BUILDING ELEMENTS RECOGNITION USING SITE IMAGES AND 4D MODEL

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ABSTRACT

The paper presents the latest findings in our efforts to automatically detect the stage in the building process. The concept is based on automatic recognition of building elements using site images. In the recognition process the existing geometry in the 4D model of the building is used as a reference to find matching elements and to reconstruct a 3D geometry model of the building on site (3D realized). By using the time dimension of the 4D model it is then possible to identify differences between the already built parts of the building and the parts that should be built according to the schedule plan, or with other words, the difference between plan and realization.

The paper describes the concept of the process as a whole, as well as the current findings, including the image capturing process, 3D and 4D modeling, and the element recognition algorithm.

KEY WORDS

building element recognition, 4D model, building site, automatic comparison, convex shell

INTRODUCTION

The project management in the traditional building process is incapable of effective continuous detection of differences between schedule plan and the real situation on the building site. This is generally done by inspecting the building process, which is time consuming and obstructs the project information flow. Supervision of the construction process in such way increases the time needed to identify critical events in the schedule plan and therefore often leads to delays or budget overdraws.

The information technology enables combining of different types of information into consistent structure called 4D model (Chau 2004). It contains the product and the process model and thus integrates the information of geometry and building activities into an integrated model. For previously mentioned problems regarding effective supervision or detection of differences between the planed and the built respectively, we proposed a solution and developed a system for automatic construction activity tracking (Podbreznik and Rebolj 2005, Leinonen and Kahkonen 2003) by using logical, temporal and spatial information (Bonsang 2000) from a 4D model. The system enables generation of reports on differences between the planed and the built (Tong Lu 2004). The system is based on building elements

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recognition (Pavešič 1992) by using site images and a 3D reference model, extracted from a 4D model. The information flow of our solution is depicted in figure 1.

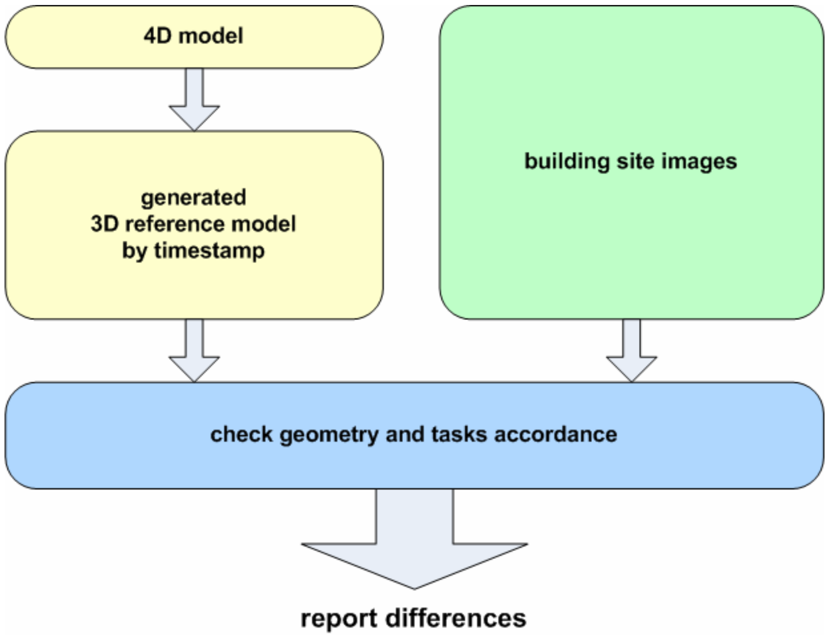

Figure 1: depicts the basic concept of automatic activity tracking.

4D MODELING

Civil engineering has a long evolution and lots of experiences with the building processes. Initially the human beings built more or less by trying and learning on their failures. Their first ideas were drawn on stones. By time the building process became more complex and required methodical access to construction. Ideas drawn on stones transformed into drawings on paper and then to digital representations of design plans. The next phase of the digital evolution has been in developing complex models, representing the building and the process. Two kinds of models are the current result of this evolution:

- product model,
- process model.

Product and process models will be independently described in the next sections as independent technologies used in the building process. The 4D model represents integration of product and process models (Sriram 1998).

PRODUCT MODEL

With development of different geometry representations - writing the internal geometry structure into computer - the engineering branches quickly began to use more efficient geometry structures for describing building properties like acoustic, thermal, luminosity, material of building elements, color design, etc.

