Automatic comparison of site images and the 4D model of the building

P. Podbreznik & D. Rebolj
University of Maribor, Faculty of civil engineering, Construction IT centre, Maribor, Slovenia

ABSTRACT: A method for automatic comparison of on site building images and the 4D model is proposed. The process and the main system modules on the path from real images to a reconstructed geometry model are explained. Finally, the decision about the geometry modeler is argumented and the semantic links between the reconstructed geometry model and the 4D model are explained.

1 INTRODUCTION

A 4D model includes a product and a process model, where information about the product as well as about the process is integrated [4]. Project management applications are widely used in construction and are also an important part of the 4D model environment. One of the recognized problems in project management in the building phase is the comparison between the schedule plan and the realization. This is generally done by inspecting the building process on site, which is a time consuming and inaccurate process and as such a hindrance in the project information flow.

In the paper we are proposing a solution based on the automatic construction of a 3D geometric model from 2D images. To perform automation of the building process inspection, the fundamental parts of the building object, the fundamental elements, have to be recognized on 2D images. The system gets 2D images directly from the construction site by using web cameras. Fundamental elements are then used in a 3D reconstruction process to build a specific 3D geometric model, which is compared with the product model component of the 4D model. The project manager can see differences between both models and accept changes to the 4D model, and the schedule plan respectively.

The solution concept is depicted on figure 1. With the proposed automation we can significantly improve the information flow in the construction process. Failures and differences between the planned and realized activities discovered earlier will decrease costs caused by false or missing information. A product model with recorded changes can be used as a source for the realization plan of the building.

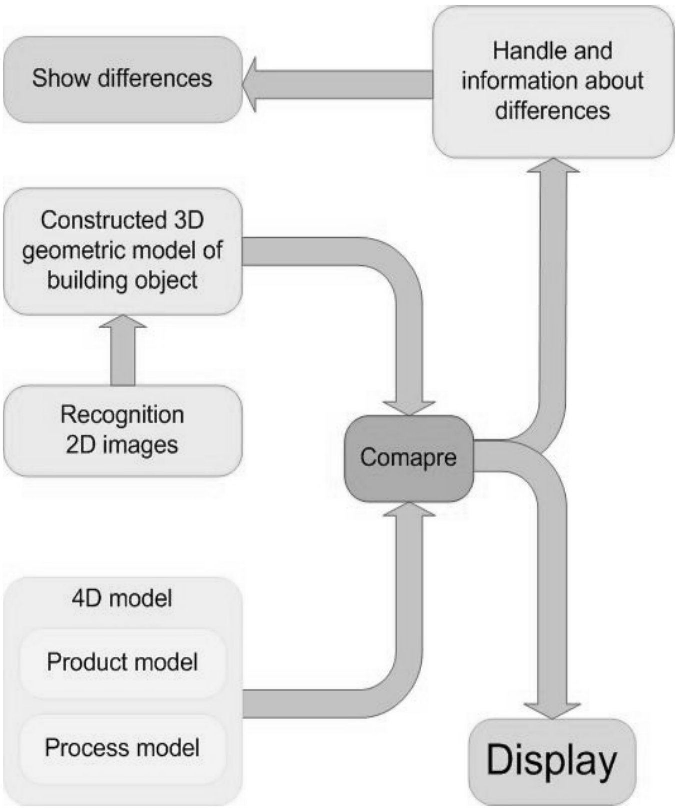

Figure 1: Base shame of application

2 4D MODELS

Construction of buildings is probably the oldest engineering activity, which has caused the evolution of building methods, materials, improved methods for designing, etc. In the early days of mankind human beings built more or less by trying and learning on failures. With time enough experiences and knowledge has been collected to try more complex buildings. However, they had to put their ideas to some form of plans. At the first phase planning was organized as a sketch, which was linearly evolved with pretentiousness of buildings and schedules. The civil engineers had to divide the building plans into two parts, which we today address as:

- product models, and
- process models.

Each of them could be independently presented as individual object in the building process.

2.1 *Product models*

Product models are the most important concept to make complete and integrated representation of the whole building, which includes:

- 3D geometry model,
- building properties (acoustic, thermal, luminosity, materials . . .),
- connectivity of different professional aspects (mechanical, electrical engineers . . .),
- environment for inter-operability.

