TECHNICAL REPORT

VIPP

Visualization in Design and Construction
Visualisering i Projektering och Produktion

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Preface

This report completes the VIPP I project (Visualisering i Projektering och Produktion, SBUF project no. 11693), and is the first progress report of the VIPP II project (SBUF project no. 11843). The purpose of this report is to provide an overview and update of the developments in the project and initiated activities.

The VIPP I project started in June 2005 and was continued under the name VIPP II from June 2006 on. VIPP II is planned to be completed in 2007.

The work in the VIPP I and II project has been conducted in close cooperation with a number of industry partners during two construction projects by JM AB: Hotellviken-Ringvägen and Hotellviken-Restaurangholmen in Saltsjöbaden. We acknowledge the time and input from the project participants and especially like to thank Magnus Nordström for application of the project work in practice. The financial support has been provided by the SBUF.

Luleå, June 2007

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Abstract

The purpose of the VIPP project is to improve the efficiency and quality of the design review and production scheduling process by using VR models based on 3D models from the design process. Visualization is increasingly used in early stages of development projects to facilitate communication processes, but the use of these models during phases such as detailed design, planning and construction is very limited. It is time-consuming and complicated to keep a VR model up-to-date as a result of differences in data structures and formats between the 3D CAD applications and VR applications. The VIPP project aims to facilitate the transfer of 3D CAD models to VR applications, but the main objective is to set a true example for the practical use of 3D models by professionals in the construction industry.

The VIPP project shows in a real construction project that VR models are beneficial for design review and construction scheduling purposes. By means of defining scenarios for the early and detailed design review process and for production scheduling purposes the project shows benefits that can be divided in: facilitation of the communication process with project stakeholders, increased process efficiency and higher quality of the design and construction process outcome.

The VIPP project shows that the 3D design process is different from the traditional 2D design process, but not radically different. The time required to create 3D and 4D models for the industry case study project was surprisingly little. However, it was found that it is critical to define early and clearly in a project for what purposes the 3D models will be produced.

IFC, a neutral exchange format for building model information, is used to capture and transfer graphical and non-graphical data from 3D CAD models to VR applications. An IFC interface was developed for two VR applications in the VIPP project, but is set up in such a way that other VR applications also can benefit from the developed IFC interface.

The objective of the VIPP project was to keep the definition of use cases, requirements and processes concrete in order to maximize the practical applicability of the VIPP project for other professional users in the construction industry. The practical approach might have compromised the scientific level of the project work, but we believe that the concrete results from the VIPP project can stimulate the industry to start using 3D models and VR environments in real building projects.

Key words: Visualization, Virtual Reality, 3D CAD, 4D CAD, Design, Construction

Abbreviations

3D CAD	Three-dimensional Computer Aided Design
4D CAD	3D CAD integrated with schedule data (time)
ADT	Architectural DeskTop
AEC	Architecture, Engineering and Construction
BIM	Building Information Model
CAD	Computer Aided Design
DLL	Dynamic-Link Library
DWG	Drawing file developed and used by Autodesk Inc.
GUID	Global Unique IDentification number
HVAC	Heating Ventilation Air-Conditioning
IAI	International Alliance for Interoperability
IFC	Industry Foundation Classes
IFC 2x2	IFC schema version 2 with extension 2
IFC 2x3	IFC schema version 2 with extension 3

IT	Information Technology
MEP	Mechanical, Electrical, Plumbing
nD	n-Dimensional, in which n is a number
PIO	Project Information Officer
SBUF	Svenska Byggbranschens UtvecklingsFond. Development Fund of the Swedish Construction Industry.
VBE	Virtual Building Environment
VDC	Virtual Design and Construction
VRML	Virtual Reality Mark up Language
WBS	Work Breakdown Structure
XML	eXtensible Mark up Language

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1　INTRODUCTION

1.1　Background

3D visualization is increasingly used in early stages of commercial and public development projects as an instrument to inform and align project stakeholders on the relation of planned artefacts and the built environment. 3D models are integrated in virtual environments that allow users to experience and gain an understanding of the physical settings of planned construction projects. Today, the use of these Virtual Reality (VR) models is mainly limited to early stages of projects, when the project is defined and when for example property is sold to investors.

The use of VR models during the actual development project in phases such as detailed design, planning and construction is very limited. One of the main complicating factors is the fact that it is time-consuming and complicated to keep a VR model up-to-date with all revisions in a project. As a result, most of today's VR models are one-off products that are created early in a project, but that are of relatively little use when the project advances into detailed design, planning and construction.

Design reviews are currently mainly carried out using overlay of 2D drawings that are produced by different design disciplines in projects. Construction scheduling and the actual construction process are also strongly relying on 2D drawings for information exchange and communication. Numerous reports have been written about the shortcomings of using 2D drawings in construction. The VIPP project does not aim to address this issue, but rather focuses on the possibilities offered by the increased use of 3D CAD tools by architects, structural engineers and MEP-consultants.

In a traditional 2D-based design process one is forced to create a 3D model from 2D drawings when creating a VR model. As soon as one of the drawings changes the VR model has to be changed manually, which makes the process time-consuming, prone to errors and costly. The availability of 3D models from the design process provides an improved basis for the creation of VR models. 2D drawings do no longer have to be converted into 3D models, thereby significantly reducing conversion errors and the time to create a VR model. However, changes in the 3D design models still require a number of time-consuming and repetitive steps to update the VR model with the latest 3D design information. This is mainly a result of the differences in representation and structuring of information in the 3D models. For every update of the 3D models one has to convert and publish the information from a 3D CAD program to a VR environment. As a result of the conversion and publishing process there is no direct link between design data in the 3D CAD system and design data in the VR environment, which limits the possibilities to manage changes in the 3D design models.

A promising development is the definition of a standard exchange format for building model information. The model standard, called IFC, provides mechanisms to capture graphical and non-graphical data from 3D models. The application of IFC can possibly facilitate the data transfer between 3D design systems and VR environments, but the use will also imply a number of prerequisites and changes for the systems and for users of these systems, including a change in working methods.

1.2 Aim

The purpose of the VIPP project is to improve the efficiency and quality of the design review and production scheduling process by using VR models based on 3D design models. The main objective is therefore to use 3D design models in practice by design managers, construction planners and construction managers.

The VIPP project aims to develop the following areas in order to arrive at the practical use of 3D design models and VR environments throughout the building process:

- Enable the transfer of 3D design model information to VR environments by developing an IFC interface for two different VR systems.

- Define requirements and methods for the information delivery by architects, structural engineers and HVAC consultants, for the purpose of facilitating the generation of VR models and for the use of non-graphical design data in design review, planning and construction processes.

- Establish and apply routines for 3D model-based design reviews and communication of production planning information.

1.3 Method

The VIPP I and II projects have been divided into two parts. The first part concerns a pre-study and system development. The second part concerns application in practice and analyses from the practical application. The VIPP project uses two industry case study projects around which the main components of the project are implemented and tested. Both case study projects are part of the Hotellviken project that in total counts four successvie sub-projects.

The first VIPP project, VIPP I, uses the Hotellviken-Ringvägen project as a case study project, Figure 1.1. The Ringvägen project comprises the construction of 62 apartments in four apartment blocks, connected by two parking garages. The second VIPP project, VIPP II, uses the Hotellviken-Restaurangholmen project as a case study project. The development of Restaurangholmen comprises the construction of four residential apartment blocks connected by a garage and a separate spa centre.

The Hotellviken-Marinan project was used as a case study in the completed ITstomme project (SBUF project no. 11333, (Jongeling 2005)). The fundamental ideas and developments from the ITstomme project were used as a starting point when the VIPP project was initiated. Compared to the ITstomme project, which had a more technical character, the focus in VIPP is the application of technology in practice by construction professionals and the development of working methods for these professionals.