The integration of building properties and geometry allow the construction of virtual buildings. From this kind of model it is possible to make various building analysis, which allow finding the optimal combination between geometry, construction and materials for constructing a contemporaneous building. A particular building property has its own relationship to other properties, which defines the set of dependencies between geometry and materials.

In this way the integrated structure of geometry and building element properties becomes complex. Writing this structure into a file in a standard form is a difficult issue. CAD tools enable the possibility to install additional software components in order to write the integrated structure into one of the standard forms. By using a common data model companies could establish information flow and could cooperate.

Engineers have seen the solution in the standard data structure STEP (Nell 2006), which means Standard for the Exchange of Product data model and was accepted as a standard in 1994. With STEP it is possible to describe any product model, independently 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 are described with different application protocols. Each protocol implements specific engineering area and has its own code (AP203, AP209). We already mentioned the complexity of product models. STEP has the same problem and is impractical for high abstract level usage. Proposed solution based on similar concepts with predefined elements, which are ready to be used, is IFC – Industry Foundation Classes (IAI 2006) - a collection of element definitions for the civil engineering area.

PROCESS MODEL

A process model describes the sequences of building activities and dependences between them. CPM (critical path method) can represent different levels of activity details, and relationships between activities from the schedule plan, which can be performed with tools like MS Project, Primavera (Primavera 2006), etc. The disadvantage of this method is its inability to solve *time-space conflicts* (Bonsang 2000, Akinci 1997), which means that the method cannot represent activities from the same place at the same time. Users need their own interpretation and have to construct the geometry situation, by considering the schedule. By its sufficient simplification in general CPM has been mostly used as a method in schedule tools.

CONSTRUCTING 4D MODEL

The first generation of 4D tools was able to create time-space representation of a building as an animation. The next generation of 4D tools contained geometry and schedule, represented by semantics. 4D model (Kathleen McKinney Liston 1999) is defined as connections between elements from product model and activities from process model. 4D tools have ability to solve conflicts like time-space and constructability (Chau 2004, Akinci 1997, Bonsang 2000, Sherly 1998), before the building process has started. With such tools site managers can quickly check compliance of geometry of the product model with the real building situation, and schedule tasks with activities from the building site.

INPUT DATA MODELS

In the scope of the research work the prototype has been implemented for the recognition of building element by using site images. The prototype is based on Java technology. Figure 2 depicts the recognition process and both input data models:

- 4D model and
- image model.