Most often civil engineers made their virtual buildings with different modeling tools or 3D geometry models, which had different solution to represent the virtual building with building properties as a computer file [5][3]. How data is structured and formatted was depending on modeling tools and their support for different export formats. Most often it has been impossible to reuse the same file in different modeling tools and engineers lost useful information when they recompiled files between different formats.

One solution suggested common data structures, which would enable exact definitions for:

- geometry for fundamental elements,
- relationship between elements,
- linking elements with the corresponding activities
- topology,
- properties of each element or object.

Exchange structures evolved and in 1994 a standard has been accepted for the description of data to be exchanged between applications (STEP[5] – Standard for the Exchange of Product model data). With STEP it is possible to describe any product model, independent of its complex geometry and property structure. For practical use STEP has to be divided into many engineering branches (civil, mechanical engineering, ship building, etc.), which could be described with different application protocols. Each application protocol implements specific engineering area and has its own code (AP203, AP209).

The STEP's main problems are complex definitions for elements and relationships between them, and its impractical high abstraction level. Therefore a solution has been proposed in form of predefined elements, which are ready to be used. IFC[3] - **I**ndustry **F**oundation **C**lasses, is a collection of element definitions for the civil engineering area, and is based on STEP.

2.2 *Process models*

Process models are more abstract than product models, since they describe activities. In the scope of a 4D model, a process models defines the product model in time. Process models have been constructed from different methods and define the schedules in different ways. Gantt charts have mostly been used in scheduling tools, but couldn't represent clearly all overlapping tasks across the building process.

The method Line of balance could be another possibility to represent task sequences and conflicts between them. This method enables an efficient representation of task overlapping and supports simple activity management and schedule.

2.3 *Constructing 4D models*

Integration of both models, with links between activities from the process model and elements from the product model, represents a definition of the product model in time. Applications, which enable linking of objects from both models, are called 4D tools.

With 4D tools [4] site managers can quickly check accordance of geometry of the product model with the real building situation, and scheduled tasks with activities from the building site.

3 3D GEOMETRY MODELERS

Today CAD tools are the basic assistance for engineering design. Each engineering area has its own specific requirements and appropriate specific CAD tools. Civil engineering CAD tools provide functionality to construct the product model and are based on the geometry model, which is the core structure. The CAD tools can be divided into several components:

- geometry kernel to construct geometry model and set topology,
- specific modules to set properties for geometry elements,
- calculation modules (structural analysis e.g. FEM, thermal calculations etc.)
- representation modules (e.g. VR)

- modules for data exchange,
- user interfaces: (GUI - graphical user interface, API - application program interface, scripts).

3.1 *Geometry kernel*

A geometry model [12] consists of specifically organized data structure with relationship between objects in the model. Data structure is depending on geometry representation or geometry modeler with various geometry kernels respectively - depending on the requirements. Each engineering branch has to handle specific geometry problems, which would be solved in specific ways. For that reason many geometry representations exist and gives many possibilities to construct geometry models. The main geometry representations are:
- spatial occupancy enumeration,
- constructive solid geometry - CSG,
- boundary representation - B-rep.

3.2 *Product model construction*

4D tools usually require a geometry model and a schedule to import. How a product model is built with a CAD tool depends on the tool characteristics, but designers always have to separate geometry object into parts, which can be linked with activities in the process model. This is the basic concept of constructing product models and CAD tools have to have the modules to enable parts separation. Other modules are needed for object description and set properties for fundamental elements.

Module for object description includes libraries with fundamental elements (column, wall, slab …). These elements usually have full description with permanent settings and functionality name like bear wall, indoor wall. Designers or constructors have possibilities to make their own elements with custom description and settings and save them into libraries. The possibility to build fundamental custom elements with properties and setting depends on CAD tools.

3.3 *Data exchange modules*

Designers and constructors build geometry models, set properties and separated the building objects into different parts and finally build a product model. CAD tools save the product model into specific file types, but mostly also enable exporting into other types too. Often it is necessary to save the product model into STEP of IFC files to keep the complete structure and data information.