*Figure 1.1: Hotellviken-Ringvägen. The architectural 3D model is integrated
in an environment showing the surroundings of the project.*

The following chapter provides a theoretical basis for the developments and
applications within the VIPP I project. Chapter 3 - 5 gives a description of the
main results of the system development and the case study applications. Since
the VIPP II project is still ongoing at the time of this report, only the results
from VIPP I are presented.

2 THEORY

The VIPP project applies 3D design models for a variety of purposes by using VR environments. The process of developing and applying these models is referred as Virtual Design and Construction (VDC). The following sections describe and exemplify the Virtual Design and Construction process, including a section on VR and construction simulation. A more comprehensive description is given in the PhD thesis by Rogier Jongeling (Jongeling 2006).

2.1 Virtual Design and Construction

The Virtual Design and Construction process aims to analyse, simulate and predict the quality of the end product (e.g. a building) and the characteristics of the process to build and operate the product. Both the product and the processes must be virtually designed and simulated, before construction commences, in order to be able to truly evaluate different design and construction alternatives against project objectives. The Virtual Design and Construction process relies on the use of CAD and other IT systems, but is not limited to these tools. The organization of the process is as important as the applied technology in the process.

Figure 2.1 presents a simplified outline of a concurrent property development process including the main decision-making processes and decisions points (DP). A project typically consists of a number of parallel and interrelated decision processes. The application of Virtual Design and Construction techniques in such a building process results in a large variety of different applications and analyses. Each of these applications aims to facilitate the decision-making process by (partially) analysing, simulating and predicting the quality of the end product and the characteristics of the process to build and

operate the product. Figure 2.2 shows a number of Virtual Design and Construction methods that can be applied to facilitate the design of the product and process.
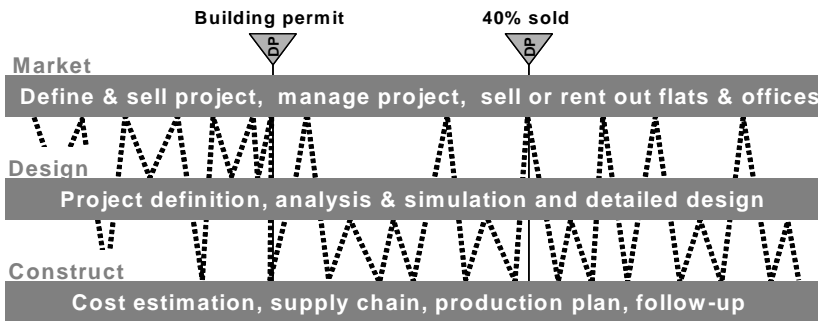

Figure 2.1: Outline of a property development project, including a schematic representation of the decision-making process. The dotted line represents the main decisions between a number of concurrent key-processes in the property development process (Jongeling 2006).
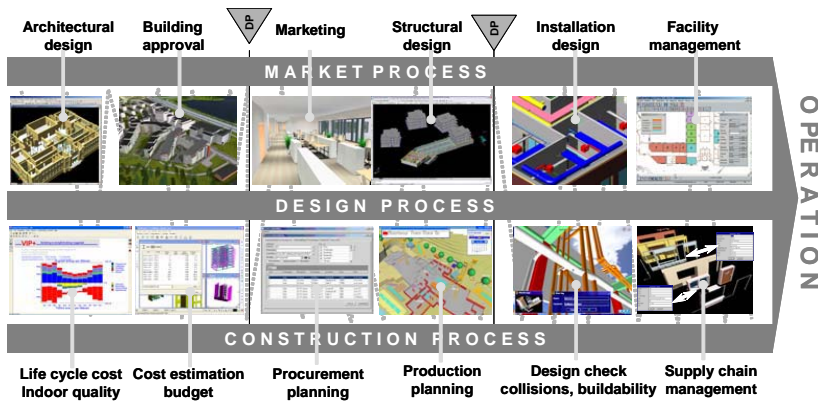

Figure 2.2: Applications of Virtual Design and Construction techniques in a property development project facilitate the communication in the decision-making process (Jongeling 2006).

Examples of the potential benefits of the application of Virtual Design and Construction techniques in a property development process can be summarized as follows:

- The process of obtaining a building permit process becomes faster and more efficient. Visualisation of the overall design improves communication and clarification, resulting in less complaints and misunderstandings of the layout and effects on the neighbouring environment.

- The sale process improves in early stages of the project. Selective price tags on attractive flats can more easily be determined by the developer. Potential customers can get a visual impression of the layout and the view from the flat before they sign the contract.

- Life cycle cost can be estimated early and the design can be changed to meet design targets.

- Early procurement of critical components with long delivery times, such as windows, can be made earlier with lower prices as a result.

- Integrated structural and installations design leads to fewer collisions in the design and hence, less re-work on the construction site.

- Integrated design and production planning (4D), improves the build-ability of the design, the site layout and work-flow on the construction site with less waste during construction as a result.

- Integrated design, bill of quantity take-off, cost estimation and supply chain management reduces the waste related to waiting for and storage of components and material on site.

- Handover of an AS Built model for e.g. facility management increases the value for the owner.

The applications of different Virtual Design and Construction methods are dependent on each other and should be applied in an iterative manner in which several analyses are repeated until a satisfying solution is found. The iterative and interdependent use of the Virtual Design and Construction applications puts high demands on the definition and structure of the data that supports the various analyses.

2.2   Product Modelling

A product model is an academic and technical term to denote a Building Information Model (BIM). Two other concepts that are often referred to are nD modelling and a virtual building environment (VBE). Product models can contain both product and process data of a building project, such as geometry, material definitions, but also planning information and data on construction costs. A BIM is a computer model database of building design information, which may also contain information about the building's construction, management, operations and maintenance (Graphisoft 2002). An nD model is an extension of the BIM, which incorporates multi-aspects of design information required at each stage of the lifecycle of a building facility (Lee 2003). A Virtual Building Environment (VBE) is a "place" where building industry project staffs can get help in creating BIMs and in the use of virtual buildings (Bazjanac 2004). A virtual building is a BIM, or an nD model, deployed in software. We define BIM and nD models as (building) product models.

One of the main developed standardized schemas for building product models is the Industry Foundation Classification (IFC) by the International Alliance for Interoperability (IAI 2007). The IAI is an open international consortium of CAD vendors, such as Graphisoft, Autodesk, Bentley, Nemetschek and many other organisations. The IAI defines interoperability as an environment in which computer programmes can retrieve data automatically, regardless of the type of software or source of data (IAI 2007).

The interest in work by the IAI on IFC is gaining momentum. Several large public and commercial clients start to require information delivery in their projects by using IFC. In Denmark for example, for public building projects over 40DKK delivery of IFC models is required. Similar requirements are starting to be made by large clients in the Norway, Finland and in the US. These types of requirements speed up the definition of the standard, the deployment in software and the practical use by industry professionals. The worldwide seminars organized by the IAI, under the name of Building Smart, have drawn serious attention by actors in the construction industry and IFC has moved beyond its academic and limited use.

The eventual goal of the IAI is to develop product data models for sharing information between software tools, which are utilised throughout the building industry. This is done by specifying how the 'objects' (products and processes) that a construction project consists of, such as doors, walls, rooms, etc., should

be represented electronically. Each specification is called a 'class'. The term 'class' is used to describe a range of things that have common characteristics. For instance, every door has the characteristic of opening to allow entry to a space; every window has the characteristic of transparency so that it can be seen through. Door and window are names of classes. The classes defined by the IAI are, as mentioned earlier, termed 'Industry Foundation Classes' or IFCs. A wall object created in one application can be exchanged with another IFC-compliant application, which recognises the wall object and the accompanying specifications. The objects have a global unique identification number (GUID), which allows one to keep track of individual objects. A shortcoming of the IFC standard is the fact that there is no support for multiple versions and representations on individual object-level.