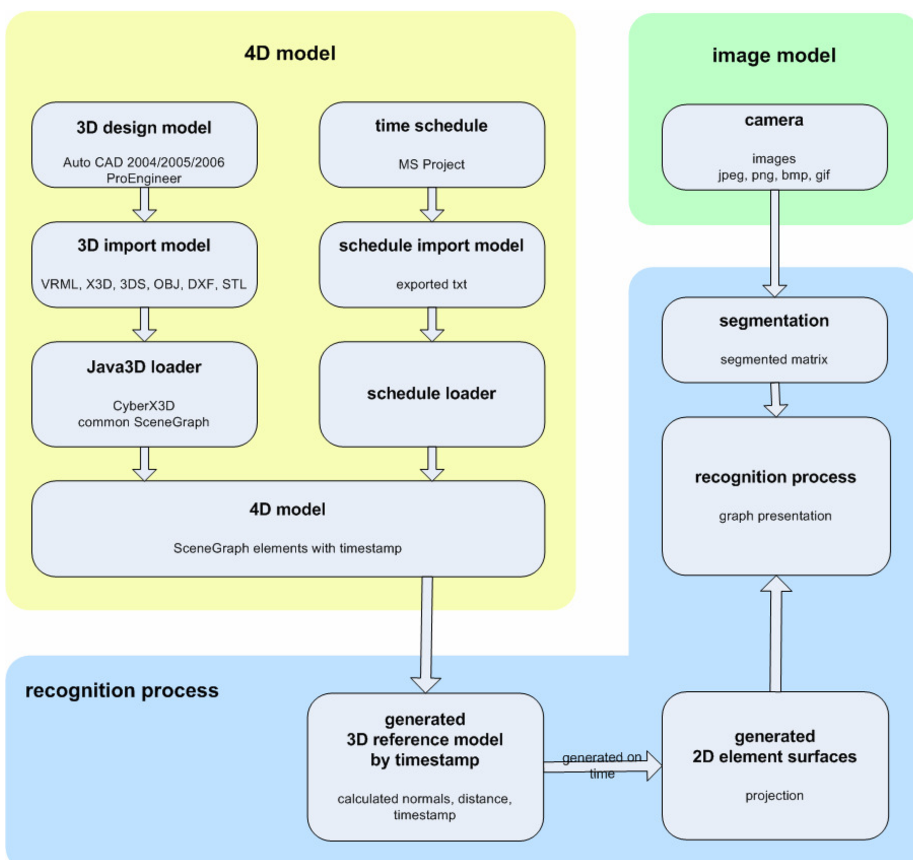

Figure 2: data models and recognition process

4D MODEL

Geometry

The architects and civil engineers use accomplished CAD tools to design buildings and construct independently *3D design models*, which have specific geometry structure depending on geometry modeler and type of geometry representation (Žalik 1999) (CSG, B-rep). 3D design models are generated by different CAD tools and need different 3D geometry Java loaders to further use the loaded geometry. In general, each loader has specific geometry structure and representation of geometry elements. Reusing the same application module to manipulate with the loaded geometry is generally impossible.

The problem is solved by transforming the *3D import model* into an intermediate model, which establishes independent architecture and enables an undisturbed data flow between 3D design model and 4D model. 3D import model supports different types of geometry data formats like: VRML, X3D, 3DS, OBJ, STL, DXF. CAD tools can export the geometry model (3D design model) into at least one of these formats.

Application specification

Sun specification requires defined software structure and consistent naming of classes and methods. The teams that want to implement any peace of Sun specification have to consider the recommendations. Users can chose between different software, which have the same functionality and are implemented on the same specification, but have different vendors. In evolution of an application users can change their mind and choose an application module from another vendor without any intervention into the source code. In Java programming the application module calls *library*, which is compressed file with the extension *"jar" (Java Archive)*.

The advantages of Sun specification bring us different *Java3D loaders* (Java3D 2006) with the same internal programming architecture. The choice of Java library to load 3D import model depends on the library's features. For loading 3D import model we have chosen **CyberX3D** (Satoshi 2006) library, implemented by Satoshi Konno. It has the advantage to support many standard geometry files like VRML, X3D, 3DS, OBJ, STL and DXF, and can load them. The second preference of the library is based on VRML structure and ability to translate other geometry types into common structure, called *SceneGraph*, mapped from VRML scheme. With Java3D developer can use such structure and libraries to manipulate and render the scene with elements. The SceneGraph in original form is presented as the geometry in our 4D model.

Time schedule

The process model is the second part of the 4D model and represents the time dimension to the 3D design model. It could be constructed in a different way by different schedule tools. Engineers mainly use MS Project or Primavera for constructing the *time schedule* with the CPM method. Loaded time schedule needs prepared *schedule import model* on accurate format, prepared by export function from the schedule tool. Such model can be loaded into our application.

Constructing 4D model

4D models cannot be written in the standard form. For this reason we have to develop a tool with ability of linking the elements with activities from both models. Current implementation does not support construction of 4D model with GUI. The connections between building elements and activities are saved in the configuration file in the XML form. Given enough time we should implement application features for constructing 4D model with GUI and prepare it for general use.

IMAGE MODEL

Images from building site present real situation of:

- building geometry,
- building process.

Successful recognition process requires conditions for image composition and additional information like:

- camera position vector,
- camera look at vector,
- camera up vector and
- time.

PREPROCESSING 4D AND IMAGE MODELS

Recognition process needs *4D* and *image models* prepared in the correct form. Both models have to prepare their data as a *convex shell* (Tong Lu 2004, Collier 1996).

GENERATING ELEMENT FACES FROM 4D MODEL

3D reference model represents 3D geometry extraction from 4D for required time slice and contains additional information on geometry model and its elements like:

- normal vectors of element faces,
- elements timestamp and
- element faces distance from camera .

Additional information allow generating of projected 2D element faces (Guid 2001), presenting the virtual shape of building element in time from defined virtual camera position, direction and orientation. All virtual camera parameters have to be equal to the parameters of camera on building site.

