Interactive visualization for information flow in production chains: Case study industrialised house-building

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Abstract –

Predefinitions in house-building platforms is developed as routines to manage project building information models over to production data by documents and digital drawings. Visualisation of the information flow in the industrialised house-building process is hard to track and information are often presented as islands, seldom described in the flow for the entire process. Interactive visualisation, using game technology, has open up for new applications of data -transformation, -visualization and -simulation of project information which is less studied in the context of industrialised house-building. This paper tries to address this issue via a combination of game engine technology and the predefined industrialised house-building process. The game engine technology allow development for end-user demands and functionality to express and visualise values for the daily planning and execution of processes. In a case study approach the development and analysis of four building projects were studied and chosen to the range of product platform predefinitions. Based on object structure for different views, models and the related metadata were visualised with an immersive virtual environment prototype. The prototype, based on game engine technology, was developed to manage incoming building projects variations that followed house-building platform predefinitions. As a visualising tool of engineering, on-site planning and production process the game engine technology simulates and visualize views on product structures, production information, assembling and operation instructions by interactive functions in the game environment.

Keywords –

Game engines; industrialised; house-building; information flow; visualization

1 Introduction

Industrialised construction companies are described in a range from high level of prefabrication to fully on-site construction [1]. The range of predefinition of the product affects how to manage a design process in construction and how information systems support the progress with human knowledge of the work. Visualising planning, as the artefact of planning construction projects in flow-oriented work, are used instead of traditional resource-planning with schedule techniques [2].

Using game technology in virtual environments has the potential as a communication tool for architects to customers to understand the house-building process [3-6]. By providing virtual models across extended supply chain representations Whyte et al [7] argue that combined visualisations are evolved through practices in reified and hybrid forms in fabrication, assembly and on-site work. Industrialised house-builders has developed their information flow using drawings and instructions in documents. BIM-software are used to speed up modelling of house-building projects, and design automation is used to provide template-based configuration functionality for example regarding the interfaces between wall-to-wall, wall-to-floor, and wall-to-ceiling. Other configuration in the BIM-software could be generation of studs, boards and stud-cutting around doors and windows. Automation between design and production has focused on robot and machine control since the beginning of the nineties [8]. Even if BIM-software with data for production has been around since the start of the millennium only a few applications for visualising information flow has been evaluated and implemented in house-building for factory production [1].

In the development of information systems for industrialised house-building processes the aim of this study is to describe how interactive visualisation could visualise the information flow for different views in the house-building production chain. To reach and confirm the research aim, the following questions about interactive visualisation in industrialised house-building has to be answered:

In the chain of information flow, how can progress be visualised by game technology through variation of different information views?
How can interactivity be used to visualise changing scenarios for BIM data in a factory production setting?

2 Frame of reference

Communication of building concepts is often based on rendered pictures, sketches, drawings and documentation by text where lights and movements is hard to compresence for decision makers in the early stages of design [3, 5]. Visualising the third dimension from 2D-descriptions demands experience and training [6, 9] and the static 3D-view do not enable expression of different perspectives for a specific place and a specific time [9]. Since the nineties the evolvement and application for building projects with virtual reality (simulated virtual environments based on physical environments), augmented reality (physical environments augmented by virtual input) and immersive virtual environment (user interaction supported within virtual realities) has become technologies that not only focus on design aspects but also on the life-cycle visualisation and simulation of a building project [10]. The immersive virtual environment enables possibilities for reviewing alternatives in the realisation process of a project before it becomes physical reality [6]. BIM-models are constantly becoming more detailed which opens up for opportunities to use game technology for VR visualization, but this also creates problems for a seamless use without further optimization. BIM-models are created to describe buildings in detail and many 3D models extracted from BIM models are too big and complex to be used directly in real-time visualizations [11]. Because of this, it is still difficult to integrate VR as appropriate tools during the design process [12]. The introduction of a new generation of VR glasses has made the situation even more challenging, though these new types of VR devices offer enormous possibilities in terms of realism and sense of scale they are also much more demanding when it comes to real-time rendering performance [12].

Industrialised house-building in Scandinavia has developed their processes from manual production to automated production lines in factories. Standardisation of house-building platforms that manage component, process and relations describing different market positions and relates to how the company organisation could arrange production planning [8]. Using design automation in industrialised house-building is described by Sandberg et al. [13] as a chain of engineering activities in the design work. By the use of software, configuration through parametrisation of building systems generation of components up to building is possible [8]. Balancing resource and flow efficiency is an important issue for industrialised house-building companies [14]. The use of standardised workflow with single unit flow is identified as efficient for operation in factory production [2, 14].