3.4 *User interface – UI*

Direct communication with the machines like computers is a very difficult task, especially for non-professionals. Any kinds of interfaces [1], which establish the convenient communication between users and machines, are much more user-friendly. Software companies have professionals to design user interfaces because it is very important how they are organized and how they communicate with the user and application site. Software designers have many possibilities how to improve interaction between the user and the application and choose convenient type of interface.

The first computers haven't had user-friendly interfaces and usually they had been text oriented without colors and visualization effects. The main problem for graphical effects, in the past, was memory, which disables software engineers to make attractive interfaces.

3.4.1 *GUI - graphical user interface*

With hardware and software development the interfaces became more and more complex and useful for general users to work with the machines. The user interfaces became graphical oriented and relieve usage with command suggestion to user.

3.4.2 *Application program interface – API*

API's interfaces are suitable for advance users, programmers and software designers to use application functionality as components or procedures call. Programmers could used API as a core of application and develop some additional functionality or as components to include existing modules and use them as an add-on.

Both methods are used very often today, because they make it possible to include a lot of knowledge very quickly and simply. Flexibility and suitability depend on environments, which could be adopted for different types of professionals. CAD tools have their own environment with specific language to call the procedures, which enable data manipulation, computation, visualization etc.

The most interested for computer engineers are APIs in different programming languages, but API has to support language wrapper for each programming language. C++, C, Java, Python are often supported in nowadays engines and reach high performances of the final application.

4 CONSTRUCTING GEOMETRY MODEL FROM IMAGES OF BUILDING SITE

The construction of the geometry model as a process is illustrated on figure 2 and has the following basic phases:

– building site images input,
– pattern recognition,
– include knowledge about 4D model,
– construct geometry model.

The main difference between conventional automatic object recognition and the proposed method is the existence of the 4D model, which can be referenced to solve conflicts or ambiguities in the recognition process. In this way the 4D model is both used as a knowledge repository and as the model to be analyzed and updated according to the real situation.

4.1 *Images of building site*

The choice of method to get correct images as an input to application is difficult, because we have to consider many parameters that enabled us to make geometry construction successful. If we want to simplify reconstruction process from 2D shape to 3D object it would be necessary that each single camera has:

– defined fixed position,
– fixed zoom,
– defined time intervals between image sequences, which enable elimination of temporary objects from the final image,
– the same exposure time settings,
– exact geodetic position and heading.

4.2 *Pattern recognition*

After successful input of all necessary data (images, product model and schedule) the process of pattern recognition can start. The results are classified into object define classes depending on algorithm shapes criterions. At this point it’s necessary to make the first connection with information from the product model, which serves as a reference model across the geometry model construction process.

At the beginning we will focus only to very simple building elements like bear walls, columns, etc. We have to assure enough quality of recognition and then make algorithm improvements [10][11] for more complex building elements and more details that accompany the building process.

Application calibration has to be realized in artificial control environment with small models, built of wood or paper. Images from those circumstances are clear without any noise signals like fog, temporary equipments, shadows etc. To make real images it is necessary to analyze the real images from building site (figure 3) and gain the mathematical characteristics, which have to be included into clear images to become suitable for input.

