selects corresponding data in a quantity calculation tool. Multiple 3D IFC viewers can also be linked together at runtime to provide visualization for multiple large displays to an IFC model from

a different viewpoint. The UPnP interface allows external applications to highlight and hide/show objects or to make them transparent. The message passing utilizes IFC global identifiers to identify items. Similar operations are available for a group of objects. Different interaction methods are provided for the user to navigate in the model: space mouse for intuitive and efficient 3D navigation or game like mouse and keyboard navigation. The 3D viewing component can be used in normal laptop or desktop environments as well as for stereoscopic viewing in virtual reality applications or advanced meeting room setups.

Summary of the IFC client features:

The following can be used via UPnP from an external application:

- IFC geometry visualization from an IFC file
- Highlighting, coloring, changing transparency, making an IFC object/ a group of objects invisible/visible
- Moving user viewpoint and direction

Navigation:

- A game style first person keyboard movement & mouse for steering one's gaze direction
- Space mouse navigation

Other:

- Stereoscopic 3D viewing mode for passive/active/color stereo + head tracking
- User controllable clipping planes to reveal hidden detail
- Receiving live USB camera input and making that a background for the 3D presentation
- Augmenting 3D IFC geometry with 3D geometry from other file access based sources, like model files from 3D modeling and animation packages.

The intention is to keep the feature set relatively limited and let external applications control the visualization according to their needs. As the mobile, tablet style small form factor PCs are not yet as powerful as laptops or desktop computers, it is important to keep the client relatively lean. Figure 1. presents some of the different visualization modes available to other applications via the UPnP service interface.

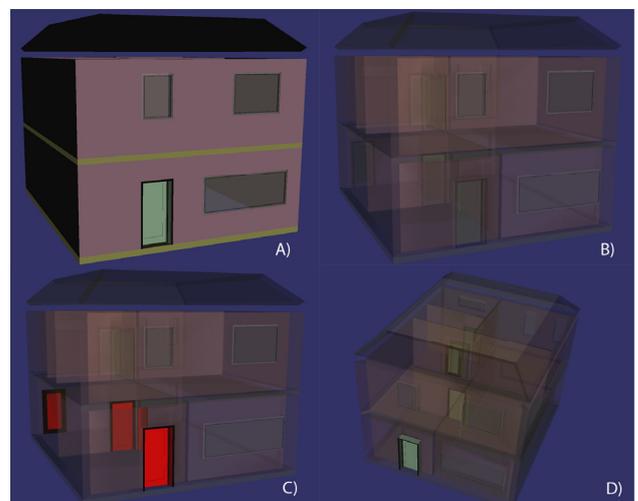


Figure 1. Visualization controlled from an external application showing IFC model a) in normal mode b) all objects transparent c) a group of objects selected d) some IFC objects using externally specified color.

### 3.1 Architecture for connecting applications together

Our approach uses loose coupling between existing business applications and the IFC viewer. All applications participating a session are launched separately and connected together at runtime using UPnP. The same IFC data set is loaded into the applications. When the setup is ready the applications can start controlling each other. This approach offers flexibility, because the same IFC visualization client can be used together with multiple business applications. One business application can also use several 3D applications at the same time. Also one 3D application can be connected to many business applications at the same time. The drawback is the need to load exactly the same IFC data set into all the involved applications as well as the fact that the existing applications need to be open enough so that a UPnP module can be written to them.

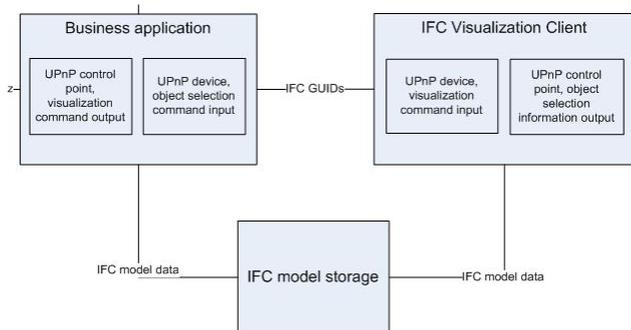


Figure 2. UPnP based connection architecture for IFC viewer utilization.