3 Methodology

This study was designed in a qualitative research approach based on interviews and collecting data by archiving data in drawings, documented rules in platform predefinitions, and production routines. The case study approach gives opportunity to reach value rich information from the combination of interviews and deeper knowledge from cases [16]. Semi-structured interviews give opportunity to follow answers from respondent and to develop the insight in for the research [17] where three technical managers at the studied company were chosen. Interviews with focus on both product concepts with predefinitions and IT-structure to manage object designations created the design phase in description documents and BIM-models. Industrialised house-building in Scandinavia is based on high levels of predefinitions in platforms or a combination of predefined products that are modularised in combinations. To reach the variation of predefinitions of house-building platforms two projects from two companies were chosen to facilitate the range from high levels of predefinitions to medium levels of predefinitions. The studied context is based on two volume-module production companies that has 15 years of experience of of-site production based on platform-products in their production.

Company 1 has a capacity of 2 000 apartments per year and a turnover of 100 million euro have reached a speed in production of about 60 volume units per week with two production units served by one design organisation. Company 2 has a capacity of 700 apartments per year with a turnover of 30 million euro and have reached a speed in production in about 40 modules per week with three production units served by one design organisation. Selection of building projects focus on volume module variation, general object selections and medium complexity for client choices. Volume modules with varies in dimensions from 3.1x6.2x2.8 meters to 4.2x9.1x3.1 meters in width, length and height.

Software selection were based on CAD software, databases and game engine platforms that are frequently used in general but also ones that enabled functionality of transforming object related information with relations. To develop the IVE, a prototyping approach was used. Development was done according to interview results, platform predefinitions and with one reference project in one production unit as a start. The prototype section of the study did not aim to find the most efficient application of software for an IVE, but rather to describe different scenarios of the information flow that could be developed further and as a foundation for flow oriented analyses of objects.

There is an increasing interest in articulating methods used in the field of IVE development for application in the construction industry [9, 11, 12]. Analysis of the

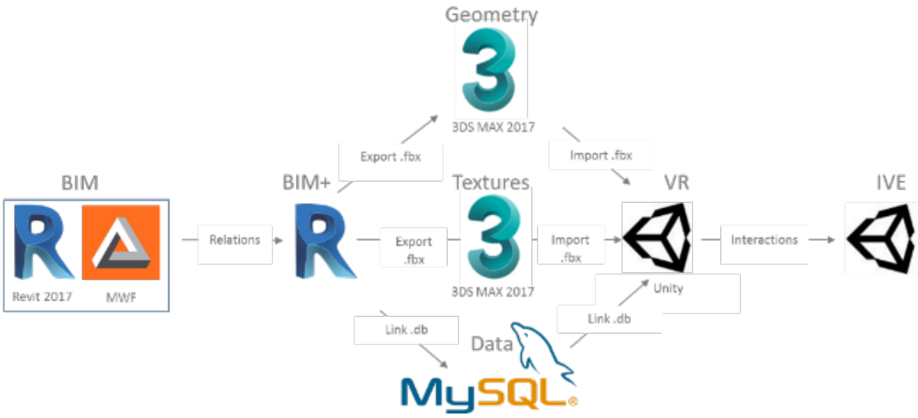

Figure 1. Transformation process of industrialised house-building BIM to IVE.

results were therefore made to provide insights to aspects included in visualising information flow using IVEs.

4 Game-technology for information flow

Describing the value chain of information was setup using game-technology to describe different process stages of managing information. BIM-models constitute an information base for communication of information between stages in the chain from design to production. The traditional use of drawings from design to different stages has until now been used as the primary communication from BIM-models. To enlighten the possibilities of managing information from BIM-models, without the transformation to drawings, the aim for describing a continuous flow of information was to set up a structure of product views and the communication of product transformation between these views. Game-technology was the enabler to visualise the transformation in the chain for the following views: engineering view, manufacturing sequence view, production process view, and on-site production view.

Implementation of game-technologies was achieved using Unity, a cross-platform game engine, which allows for the creation of applications with 2D and 3D graphics support with interactivity and functionality. Autodesk Revit, together with the add-in MWF Pro Wood for creating timber structures, worked as BIM-generators for the selected building projects (see Figure 1). Using a custom add-in for Autodesk Revit, written in C#, the BIM-models were developed further to BIM+, where extensions of the possible relationships between objects were implemented. The relations that were implemented for the house-building structures where the relations included-in and consist-of, e.g. a stud could now be described as included-in a specific wall, or a volume-module could consist-of specific walls, floors and ceilings. The add-in used calls to Autodesk Revit's API in order to extract data regarding the different elements in order to determine their relationship in one of two different ways: through attributes, or through geometrical analysis. As some elements already contain relationships, e.g. a window has an attribute which links it to its host, these relationships could be derived directly from the BIM model. Other relationships which are not already present, e.g. which wall a stud belongs to, were subject to a geometrical analysis. This analysis used the geometries of elements to determine geometrical intersections in order to identify relationships. These relationships were later used to give names to, and to track objects of buildings, volume-modules, elements, components and details in the visualization process.