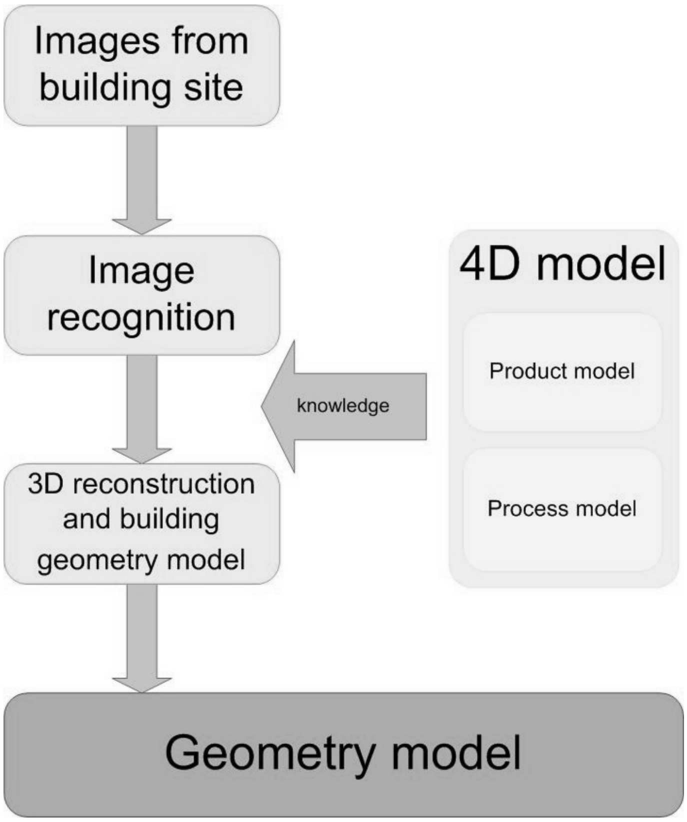

Figure 2: Construction phases

Figure 3: Image with noise

In previous chapter we mentioned the image sequences that help to eliminate temporary objects from images of the building site. It is not necessary to be double, could be triple or more. The idea is to exclude differences between images and reject all dynamic objects.

4.3 *Constructing the geometry model*

One of the requirements is the exact definition of the position and heading of each camera. This requirement simplifies the process of 3D reconstruction [2][7] and enable us to put recognition objects to coordinate system with correct object dimensions and relationships to other objects. Geometry model have to have the reference links between elements from 4D model and reconstructed elements, which enables us to make comparison between both models. To construct the geometry model we decided to use Open CASCADE [8][9][6] modeler, because it has a lot of useful features:

- it is under LGPL license,
- support many language wrappers (C, C++, C#, Java, Python),
- support OpenGL rendering,
- enable programming with different libraries for graphical user interfaces (Java, TCL, Tix, QT, FLTK, MFC),
- improve mash algorithms,
- enable combining visualization with other tools, specially with VTK -
- Visual ToolKit,
- it could be commercial oriented,
- useful documentation, e-learning, on-site training session, technical support, . . .

5 CONCLUSION

This paper presents the global concept to control the building activities on building site. In the first phase we established the base platform with 4D models and on the other side a geometry model. Open CASCADE geometry modeler can import product model data in STEP format, and construct its own data structure, which can be reused further. In the same way geometry modelers enables constructing our geometry model with all necessary settings and export it to many types of files.

The second phase is the pattern recognition, 3D reconstruction and finally construction of the geometry model, which will be compared with the imported product model. Finally we will implement a module with useful visualization, which offer building managers a simple control over the building process.

REFERENCES

[1] Nikola Guid. Računalniška grafika. Fakulteta za elektrotehniko, računalništvo in informatiko Maribor, 2001.

[2] Arne Henrichsen. 3D reconstrucition and camera calibration from 2D images. PhD thesis, University of Cape Town, 2000.

[3] IAI. Industry foundation classes. http://www.iai-na.org/technical/faqs.php, 2004.

[4] Jarkko Leinonen and Kalle Kahkonen. Virtual reality applications for building construction. http://cic.vtt.fi/4D/4d.htm, 2003.

[5] Jim Nell. STEP on a page. http://www.mel.nist.gov/sc5/soap/, 2001.

[6] Peter Podbreznik. Primerjava geometrijskega modelirnika ACIS in Open CASCADE (occ) za potrebe gradbene informatike. 2005.

[7] Marc Pollefeys. Self-calibration and metric 3D reconstruction from uncalibrated image sequence. PhD thesis, Katholieke universiteit Leuven, 1999.

[8] Open CASCADE S.A. Open CASCADE. http://opencascade.org, 2005.

[9] Open CASCADE S.A. Open CASCADE. http://opencascade.com, 2005.

[10] Nikola Pavešič. Razpoznavanje vzorcev, Uvod v analizo in razumevanje vidnih in slušnih siganlov. Fakulteta za računalništvo in informatiko Ljubljana, 2000.

[11] Leo P.J. Veelenturf. Analysis and applications of artificial neural networks. Prentice Hall International, 1995.