2.3   Virtual Reality

VR is a spatial and communicating medium well-suited to facilitate collaboration and understanding about the construction and the processes needed to erect it (Woksepp 2005). Even though VR today primarily is used for visualizing the final product there is also a great potential to use it as a universal interface applications used during design, planning and production (Aouad 1997).

VR models are typically created by using 3D CAD tools and dedicated 3D visualization software packages from where graphics are published to a VR environment. These VR environments are often based on technology from the computer game industry and work accordingly, with for example similar types of navigation modes and representations of the environment. The VR environments are easy to use and allow non-CAD users to access and interact with 3D models. The use of these tools significantly increases the number of potential users and uses of 3D models.

The main differences between 3D models in CAD systems and 3D models in VR environments, apart from differences in navigation and accessibility, are the definition and representation of objects. A building objects such as a wall is represented as a solid box in a CAD system that can have definitions and materials assigned for its contents and surfaces. The same wall is often represented as just a surface in a VR environment in order to minimize the required computing power when exploring the VR model. Compared to a 3D model in a 3D design system the VR model includes additional definitions for surfaces and spaces for the purpose of photorealistic representation. In addition, objects that can be identified as individuals in 3D design systems are

often grouped in a different way in a VR environment. These differences in definition and representation of objects currently limit a direct transfer of 3D design models into VR models. As a result, VR models are often made once in early stages of a project, but are subsequently not updated and lose their value as an instrument to inform and communicate design and construction issues.

2.4   Production Simulation

4D CAD is a method for communication and simulation of construction scheduling information. The method combines 3D design models with construction schedules and represent the construction process over time (McKinney 1998). 4D CAD, in this respect defined as a specific type of VR, promotes improved understanding of construction operations (Li 2003). Construction projects have unique spatial configurations and the spatial nature of projects is very important for planning decisions (Akbas 2004). 4D CAD models provide planners with a spatial insight in the scheduling process of construction operations, which is not clearly and effectively provided by using 2D drawings in combination with CPM schedules or Line-of-Balance diagrams.

4D CAD models are typically created by linking building components from 3D CAD models with activities that follow from CPM schedules, e.g. (Koo 2000; Tanyer 2005). Building components that are related to activities that are ongoing are highlighted. The 4D CAD model provides the user with a clear and direct picture of the schedule intent and helps to quickly and clearly communicate this schedule to different stakeholders in a project. 4D CAD models allow project participants to simulate and analyze what-if scenarios before commencing work execution on site (McKinney 1998).

In order to use the 3D design models for production purposes one has modify the design model, which is done by restructuring the design model according to the projects Work Breakdown Schema (WBS) and by adding and modifying 3D objects. A WBS establishes a common frame of reference for a construction project and divides the project into a hierarchical structure of manageable parts or work-packages, which enables resource loading of schedules and cost estimations at different level of detail. It is also used to identify parts of the project that can be sub-contracted.

The most common technique to restructure a 3D model is to add existing 3D objects to CAD layers representing the desired level of the WBS. The resulting production adapted CAD model, referred to as production model, can be

further refined by adding objects specifically used for production purposes, such as the lay out of the construction site, equipment, transport ways, shoring, form work, etc.

3   APPLICATIONS IN VIPP I

3.1   Scenarios

The application of VR models in the Hotellviken-Ringvägen project are defined by two practical scenarios (use cases) that set the scope and ambition for the project.

Scenario 1: Design review

The purpose of use case 1 is to facilitate the design review process by using VR models that are based on 3D design models and that can directly and smoothly be updated from revised 3D design models.

- The architectural 3D model is modelled with CAD software and published to a VR environment.

- The model by the architect is updated, by for example repositioning a window frame.

- The VR-model can easily be updated with the newer version of the architectural 3D model.

Scenario 2: Production simulation

The purpose of use case 2 is to bridge the gap between the design and production process by making 3D design information easily accessible for production simulation purposes.

- The structural 3D model is published to a VR-environment.

- The construction site is modelled in 3D, including the layout of the site, cranes and scaffolding. This 3D model is also published to the VR-environment.

- The construction planning is created with typical project planning software (e.g. MS Project, Plancon, Primavera)

- The structural 3D model is linked to the construction planning which is imported to the VR-environment

- The resulting 4D-model can be used to show the ongoing construction activities per construction day

- The construction schedule can be updated, without losing links to the 3D models

- The 3D models can be updated, without losing links to the construction schedule.

The defined scenarios require the development of working methods and software tools to be fully realized. Especially since the applications in the two use cases are supposed to exchange information using the IFC format. However, in order not to get stuck in technical developments we decided to conduct the two scenarios using existing software tools that, where possible, were to be modified along the applications in the case study project.

3.2 Scenario 1: Design review

Scenario 1 was split into two different applications: 1A early design review and 1B detailed design review.

3.2.1 Scenario 1A: Early design review

This VR model includes the architectural 3D model and the landscape, including vegetation and main landmarks in the vicinity of the project.

Purpose

The first VR model was created to support the early design-making process by the project team and its stakeholders, including potential buyers of apartments.

Method

An architectural 3D model was created in ArchiCAD by the architect of the project and was imported to 3D studio max by using the .3ds file format. The following modifications and additions were made by graphical designers in 3D studio max to make the architectural model suitable for visualization:

- Textures and shading were added to existing objects

- Objects that are part of the building, but that are not visible were removed

- Objects with complex geometries were simplified/modified

- Missing objects and information were added, such as building volumes, apartment layout and pricing.

The surroundings of the project, landmarks, vegetation were imported to 3D studio max and were published, together with the modified architectural model to a VR environment called Neo. It took 15 days to create the surroundings of the project and 5 days to import the architectural model to Neo. The VR model was 4 times updated during the project.

Figure 3.1: Architectural model from Ringvägen in the VR environment Neo

Changing the architectural design requires the aforementioned modifications and edits of the architectural 3D model in 3D studio max before the VR model can be updated. With a limited number of small changes, such as changes in window sizes, the modifications can be made directly in the existing 3D studio max model. This way the export and import from ArchiCAD to 3D studio max can be excluded from the process, but this procedure causes the design and the visualisation model to get inconsistent. In case of main design reviews one is forced to update (i.e. replace) the whole 3D studio max model of the architectural 3D model.

Results

The VR model in Neo was used by a number of stakeholders in different settings.

The project manager used the model during design meetings to create a common understanding of the project and to review the architectural design. Several misplaced walls and windows could be detected by exploring the VR model in Neo, by means of walking and flying around using a game control pad. The detected design issues were directly communicated to the architect using the VR model. The project manager had no experience of CAD systems and could as a result not review the 3D CAD model with ArchiCAD. Using the VR model for this purpose was making the 3D design model accessible for non-CAD users.

The VR model was also used to communicate the project to the local government and planning committees in order to facilitate the process to obtain building permits and other permissions. The project manager considered the VR model of great use in this process. The use of the VR model minimized misunderstandings about the project intent, created quickly a common understanding among all stakeholders and gave the decision-makers a professional and serious impression of the project developer. The project manager is convinced that the use of the VR model has speeded up the process of obtaining permissions.

The project manager used the VR model to set the prices for the apartments of the project, by walking around in the apartments and by inspecting the view from the apartment's balcony. The clients used the VR model in the same way and could obtain a direct and photorealistic impression of their potential future home, including price information, apartment layout, etc. The project manager believes that the use of the VR model has speeded up the early sales of apartments (i.e. the sale of apartments before the actual construction). The manager also believes that it has been a valuable instrument to set specific prices on different apartments, based on early (virtual) impressions of the final product and settings in its surroundings.

Figure 3.2: The 3D model in Neo shows the project in its final state when construction is completed and when the site is cleared and landscaped.