In order to produce a 3D representation of the BIM models in the game engine, a solution where passing the geometry and materials from Autodesk Revit through Autodesk 3ds Max was used. This method was used as importing FBX-models directly exported from Autodesk Revit failed to provide the materials and textures found in the BIM-model. Using Autodesk 3ds Max as a middleware also provides the possibility to optimize the geometry and materials (see Figure 1).

Like with other game engines, Unity is limited in its ability to directly read metadata from BIM and CAD-tools. As such, to facilitate this transfer an information link was created through the use of a database. In this instance, MySQL was used as the database management system as it has the possibility to meet Autodesk Revit's database link interface and also to serve Unity with data through the use of custom scripts written in C#. In order to link metadata between the BIM model and the representation in the game engine, the unique element id that is generated for each element in Autodesk Revit was chosen as a common denominator.

As the geometry for the BIM model is exported, each object is given a name that contains the unique element id. Equally, the database that is populated from Autodesk Revit also contains a reference to this unique element id in each entry. Using this method, the geometry and metadata could be linked within the game engine.

The combination of the visual representation and a database containing the metadata, produces a virtual environment of the BIM model. The separation of geometrical representations, materials, and metadata as the three types of input sources became the method of transformation through the game engine development process (see Figure 1).

Linking design, manufacturing and production data from the BIM+ model into the virtual environment became the enabler of object structures that follow the building project through the entire life cycle. Geometry and material models were updated manually by traditional export/import using the format FBX. In this type of communication for information flow, the methods of combining transformation scripts through the use of unique object identifiers became central to the ability to first separate and then combine in the IVE prototype.

4.1 Interaction between and in building stages

The building stages in industrialised house-building with prefabrication of timber volume modules, when an order is set, is divided into the following visualisation views: engineering view, manufacturing sequence view, production process view, and on-site production view. The engineering view describes the building from its functional perspective with timber volume structures and space objects. Here, the interactivity in the game engine was programmed to give a variation of choices for changing between predefined views and fly-trough features and visualisation of combinations of space and physical objects. The transformation from engineering view over to the manufacturing sequence view visualises in which sequence each volume module were planned to be assembled on-site. Functionality was programmed here so that a user could select a volume module and get information corresponding to the current view. This can be seen in Figure 2 where data for the specific assembly sequence are presented, where the first number represents a sequence ID (23, 24, 25, 26) and the second number represents an object ID for each volume module (502, 503, 504, 505).

The production process view shows the transformation from the manufacturing sequence to a visualisation of the flow of volume modules and elements in a factory. In the production process view, interactivity were developed to visualize different product assembly lines with stations and visualising BIM metadata for the volume or element object at the station in the specific time (see Figure 3.). Alternative flows of assemblies lines were built in with Unity functionality based on a list of instructions and derived from the manufacturing sequence. From that list the both the main line (volumes) and sub-lines (elements) were programmed in C# for the specific flow. The number of elements in each volume and number of stations in the sub-lines gives the enter time