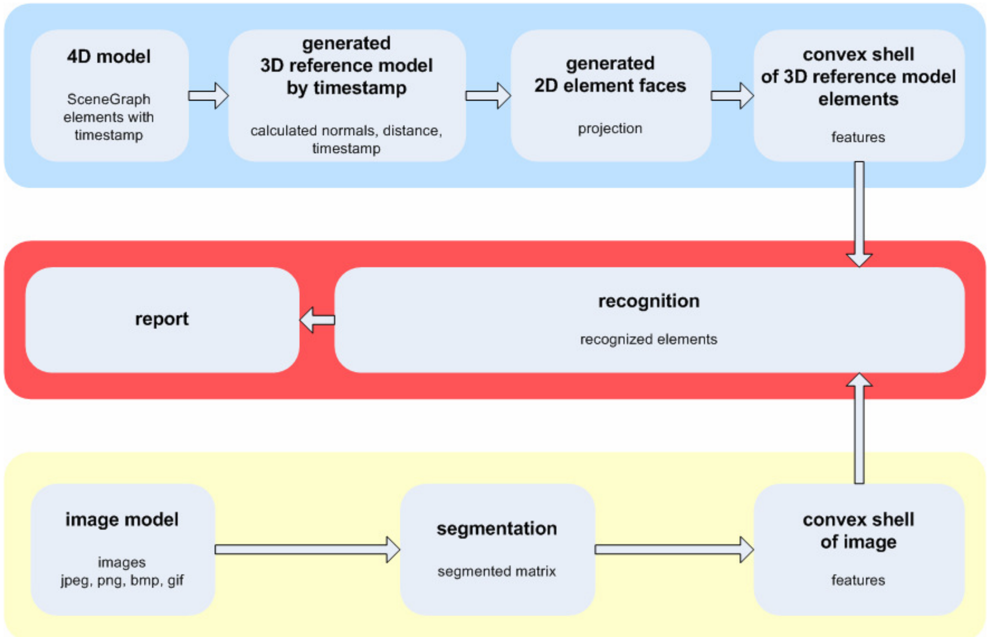

Figure 3: Preprocessing 4D and image models

GENERATING FACES FROM IMAGE MODEL

Image model contains more or less useful information to perform successful element recognition process. Extracting of applicable data, needed to construct image information, is performed by *segmentation* process. The results are indexed and separated element faces from the common image, written in *segmentation matrix*. Figure 4 is representing the image and its segmentation matrix.

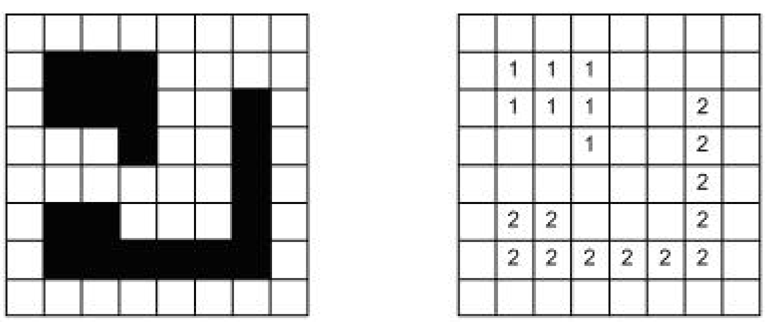

Figure 4: image and segmentation matrix

RECOGNITION PROCESS

Convex shell of element face is representing its contour. Faces have more or less common properties. The faces with many common properties are grouped together by the algorithm and its properties are written into the common form, called *feature* (Pavešič 1992). The groups are named *feature classes*.

In the recognition process a *learning set* exists as a container of knowledge. It is a collection of correctly classified features in feature classes. Recognition algorithm calculates the estimation function of face characteristics and tries to find the matching face from the learning set. The minimum function value of differences gets the recognition face with the expected probability of correct recognition. From recognition faces it is possible to construct a recognition element without successful recognition of all element faces. Missing recognition faces and information are supplemented by 3D reference model in order to complete recognition of building elements.

CONCLUSIONS

This paper presents the basic platform for 4D model construction, describes the implementation of building elements recognition process and defines conditions for successful recognition. We decided to use Java3D for geometry structure and CyberX3D as a geometry loader to establish independent architecture. 3D reference model was described as generated from 4D model with additional calculated information to complete missing information of image model in the recognition process.

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