In addition to clients, the VR model was shown to project stakeholders such as cost estimators, planners, the site manager, suppliers, etc. Most of the project stakeholders considered the VR model useful, but some, such as the site manager, considered it of little use for production purposes, since the model showed the final product and not the process to get to the final product, Figure 3.2. The model is not built to show the construction process and the layout of the construction site and is therefore of limited use to support the construction process. The 3D model in Neo is stripped from all unnecessary 3D objects, which are those objects in the final product that are not visible for the main users of the model (e.g. potential buyers of apartments, politicians, etc.), Figure 3.3.
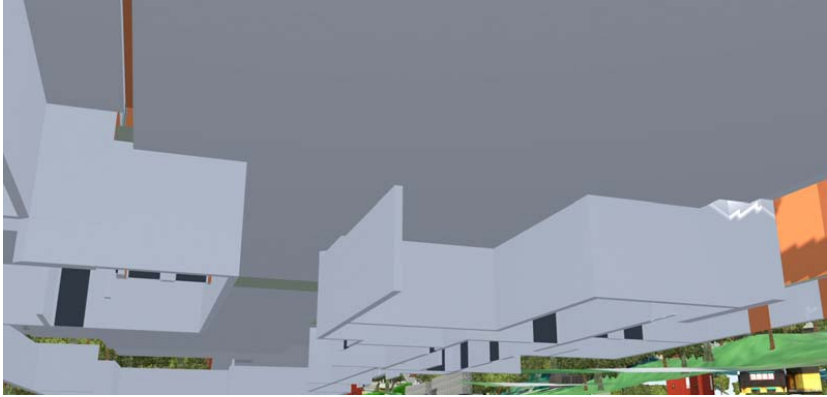
Figure 3.3: The 3D model in Neo showing the roof of the parking garage from beneath. The figure shows the absence of slabs, walls, columns, installations and ramps.

3.2.2   Scenario 1B: Detailed design review

The VR model that was used for the detailed design review includes 3D models from the structural design and building services design, including heating-, ventilation- and plumbing systems.

Purpose

The purpose of the VR model in the detailed design phase is to better understand and communicate the complex geometry of the structural design for planning the production. The VR model is also useful to review the structural design and to check the structural model against the building services model for possible interferences.

The structural design was already completed in 2D when the 3D model was built during the VIPP I project. This is not optimal from the perspective of the use of VR models for design review processes, but an advantage of checking the consistency and completeness of the final structural design. During the on-going VIPP II project the VR model is constantly used and updated along the complete design process, and combines the architectural, structural and HVAC models of the final stage of the Hotellviken project.

Method

A 3D structural model was created for Hotellviken-Ringvägen from 2D structural design drawings using AutoCAD Architectural Desktop (ADT). The 2D structural design drawings, in DWG format, were used as a reference in the 3D modeling process to model and position the 3D structural objects, such as walls, slabs and columns. Reinforcement was not modeled in 3D.

The 3D structural model was built floor by floor and building by building. When the modeling process was completed the 3D model was published to a VR environment called Ceco Visual, using a plugin software to AutoCAD ADT. The plugin converts the CAD model to VRML and creates unique entries for each CAD object in a database used by Ceco Visual. The main difference between Neo and Ceco Visual is the fact that Neo is built for high-end graphics and photorealistic views and Ceco Visual is built to visualize detailed CAD models and accompanying property sets of CAD objects.

The HVAC model was created in MagiCAD and was from the start not prepared to be used in the 3D design review. The model contained 3D objects, but the objects were not positioned at a correct Z-level and was therefore corrected along the design review process. The HVAC model was also published to Ceco Visual via AutoCAD ADT using a 3D object enabler to show MagiCAD objects.

The two models were subsequently used by the project manager, planner and site manager to review the different design disciplines in 3D using the VR environment Ceco Visual.

Results

Overall, the VR models of the building structural and installations have been constantly used by different stakeholders to understand the building geometry and to communicate design and production issues. As mentioned in Scenario 1A: The project manager had no experience of CAD systems and could as a result not review the 3D CAD model with AutoCAD ADT, MagiCAD or ArchiCAD. Using the VR model for this purpose was making the 3D design model accessible for non-CAD users, such as the project manager.

The site manager used the models for example to show HVAC contractors how the installations were supposed to be installed on site and checked also the interferences of the installations with the building structure.

Ceco Visual shows the project hierarchically and allows users to partially load and unload the project, such as floors, buildings or single objects. The project hierarchy is structured according to:

- Design disciplines (structural, HVAC, architectural, site) and

- The spatial decomposition of the project (e.g. building 10, floor 1, beams, column, slabs and walls)

Modelling and reviewing the structural design in 3D revealed several inconsistencies. The modelling process itself forced the project team to build the project virtually and was thereby confronted with a number of design issues. After the design was completed it was reviewed by using the VR model to search for issues that were not obvious in the 3D modelling process. The design review was performed by simply walking and looking around in the buildings and parking garages of Ringvägen. It was found in the 3D modelling and 3D review process that:

- The design was incomplete. Certain objects were missing on 2D drawings. A missing column was for example detected in the garage.

- The design was inconsistent. Several of the 2D-drawings did not match. This was especially the case with 2D-section drawings of the buildings, showing building storey heights differently on different drawings. Also, several instances of openings in concrete slabs were detected that were differently shaped on different drawings.
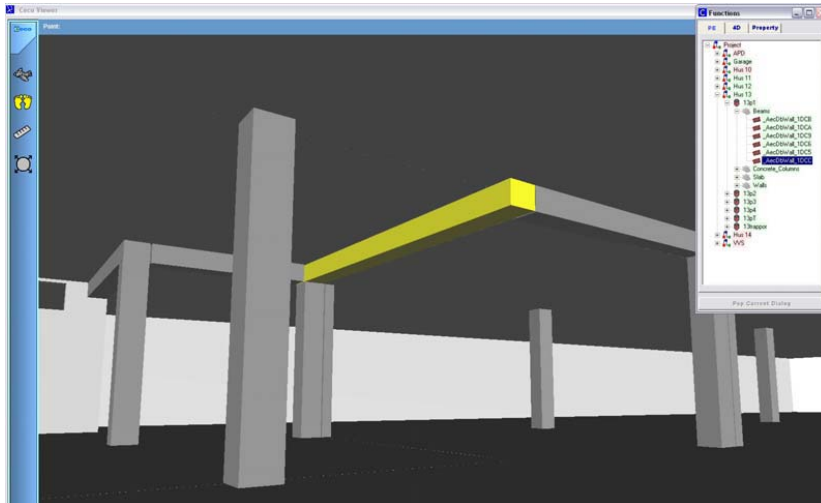
Figure 3.4: A capture from the structural 3D model down in the parking garage of Ringvägen. The model shows clearly a missing concrete column to support a concrete beam, which in its turn supports the roof slab of the parking garage and the building above. The concrete beam is highlighted for clarification purposes.

The 3D model of the structural design was considered very useful to understand complex sections of the building. Especially, it gave a clear picture of the connection between the buildings and parking garages. The 3D environment was considered a valuable tool by the project manager and site manager to check the design, plan assembly procedures and communicate the design to involved production personnel.