The visualization client acts both as a UPnP device offering services to the UPnP network and as a UPnP control point. The UPnP device functionality provides an interface from external applications to access features described in chapter 2. The UPnP control point functionality is used to convey events from the user selecting IFC items from the 3D component window. The services of the UPnP device are described in an XML document, which is used as a service description for UPnP control points that want to connect to the visualization service. After a business application has registered to the UPnP network and found the visualization service, it can use commands like:

- setVisibility(GUIDList, Visibility), the GUIDList is a list of IFC GUIDs, the visibility is either SHOW or HIDE.
- setTransparency(GUIDList, Transparency), the GUIDList is a list of IFC GUIDs, the transparency is a number between zero and one.
- setColor(GUIDList, ColorRGB), the GUIDList is a list of IFC GUIDs, the ColorRGB is the color in RGB format, e.g. red is “255,0,0”.

The visualization client transmits to the listening UPnP control points:

- select(GUIDList), the GUIDList is a list of IFC GUIDs.
- unselect(GUIDList), the GUIDList is a list of IFC GUIDs.

### 3.2 Implementation

We have used a popular opensource C++ graphics library called OpenSceneGraph (OpenSceneGraph 2007) to implement the 3D geometry visualization functionality. CyberLink (CyberLink 2007) development tools have been used to implement the UPnP functionality. TNO IFC Engine (TNO 2007) has been used in implementing the IFC file loading capability. Our development and testing platform has been WindowsXP and different hardware configurations including laptops, desktop and tablet PCs.

## 4 USAGE POSSIBILITIES

In this chapter we describe three usage scenarios of which meeting room environment and immersive visualization cases have currently working setups. In the case of a construction site scenario, which utilizes augmented reality techniques, we present the concept, but it is not yet at the status of being tested at a construction site.

### 4.1 IFC visualization client usage in meeting room environments

Our IFC visualization software utilization in meeting rooms can take two forms: utilizing the client in a meeting room with dedicated facilities and in a normal meeting room environment. In the first case the room can include assistive technologies such as multiple projector screens, electronic pens to interact with the displays and local wireless networking to transmit documents from a participant’s computers to others or to displays. This type of environment offers multiple views on project data through simultaneously running applications showing on different screens. In this case the IFC component can work together with UPnP enabled project applications or there can be several IFC visualization components open on different screens showing different variants of the IFC model from a comparable viewpoint. Selecting an item from the visualization component causes an item to be selected in other applications.

Excel Space Visualizer is an example of IFC aware application that communicates with the visualization client in a meeting room environment. It has been built by the Tampere University of Technology. They have constructed an IFC module for Excel that allows space data to be loaded via SABLE API from Eurostep model server (Eurostep 2007) to their Excel program. They have also made a UPnP module to connect to other meeting room applications. This program can detect the existence of the IFC visualization client in the UPnP network and its published services mentioned in chapter 3. Tampere University of Technology has an iRoom style installation with three projector screens with electronic pens for interaction with the screens as well as a cluster of PCs to drive the setup.

If synchronized presentations with multiple applications are desired with a standard meeting environment, the IFC component as well as the UPnP enabled project applications can be installed to a single computer and used with ordinary interaction devices.

#### 4.2 IFC visualization client usage in immersive visualization

The IFC visualization client can be used in virtual reality systems. It supports stereoscopic viewing with head tracking as well as space mouse navigation. Virtual reality visualization can give the user a better sense of space and distances in a future building than ordinary desktop visualization. In this type of a setting it may be necessary to run the viewer in standalone mode with no communication to external applications, i.e. the component simply loads a specified IFC model and acts as a simple VR viewer.

A relatively compact, movable setup that has been used to run the IFC client:

- portable, foldable canvas
- InFocus DepthQ active stereo projector running at 120HZ
- a mini PC with NVidia Quadro 3450 display card
- shutter glasses
- emitter for syncing the shutter glasses
- space mouse

This setup can be erected from a packaged condition in 10 minutes and is relatively compact to transport. It is worth noting though that IFC is not suitable for photorealistic presentations as such, it is more readily used for engineering type visualization.

#### 4.3 Using IFC visualization client for construction site data

We are currently developing the visualization component to be used as a building block for augmented reality applications in construction sites, where it can provide e.g. operation sequence and timeline information (i.e. erect first wall A, then B). As mentioned in chapter 3, a set of relevant features for this purpose are already working. In an on-site augmented reality application a small screen tablet style device equipped with a camera can be carried around. Relevant 3D IFC model objects can be overlaid onto the camera image. The viewing perspective depends on feature tracking information from the environment. It is important to note that despite wireless technologies and portable computing power has increased rapidly during the recent years, efficient partial IFC model retrieval is of essence to mobile applications and according to our experience has not received enough attention in today's model server technology.