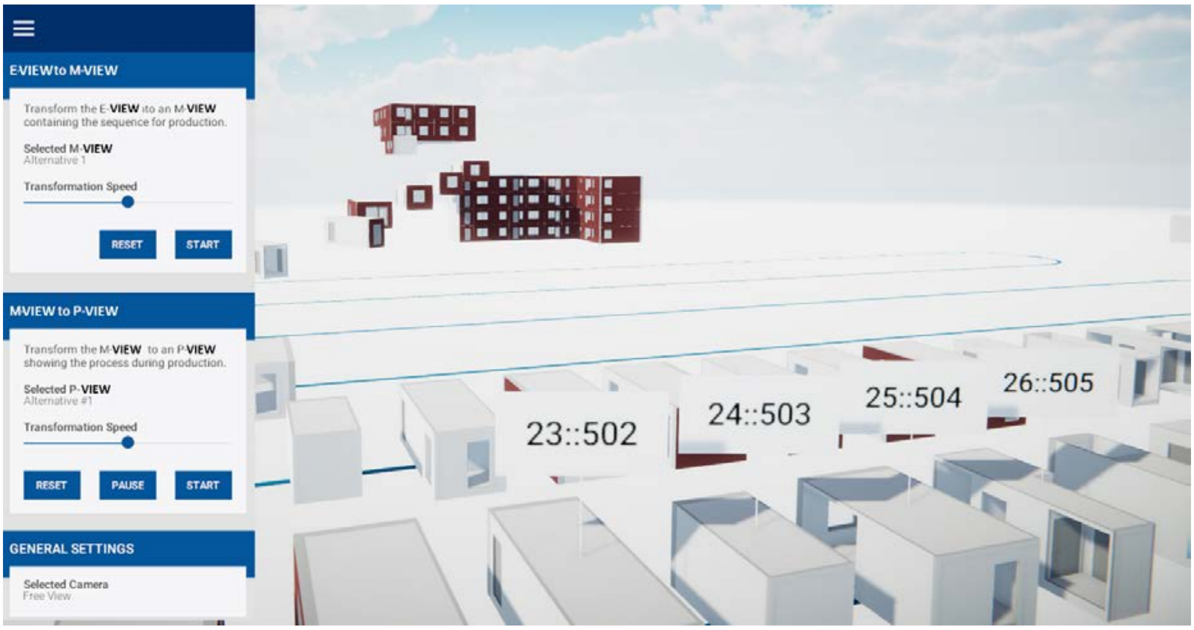

Figure 2. Visualisation of transformation from engineering view to manufacturing sequence view in the IVE prototype showing object ID and sequence ID.

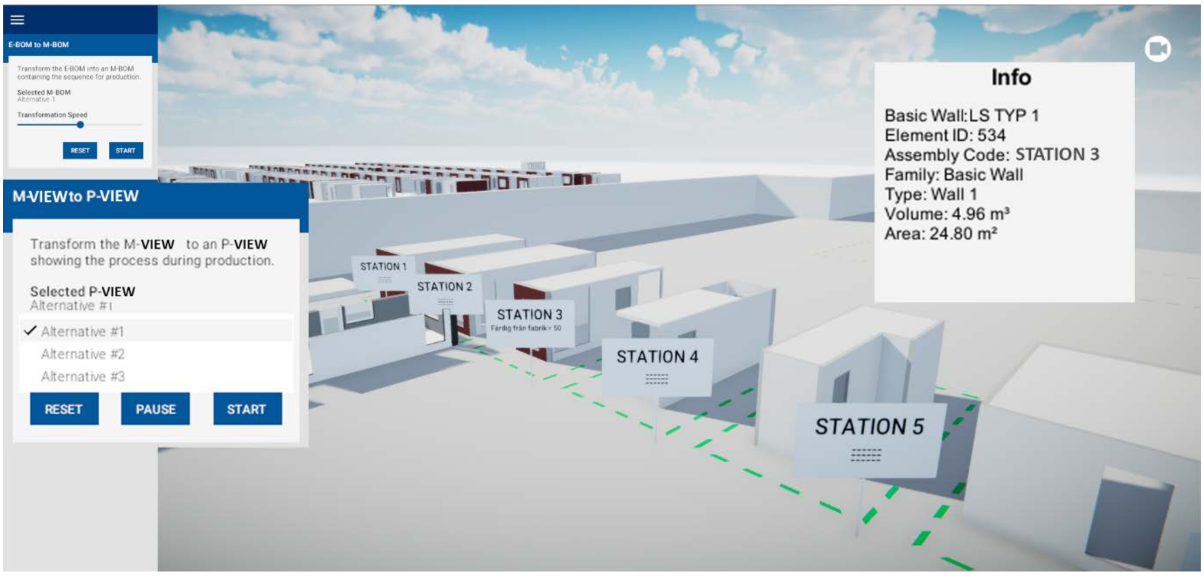

Figure 3. Visualisation of an alternative dialog and showing BIM information output with station related information in the factory production view in the IVE prototype

(instruction.Type==ProductionInstructionType.Enter) for each object for the flow. For a continuous flow from the list each object (volume, element) were asked to move to next station if they have entered the production line (instruction.Type==ProductionInstructionType.MoveTo) and ends with a general predefined pause for all stations in the main line. The entire flow of volume objects is then ended in the factory production process view if none of the two above conditions is not set (instruction.Type==ProductionInstructionType.Exit).

Lastly, the on-site flow shows the transformation of ready volume modules from the factory being assembled in the specified manufacturing sequence with a set site assembly time for each volume. In all instances of the transformations, interactive functionality was used in the game environment to combine object data and visualise different scenarios according to variation of projects, number of stations in assembly lines, production speed (pauses) and site assembly time. Possibilities to start, stop, reset and change the speed were provided. As such, the user is given the opportunity to control the events occurring within the IVE prototype.