The 3D model did not contain reinforcement bars and contained also simplifications of for example the prefabricated balconies. A higher level of detail of the structural design, including for example reinforcement bars could possibly have avoided a number of design issues that surfaced during the construction work. However, the possibility to model reinforcement bars to date in 3D is still limited and complicates to some extend the detailed design review process. For example, the reinforcement bars that support prefabricated slabs of balconies between two buildings with different elevations were drawn incorrectly in 2D, Figure 3.5. The structural design in 3D, with and possibly even without 3D reinforcement bars could most probably have avoided this

design mistake. The 2D design method used by the structural designer made it possible to create an erroneous cross-section of the balconies and slabs, without noticing this inconsistency. With design in 3D the cross-sections are derived from the 3D model and directly show the differences in elevations. Modelling the reinforcement bars in 3D would have minimized the risk even further for these types of design mistakes.
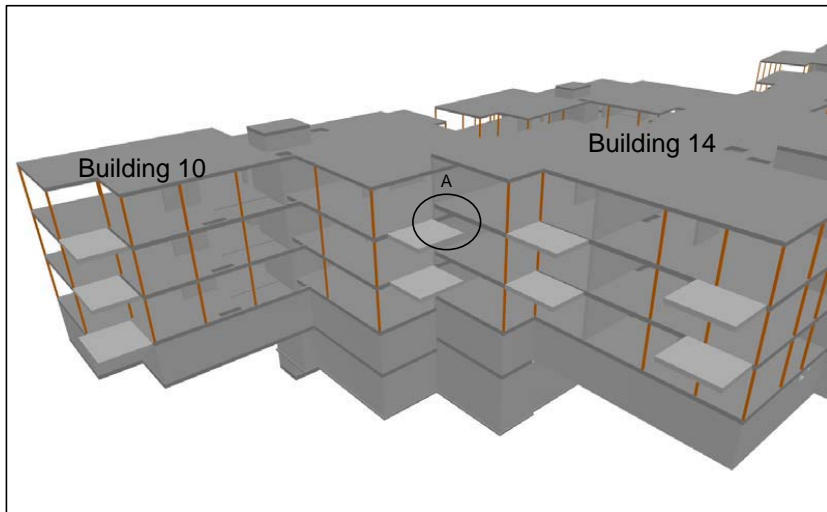

Figure 3.5: The balconies between building 10 and 14 are supposed to be supported by the slabs of both building 10 and 14, but due to the difference in elevation that was overlooked in the 2D design the connection to the slab of building 14 cannot easily be made (detail A). The issue was discovered and solved during the construction work, but could most probably have been avoided with structural design in 3D from the start of the design process.

The review of the HVAC 3D model against the structural 3D model also revealed a number of issues that were overlooked in the 2D review process. Especially the position and dimensions of openings for installations in the concrete building structure appeared to be critical points of which a number of 'collisions' (e.g. interferences of the structural model and HVAC model) could be detected.
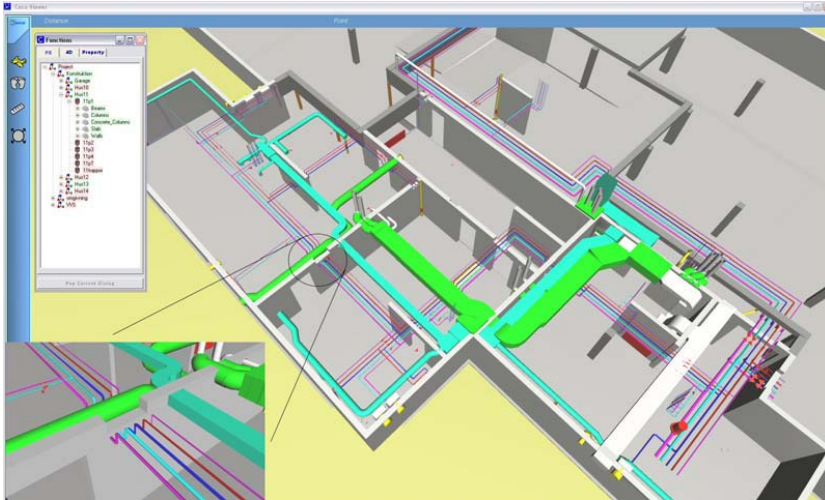
Figure 3.6: Design review of the structural 3D model against the HVAC model. The figure shows a misplaced opening in a concrete wall for installations. Several of these types of issues could be detected by using the VR model.

The review process in 3D was mainly performed in the final stages of the design process. This has limited the full integration of 3D reviews in the overall design process. Conducting design reviews in a 3D environment was a new way of working for the designers in the project and it took some time to handle the 3D models in an efficient way to support communication and decision-making during face-to-face meetings. For example, the VR model was used for an arbitrarily number of agenda-points of a design meeting, but not all. Certain views from a specific angle, with solid parts of one model loaded, parts of another model transparent, etc, seemed to bring in too much of visual information to handle for the designers when an issue was brought up during a meeting.

One can state that during VIPP I the use of the VR model and the design process were rather two parallel processes where the use of the VR model was of benefit for the design process. The VR model was renewed a number of times, but there were no procedures in place that stated how, when and by whom all the models were to be delivered, updated and dissiminated.

3.3   Scenario 2: Production simulation

The VR model created for production simulation consists of the structural design model, a simplified model of the construction site's landscape, the site layout and building site objects.

Purpose

The VR model that was created for production simulation is aimed to bridge the gap between the design and production process by making 3D design information easily accessible for review of production plan and communication of the production process at the construction site.

Method

The VR model of the structural design was used as a basis for the production model. The structural design model was modified in AutoCAD ADT to make the model suitable for production planning and simulation purposes, resulting in a production model:

- Objects were added, such as lattice girder (plattbärlag) elements.

- Objects were modified, such as the division of slabs into multiple concrete pours.

The modified structural design model (i.e. the production model) was subsequently republished from AutoCAD ADT to Ceco Visual.

Figure 3.7: The structural 3D model was further detailed to make the model suitable for production planning and simulation purposes in 4D.

The site was modelled in 3D in AutoCAD ADT, by using 2D drawings from the geotechnical consultants and from the site manager, who had created a 2D drawing of the site layout. 3D objects were created for the main building site objects, such as cranes, scaffolding, material storages areas, transport routes, etc. All models were published from AutoCAD ADT to Ceco Visual.

The site manager created a detailed production schedule using MS project and exported the planning information to Ceco Visual using MS project's built-in XML export. In Ceco Visual the site manager linked the planning information to the respective "production-adjusted" 3D objects from the various 3D models. The resulting 4D model was the ready for use on the construction site. When changes occurred in the planning the site manager updated the 4D model with the new scheduling information.

Figure 3.8: The 4D model integrates the structural model and the project schedule in one environment, showing day-by-day the ongoing activities at the construction site.

The level of detail of the 4D model was increased at a number of selected instances of the 4D simulation in order to provide more detailed instructions for specific assembly operations. As an example the connection between the garage roof and surrounding buildings can be given. At this particular section in the project different types of work crews were involved in a number of different operations that had to be executed in one specific assembly order.

The site manager established a detailed 4D model in order to understand, set up and plan for these construction tasks. The detailed 4D model required further detailing of the structural design model and construction schedule. The detailed 4D model also required specific model views to be linked into the 4D model to allow the user to move in the model from one task to another showing those objects relevant to the task at hand.

Results

The 4D model was shown during the complete construction process on a computer in the main meeting room at the construction site, Figure 3.9. The model showed for every construction day the planned work with highlighted components in the model. The model was used as an instrument to validate the scheduled construction work, but its main use was the communication of the schedule with a large variety of stakeholders in the construction process.

Figure 3.9: The 4D model was used during the entire construction process as a tool in the main meeting room at the construction site to communicate the construction schedule to different stakeholders.

Using the 4D model the schedule, that included over 1000 activities, could be presented in a matter of a few minutes with a guaranteed common understanding among different stakeholders of the scheduled construction work. The model strongly contributed to the fact that communication was efficient (i.e. required little time and effort) and effective (i.e. ensured directly a common understanding).

The model was also used as an instrument at progress and look-a-head meetings on site and as a tool to quickly familiarize new project participants, such as suppliers, with the scheduled construction work. As an example the coordination of HVAC installation work can be given. The site manager used the 4D model as a tool to instruct the sub-contractors for HVAC on work how to perform their assembly work in relation to ongoing tasks by other crews. The visual value of the model cannot be stressed enough in this respect. The sub-contractors were directly provided with a clear and common picture of the assembly work and other building systems interfacing with their particular system.