## 5 DISCUSSION

Our work focuses on a visualization tool platform for developing applications for meeting rooms, virtual reality IFC product model visualizations and on-site augmented reality construction data presentation. We propose a peer-to-peer UPnP based method to link existing IFC capable applications at runtime for the project meeting scenarios. We have chosen IFC as one of the technologies in this concept, because its utilization is gaining momentum in construction industry: e.g. Denmark demands IFC usage in construction projects by legislation. Senate Properties

(a major property owner in Finland) demands IFC usage in all but small-scale projects.

Furthermore we see that the future model server technology is likely to adapt features from areas like process industry databases, which can handle big quantities of data with real-time constraints, have triggers for special events and so forth. In this respect our work differs from the iRoom approach, which is more cautious with respect to model server or IFC usage. However in our opinion these aspects need to be taken into account in current research as the operating environment of construction industry projects show signs of further IFC adaptation. Also with this work we aim for tools for developers, not so much for a full-fledged hardware and software system concept readily usable by software users such as iRoom.

Our work differs in technological terms from iRoom in terms of peer-to-peer style UPnP networking instead of central server based approach. As UPnP is already supported by many operating systems, we see it from a developer's point of view as a light weight approach for implementing IFC based communication services between applications. However it does not provide application state storage in case of a crash as iRoom iROS does. In our concept we aim for future model serve usage. In this case model servers will store changes to the IFC data, therefore the changes are not lost to the actual data even if individual application crashes.

Also compared to iRoom and TNO IFC viewer type approaches, we see that the use of product model technology is not limited to desktop or meeting room applications, rather information and its visualization can be beneficial also at a construction site. We are targeting this area by making our visualization component augmented reality capable. We also recognize that while using a VR installation is not necessary ideal for project planning meetings between construction industry professionals, VR techniques can nevertheless provide a very illustrative means to demonstrate different construction options to people without construction industry backgrounds. The rationale behind our component development in this respect is that with today's technology these visualization fields have technically very similar components and it is up to the final application developer to decide the most suitable working environment for the application.

For the time being the most evident limiting factors in the usability of the presented concept are lacking model server technology and limited IFC functionality in various existing tools. Also while using existing tools as components of a networked application concept, it is necessary for these tools to have an interface to which a UPnP module can be implemented. If an existing application is totally "closed" it can't be interfaced with this type of technology.

## 6 FUTURE WORK

We are currently bringing together augmented technologies developed for other projects and our IFC viewing technologies. We are also interested in creating UPnP modules for additional relevant applications to utilize our visualization component. Linking several viewers to rep-

resent different model versions and otherwise utilize linked viewers is an interesting development track that requires more investigation. An interesting aspect that can be gained by multiple viewer usage is simultaneous multiple version viewing of a building target. Apart from this technical development we intend to experiment with on-site augmented reality aspects and to delve into the interaction requirements of this type of usage. We also need to gather user feedback from different typical project stakeholder representatives to make further conclusions of the potential of this technology.

## 7 CONCLUSIONS

We presented a visualization component concept for IFC geometry that enables linking to existing IFC capable applications with UPnP technology. Our approach is based on the vision of the development of IFC model server technology towards more mature product data management solutions found in other industries and the widening acceptance of IFC among different software tool makers.

The presented visualization component is suitable for use in applications in advanced meeting room environments, on-site augmented reality applications and stereoscopic VR systems. Our implementation is currently installed at Tampere University of Technology. There it works together with Excel based space tool and iROOM type environment with three back projected screens, electronic pens as well as a cluster of PCs. The described application has also been utilized in an easily transportable VR system. The latter uses active stereo projection, shutter glasses, wireless emitters, and a mini PC running WindowsXP.

The proposed approach requires existing tools to be open enough so that a UPnP module can be written for them. This module communicates with the presented 3D IFC viewer. The module is not required if the viewer is only utilized for standalone IFC viewing. Our further work consists of technical development in mobile, construction site worker domain with augmented reality technologies as well as gathering user input of the described solution.

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