The result shows that the use of game engine technology as a communication tool gives spatial understanding of both structural and space geometries, regardless of professional expertise. By exploring an environment in the IVE prototype, it comes very close to the experience of a full-scale model. The use of a game engine powering the IVE prototype provided the underlying tools to simulate and analyse processes in virtual environments. The environments allowed high interactivity and real-time performance, which meant that the goals for each stage could be evaluated before real production.

4.2 Building scenarios and metadata

Two building project scenarios of information flow were evaluated to the developed IVE prototype. The two projects were evaluated for two different assembly sequences and according to three production units (factories). Functionality with the Canvas tools in Unity gave the possibility to create user interfaces with controls such as buttons, dropdown menus, and sliders can be implemented to enable user-control over an environment. Interactive functionality for selection of assembly sequences were programmed in as drop-down menus with the two assembly alternatives in the Engineering to Manufacturing dialog (Figure 2). The three alternatives of production units were implemented using the same technique for the Manufacturing to Production dialog (Figure 3). Each building object in the IVE prototype were prepared with links to present object information for each view. An example is that the engineering view only visualise object ID, and in production view a number ofdetailed information were visualised that related to original BIM-data. If the Revit-model were to be updated with new metadata, the included links would facilitate propagation of the updated metadata to the IVE prototype.

5 Analysis and discussion of the results

Although the focus is primarily on resource efficiency, the significance of flow efficiency in house-building production is increasing [14] and systems that support and visualise the progress through production becomes needed. The open game engine technology, with a global network of solutions, gives possibilities to develop interactivity in the environment [12] and to visualize and simulate processes with product models for house-building through the entire production chain. The interactive visualisation in the case scenarios has to manage a variation of single project information to the variation of repeated process information. Simulation with IVE functionality has in this study shown possibilities for prefabricated house-building systems to visualise alternatives both for production units (factories) and also for the assembly order to prepare for building site. The spatial models with related data visualise the process in the IVE prototype as almost real objects, and as according to Heydarian et al. [10] the life-cycle perspective is important for all stages in the realisation of buildings.

Object structures with the relation of included-in and relates-of became a needed feature for the simulation of object flow in the visualisation. House-building processes with prefabrication of volume-modules uses the hierarchy in their planning of factory production in object assemblies from components up to volume modules. This serves not only the information flow but also the material flow that has to be managed in parallel.

Visualisation of different stages in different views of a production process gives an analytical method for planning production. By using both interactivity for input variables (as manufacturing sequences, production lines, and flow speed) the use of IVE enables a tool for analyse planning and simulate building process progress from a production perspective.

As the study shows, and also Whyte et al. [7] means, that total interaction and photorealism is not always necessary to make decisions through the process. The detail level should instead be adjusted according to the situation in which the IVE prototype is used. The study showed that platform predefinitions affects the information flow both on product and process information, which is central for how game engine could contribute by the interactive visualization in house-building production. A high level of predefinition of the product visualises the combination of object and process information in the IVE wile less predefinitions requires a lot more work before objects could be implemented in the IVE environment for flow analyses.

6 Conclusions, limitation, and future work

By highlighting the interactive functionality for flow it was concluded that game engine technology is applicable in industrialised houses-building on a spectrum from interactive visualisation in design, production and simulation of site assembly flow. To describe how IVE could visualise the information flow for industrialised house-building, the prototype presents the importance of alternative functionality for different views, as production processes in factory but also to the variety of assembling sequences. To visualise different views of the production progress, with game technology, the study shows how the combination of geometries, textures and data that are linked and could be updated by automation. Interactive functionality in the IVE prototype shows how the link between BIM and IVE could be updated to different scenarios by using extern databases and internal functionality in the cad and the game engine. To manage house building project for production a high level of predefinition of platform predefinitions speeds up the development of links between BIM and IVE.

The evaluated methods of IVE development for industrialised house-building could be interesting for on-site productions where standardised production work is applied and the need for visualising information flow. Limitations of two companies in this study constrain the generalisation of a prototype but enlighten the possibilities to understand possibilities to use BIM for IVE in a flow oriented production perspective. The transformation process of BIM to IVE describe a separation of geometry, textures and data with object tags as enablers for automated combination of models in the IVE prototype. This technology could be useful for other simulations, like supply chain flow of production materials or resource planning which are in relation to the studied scenario in our case.

Out of the four scenarios in the case two of them were modelled in ArchiCAD with the application Archiframe, for timber structures. Possibilities to evaluate the method for other cad-platforms is of interest for the API programming of relations and database connection, but not the purpose in this case.

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