4   DEVELOPMENT

4.1   The need for an IFC interface

The first transfer in the project of CAD models into the VR environments Neo and Ceco Visual was primarily performed by using limited (e.g. .3DS format) and propietary (e.g. DWG) data formats. The use of these formats implies a number of disadvantages and limitations:

- The VR models cannot easily be updated using .3DS and .DWG files from different CAD systems.

- Only graphical data can be transferred using the .3DS format

- The DWG format can include non-graphical data, but is limited to mainly Autodesk products for this usage.

- The .3DS format is no longer developed and the .DWG is propietary.

The need for non-graphical data became apparent during course of the project. The site-manager started to be interested in using the model for material planning. The manager envisioned that the model could be used to calculate the volume of concrete to cast and call for concrete supplies. In addition the manager wanted to be able to quickly extract the total length and area of non-bearing innerwalls per apartment and per floor in order to be able to plan for the amount of gypsum needed to be located at a floor before the scaffolding for the floor above was set up. The required data for these uses is available in the 3D CAD model. However, the data could not be extracted from the VR models used for design review and construction simulation, since the models were

limited to graphics from the CAD models. In order to improve the import and update of CAD models and take advantage of the non-graphical CAD data an interface for IFC interface was developed for both Neo and Ceco Visual.

4.2   Development of the IFC interface

The development and work-flow for the transfer of CAD models via IFC into Neo and Ceco consist of the following steps, Figure 4.1:

1. Exporting the CAD model to an IFC file

2. Converting the IFC file to a XML file

3. Importing the XML file into the VR environment
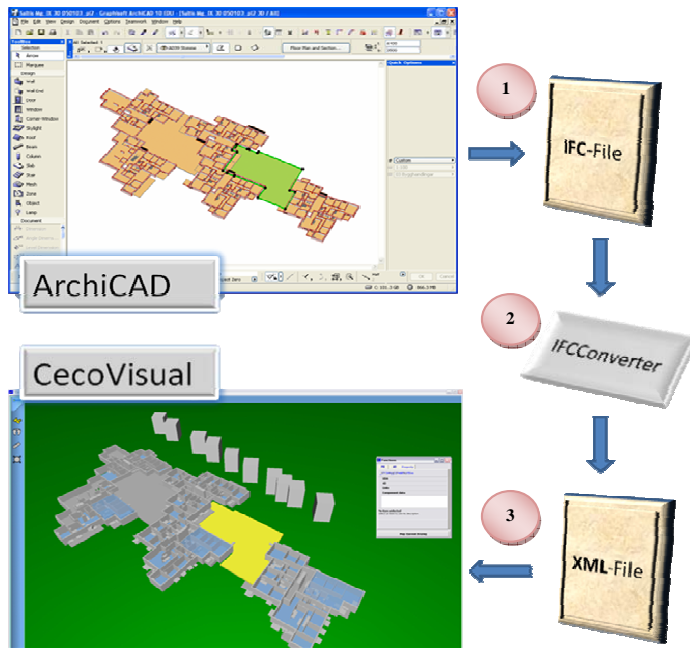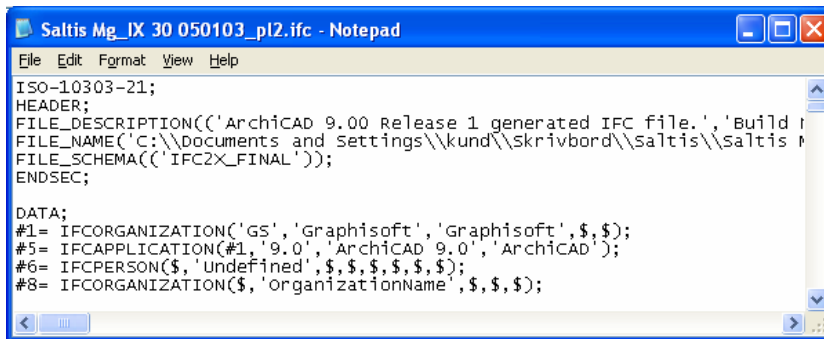
Figure 4.1: The transfer of a CAD model to IFC, which is converted to XML and imported to Ceco Visual. The work-flow for import to Neo is similar. The figure is showing one level of the Ringvägen project.

Exporting the CAD model to an IFC file

A CAD model is exported to the IFC 2x2 or 2x3 format. Figure 4.1 shows a 3D model from one level of the Hotellviken-Ringvägen project in ArchiCAD. Most of today's common 3D CAD systems, such as ArchiCAD, AutoCAD ADT 2008, Revit, Microstation and Tekla are IFC-certified. One disadvantage noticed when exporting IFC files is that they often become very large. Sizes between 10 and 100 Mb are very common. There are tools becoming available that optimize the IFC model, thereby reducing the file size and required model loading time (Solibri 2007).

Figure 4.2: *An IFC file sample in text format*

Converting the IFC file to a XML file

The IFC file format is open and free for use but is quite complex. Therefore a converter, the IFCConverter (IFCDLL), was developed in order to extract only necessary information to a more readable format for the VR programs. The main part of the extracted data in the VIPP I project contained the graphical information stored in the IFC file, but in the VIPP II project we will also address the non-graphical part of the information.

The IFCConverter is a C++ developed dynamic link library that has the following functionality:

1. Opens and reads IFC files. This is accomplished with help of an "IFC Toolbox" from Eurostep (Eurostep 2007). The use of the toolbox is straightforward. Every class in the IFC reference is mapped to a class in the toolbox.

2. Exporting parts of the IFC file to a more readable XML format, called
    VIPPXML.

```xml
<?xml version="1.0" encoding="utf-8" ?>
<IFC>
  <PRODUCT LEAFNAME="IFCSLAB" TYPE="" GLOBALID="23BvnOJLT5ZgKBDR7wFdYJ">
    <GEOMETRY ENTITY="METRE">
      <VERTEX X="-2.124464" Y="24.732666" Z="-0.300000"/>
      <VERTEX X="-2.124464" Y="24.732666" Z="0.000000"/>
      <VERTEX X="-2.124459" Y="19.776742" Z="-0.300000"/>
      <VERTEX X="-2.124459" Y="19.776742" Z="0.000000"/>
      <TRIANGLE INDEX1="0" INDEX2="1" INDEX3="3"/>
      <TRIANGLE INDEX1="3" INDEX2="2" INDEX3="0"/>
    </GEOMETRY>
    <GEOMETRY ENTITY="METRE">
      <VERTEX X="-2.124459" Y="19.776742" Z="-0.300000"/>
```

Figure 4.3: XML file sample

Importing the XML file into the VR environment

A stand-alone program, the IFCLoader, was developed to enable different
applications to import data from IFC model files; in other words not only the
VR applications that are used in the VIPP project (i.e. Neo and Ceco Visual),
but also other VR applications that are available on the market, Figure 4.4. The
IFC Loader in combination with the IFCConverter allows for an easy
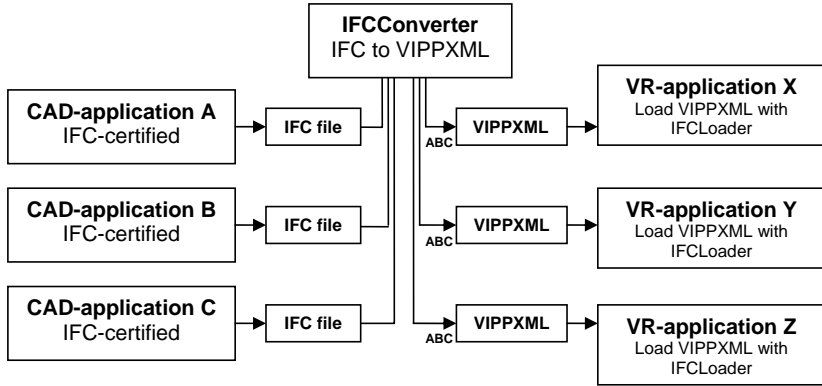integration of IFC model data in different kinds of 3D and 4D applications.

Figure 4.4: The IFC model is converted to VIPPXML using the IFCConverter. The file is loaded in VR-applications using the IFCLoader.

Figure 4.1 shows how Ceco Visual has imported the XML file generated by the IFCConverter. Figure 4.5 shows how Neo has imported a number of CAD objects using IFC.
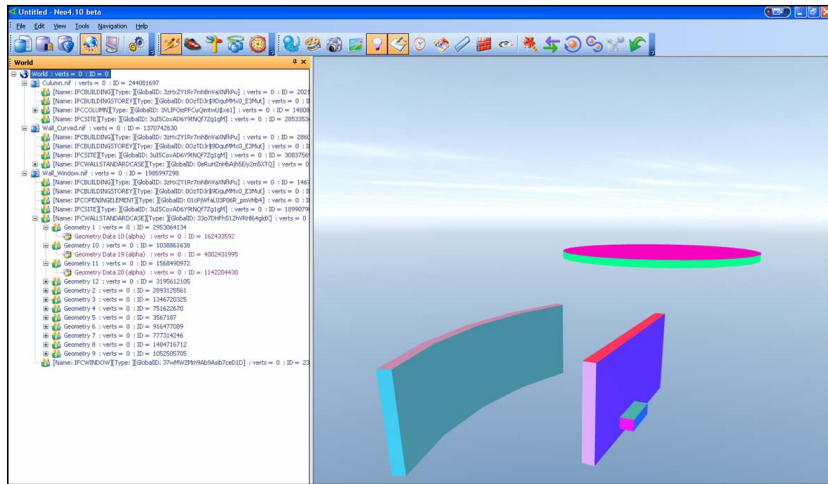

Figure 4.5: Import of CAD objects to Neo using IFC converted to VIPPXML. The object tree on the left shows the global unique ID numbers of the IFC objects.

Figure 4.6 shows the IFC import of four building storeys from the Ringvägen project in ArchiCAD and subsequently in Neo. The figure shows that the handling of geometry for openings needs further adjustment. In addition, no textures or lighting are present in the model, which limits the direct use for visualisation purposes. As a result, IFC import to Neo is considered to be applicable in early stages of projects for volume studies and early design models. For more sophisticated visualisation one is still dependent on manual processing of the geometry in dedicated visualisation software, such as 3D studio max.
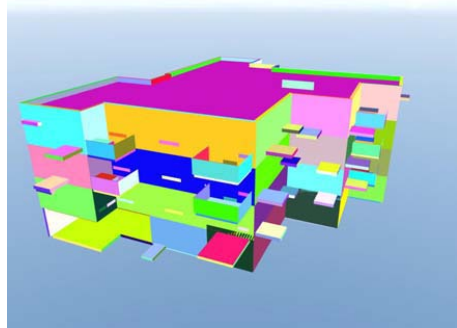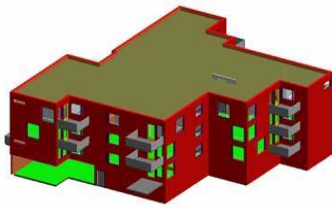

Figure 4.6: Architectural model in ArchiCAD (left) and the same model in Neo 4 by Sightline (right)

5   METHODOLOGY & PROCESSES

5.1   Recommendations and requirements for the design process

The 3D design process differs from the traditional 2D design process. However, it was found from the experiences by the different design disciplines in the VIPP project that the difference was not that radical. Most technical and methodological issues could be solved during the project. The main difference is that fact that the delivery from the 3D design process is not limited to 2D drawings. The 2D drawings are a product of the 3D design and not the primary design working material. The 3D modelling process also results in 3D models of different levels of details, including different types of non-graphical data.

Start with a joint workshop

Since the 3D models are not only used by the designers themselves to generate 2D drawings, but also by different members within and outside the project team, it is important to set a clear scope and purpose of the 3D models early in the project.

This is best done by organizing a workshop in which the different uses of the model are defined, including the different steps, format and frequency to deliver the 3D models. In this workshop all design disciplines should participate, but also the users of the models, such as the project schedulers, cost estimators, VR consultants, etc., in order to communicate what to expect from the models later on in the project.

Trail

After having defined the requirements for the models one should test these requirements before the actual design process starts, by for example creating a number of test files that are distributed according to the defined procedures that are set up for the project.

Document the delivery requirements

Requirements for the delivery of 3D models are not replacing the requirements for 2D drawings, but are rather a supplement to these requirements. CAD manuals used for 2D CAD delivery can therefore be used to a large extent to define the delivery of 3D CAD models. Examples of requirements for 3D CAD models are:

Definition of 3D models (i.e. model files)

- By building, or

- By building storey

Format

- IFC 2x2 or 2x3, and

- DWG 2004 or 2007

Coordinate system

- All objects shall have an exact X, Y, Z coordinate (mm.)

Layers

- All 2D information is hidden

Metadata

All objects carry property sets that include:

- A littra (type definition, such as V1, V6)

- Definition of object type (door, window, wall)

- The following parameters, for walls, slabs and structural members: Length (mm), height (mm), thickness (mm), area netto (m2), area brutto (m3), volume (m3).

- A checkmark stating that all included object properties are checked by the modeller

- A classification code, if supported by the CAD program, according to BSAB 96

- A Global Unique ID

DWG-specific

For DWG files there are a number of additional requirements that apply to the use of block in block references, external references, etc. Many CAD and VR programs do not handle blocks and external references as efficient as Autodesk applications and in general it is recommended not to distribute 3D models that include these types of definitions.

IFC-specific

IFC files consist of classes specific for certain building types. A wall object is for example automatically mapped to an IFC wall class, including the properties that are set for the specific wall objects. In certain cases the IFC schema does not support the objects in a 3D model. This especially applies to windows and doors, or to non-standard geometries, such as curved walls. The IFC model uses a proxy class to include the object in the model. A proxy can be seen as an information package. An IFC proxy cannot be fully read by other IFC compliant applications. The geometry appears often correctly, but the object properties are inaccessible. To avoid the use of proxies one can:

- Use 3D objects that are IFC adjusted, from for example an IFC standard object library.

- Map 3D objects when exporting objects to a specific IFC class.

An additional requirement that can be made for IFC export is the use of Global Unique IDs (GUID) and so-called BREPs. Global Unique IDs are necessary in order to be able to version different model objects. BREPs are packages for geometric data in the IFC model.

Model manager

It is recommended to appoint a model manager that assists the different designers with recommendations and tips for the modelling work. The model manager is also the one that specifies the CAD manuals, distributes templates and libraries, and the one that collects the different design models during the design review process. Specification for the role of a model manager have earlier been discussed in the preceding ITstomme project (Jongeling 2005).

5.2   Modelling methodology

Autodesk-specific

Most AutoCAD-based applications, such as ADT and MagiCAD, work with separate model files for every building storey linked together using a so-called project navigator. This does not apply to Autodesk's Revitt applications. The model files are by default all placed at 0-level by the applications as a result of requirements for display representation when creating 2D drawings from these files. The 2D or 3D representation of objects depends on where the application cuts through an object and from what angle the object is viewed (e.g. top, SW isometric, etc). In some cases, when the designer has elevated a building storey to the required Z-level for model delivery, the objects dissappear from the model-view due to incorrect cut-height definitions for a specific view (e.g. top view). It was found during the VIPP project that many designers are not aware of this behaviour by their AutoCAD-based applications.

The designer has the option to model at correct Z-level from start or to work at a default 0-level and elevate the models when they are ready for distribution.

- The advantage of working with the correct Z-level is that no separate elevated DWGs have to be made. The disadvantage is that the application reasons from 0-level for all its operations in a model, which can be impractical when performing certain modelling operations, such as creating openings in walls, etc.

- The advantage of working at the default 0-level is that the application is designed to operate from this level, including all display configurations, modelling tools, etc. The disadvantage is the fact that the models have to be elevated before they are distributed and that all the elevations in the modelling process are relative to the building storey-level.

It was found that certain designers tend to divide the model in the way 2D-drawings are defined in order to directly generate drawings from a building storey in for example 2D reflected representation. Reflective representation is the representation in 2D-drawings used by structural engineers that shows the storey on top of the storey that one is placed on. One is looking down in a mirror and up to the storey above in other words. This representation is favoured by workers on site, which allows them to work with only one drawing when setting up the formwork, etc, for the storey above their current storey.

However, the 3D modelling applications are not design to be operated this way. They are designed to be used according to typical architectural practice, by placing walls on a slab per building storey and not the other way around. Before one can begin to generate drawings, the model objects has to be assembled first (i.e. different constructs including vertical and horizontal objects) in a view that allows one to subsequently generate a reflected representation. Constructs that make up a model are best grouped by vertical and horizontal elements per building storey. To generate a drawing of a slab X on top of floor Y, one creates a view including construct vertical Y, construct horizontal X and construct vertical X.

IMPORTANT: It was found that creating horizontal 2D-sections in ADT is resulting in incorrect dimension values. It is therefore recommended to directly add dimensions in a generated 3D-view (i.e. a 3D model, viewed from TOP view - direct or reflected).

ArchiCAD-specific

ArchiCAD typically works with one model database (i.e. a file) per project. The advantage is that there is a single original of the 3D model with its generated 2D design information, compared to the collection of linked files typical for other types of design applications.

ArchiCAD has the possibility to exchange files in IFC format. However, in certain cases exports of DWG files are required. When exporting DWG files from ArchiCAD the objects are converted to DWG meshes that are difficult to work with in other applications. The files are geometrically correct, but contain too many triangles to be of practical use.

In order for other designers to use these DWG files it is recommended that those objects are isolated by the designers that are relevant for the task at hand. Practically this means that the designer hides all objects other than those necessary. This can be done by:

- Open the ArchiCAD generated DWG model separately in ADT

- Hide the objects that are not necessary to display for a specific modelling task, for example by using the hide/isolate object command

- Reference the file into the ADT project.

This process is tiresome and prone to errors. With the release of the new Autodesks 2008 applications that include an IFC interface this process should be avoided. Instead, IFC files can be used to facilitate the distribution of 3D models between the different design applications.

It was found during the VIPP project that large coordinate values can be problematic when working with ArchiCAD and subsequently with IFC models. For example, a model that is located 10 km from the origin is not supported by ArchiCAD and the IFC format. In order to avoid these types of issues it is recommended to use a local coordinate system close to origin (zero) for all 3D models. Alternatively, one can work close to the origin and move the model after export and import to other applications.

MEP-specific

Mechanical-, Electrical- and Plumbing-design (MEP), is mostly done in Magicad or Autodesk Building Systems. Most of the consultants using these applications have been modelling in 3D for a number of years and have delivered only 2D model information to project stakeholders. Requirements for 3D delivery are therefore not a radical change in their design process. There are two issues that often surface when discussing MEP design in 3D:

- All objects should have a correct Z-level

- The electrical design in 3D can be limited to cable trays, light fixtures and other objects that are relevant for interference detection with other designs in 3D.

5.3 Delivery of 3D models to VR environments

One of the objectives of the VIPP I project was to develope and use VR environments that support the IFC format. The IFC interface that has been developed for Neo and Ceco Visual partly covers the IFC model definition. Certain object and geometric definitions are not yet supported, but will be part of the interface. As a result, the delivery of 3D models is still depending on the use of the .3DS and .DWG format.

Requirements and processes for the delivery and use of 3D models in VR environments have been formulated during the VIPP I project and are applied in practice during the VIPP II project. The findings will be reported when closing the VIPP II project.

6   DISCUSSION AND CONCLUSION

The VIPP I and II project's main objective is the use of 3D design models in practice by professionals in a real construction project and to set an example for other professionals in the construction industry. In order to achieve this goal a number of system developments have been set up and implemented, but the focus has been the facilitation of the practical use of the 3D design models. The use of VR environments allowed us to transfer the 3D models from typical CAD users to non-CAD users, such as the project manager, sales agents, project planners and construction workers.

By means of defining scenarios for the early and detailed design review process and for production scheduling purposes we have been able to show the value of 3D models for a number of different applications and project stakeholders. The main benefits of using 3D that we have found during the VIPP project, and that are listed in Chapter 4, can be divided in:

- Facilitation of the communication process with project stakeholders. We have shown that vizualization facilitates the communication process from the early design, throughout detailed design into the production process. The visual value of the 3D models allows stakeholders to quickly understand the project and to develop a common picture.

- Increased process efficiency. For example, by using 3D models we were able to improve the construction scheduling and communication process.

- Higher quality of the process. For example, 3D models allowed us to efficiently conduct detailed design reviews by checking different design models with each other.

We have no quantitative evidence of the benefits of using 3D models in practice. Instead we have tried to describe the process and the resulting experienced values of creating and using the 3D models in practice. The next step would be to quantify the benefits of using the 3D models.

The VIPP project shows that the 3D design process is different from the traditional 2D design process, but not radically different. The 3D design process results in a number of deliveries of which the 2D design is one of them. We found that it is critical to define early and clearly in a project for what purposes the 3D models will be produced. This definition also includes specifications for the delivery process of the models, including the structure, contents, format, frequency and quality of delivery.

The time required to create 3D and 4D models was not considered an obstacle for designers and the project team and it was seen as a surprise how little time it actually took to create the different models, Table 1.

Task	Days	Comments
Structural 3D model, version 1	3,0	3D model based on 2D drawings
Structural 3D model, version 2	1,5	Further detailing of the model including concrete pours, etc.
3D model of the construction site	2,0	Partly based on 2D drawings
Preparing schedule for linking	1,0	Adding level of detail and structure
Linking the schedule to models	1,0	Including adjusting the schedule
Total	**8,5**	

Table 1: Time to create the 3D and 4D models

The total time that was required to establish the 4D model is 8,5 days of work, of which parts of the work have been performed by the site manager himself. The structural design was modelled in 3D from 2D drawings, but in the ongoing VIPP II project the structural design is directly made in 3D from which 2D drawings are derived.

During VIPP I the use of the VR model and the design process were rather two parallel processes where the use of the VR model benefited the design process.

The VR model was a number of times renewed but there were no procedures in place that stated how, when and by whom all the models were to be delivered, updated and dissiminated. These processes were defined during the VIPP I project and are now applied in the VIPP II project. The findings will be reported when closing the VIPP II project.

The IFC interface that has been developed for Neo and Ceco Visual is extended during the VIPP II project to cover a larger part of the IFC model definition, including non-graphical data.

In order to achieve the full practical use within the VIPP project we have tried to use readily available technology, but we have also implemented new technology in order to facilitate the transfer of 3D CAD models between different design applications and to VR environments. Our objective was to keep the definition of use cases, requirements and processes concrete in order to maximize the practical applicability of the VIPP project for other professional users in the construction industry. The practical approach might have compromised the scientific level of the project work, but finding workarounds when theory and practice disagree is part of the implementation of new methods and tools in every industry. Therefore, we believe that the VIPP project's results can stimulate the industry to start using 3D models and VR environments in building projects so best practices can be established.

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