REAL-TIME ACTIVITY TRACKING SYSTEM – THE DEVELOPMENT PROCESS

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ABSTRACT: The paper describes the development process of the 4D-ACT (Automated construction tracking) system. The paper also discusses new potentials of the system regarding real-time information flow in a construction process. The 4D-ACT automatically recognizes the building elements from the building site and searches for matches between planed and performed activities. Building elements are recognized automatically from images, created with cameras installed on the building site. The 4D model is needed as the knowledge base of relations between the designed geometry elements and activities in the process model, which ensures identification of activities on the basis of the recognized building elements. During the recognition process, the algorithm uses the 4D model for additional information, to be more successful. The concepts of the system and the algorithm have been tested in laboratory experiments and are presented in the paper.

1 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 [7]. 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 4D-ACT *(Automated construction tracking)* for automatic construction activity tracking [8][13][14][15] by using logical, temporal and spatial information [3] from a 4D model. The system 4D-ACT enables generation of reports on differences between the planed and performed activities [20]. 4D-ACT system recognizes building elements [11] by using site images and a 3D reference model, extracted from a 4D model. It can also generate the animations of building process, based on 4D model. The information flow of our solution is depicted in figure 1 and will be describes in this paper.

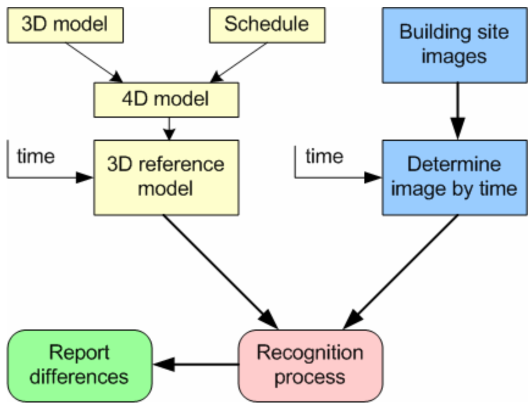

Figure 1. Scheme for 4D-ACT system.

2 4D MODELLING

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. Over time the building process became more complex and required methodical access to construction. Ideas drawn on stones are 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 and
- 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 [19].

2.1 *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 – Standard for the Exchange of Product data [9] and it 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 [4], a collection of element definitions for the civil engineering area.

2.2 *Process model*

A process model describes the sequences of building activities and dependences between them. In process model are also included the actors and definitions of relationships between actors and activities. Schedule plan can be constructs on different ways. CPM –Critical Path Method is one of method and can represents different levels of activity details, and relationships between activities from the schedule plan, which can be performed with tools like MS Project, Primavera [16], etc. The disadvantage of this method is its inability to solve time-space conflicts [2][3], 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.

2.3 *Construction 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 is defined as connections between elements from product model and activities from process model and has ability to solve conflicts like time-space and constructability [3][6][7][18], before starting process of building. 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. Figure 2 depicts 4D model, constructed with 3D geometry model and schedule plan.

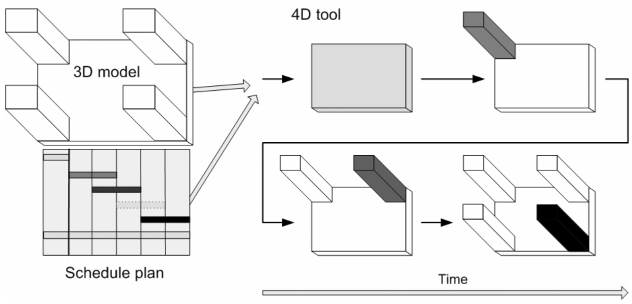

Figure 2. 4D model.

3 4D-ACT

4D-ACT has three phases of development, which can be identified as: testing pilots, base platform implementation (4D tool) and development of elements building recognition (4D-ACT). At the end of this section benefits will be discussed of such system and establishing of suitable environment between building site and office.

3.1 *Testing pilots*

Identification problems like obstructing project information flow and time consumption during inspection an actual building process manually, suggested automatically tracking activities on building site. Therefore our research work was focused on the pilot projects in order to make the definitions of requirements and features of specific application libraries.

Previous section discus about 4D models with interconnected relations between geometry and schedule plan, created with 4D tool. Generally, accession into those 4D model internal data structure is impossible. Therefore, we decided to implement new 4D tool with accessible internal data structure. The application design was divided into geometry application module and application module of schedule plan.

3.1.1 Geometry application module

There is a wide range of application libraries, which has already been implemented and tested. 3D ACIS Modeler [1] is one of commercial 3D geometry engines and enables developers to use complex geometry transformations and presentations on different ways. It is worldwide used in companies with software development. The core of 3D ACIS Modeler is written in C++ programming language, but can be also used in the other programming environment like: Java, Python, C and FORTRAN. Very important part of geometry modelers presents the loaders for different types of geometry. 3D ACIS Modeler can loads geometry formats like: CATIA V5, CATIA V4, IGES, STEP, VDA-FS, Pro/ENGINEER (Pro/E), Parasolid (PS), Unigraphics (UG), SolidWorks and Inventor. For advance solution with integrated geometry models is necessary to load the data structures from standard forms. For construction industry, most important is IFC standard, which doesn't support 3D ACIS Modeler.

Open CASCADE Technology [10] presents alternative without fee request and support very similar features like 3D ACIS Modeler. The modeler core is written in C++ programming language and enables programming interfaces for different programming languages like Java, Python, etc. The set of geometry loaders is smaller and modeler supports loading the geometry formats like: IGES and STEP with application protocols AP203, AP214 and AP209.

At the end of second pilot project it was concluded that there is no need for such complex geometry modeler as there are no requirements for geometry manipulations or any other geometry transactions. For successful generating 3D reference model from 4D model, access into geometry data structure is needed.

3.1.2 Application model of schedule plan

Similarly as geometry application model, we made review of applications for design schedule plans. Primavera and MS Project 2003, which are using CPM method for designing schedule plans, are the most wide used application in industry. MS Project 2003 was chosen, because it supports XML export and import functions, which enables loading external schedule plans into application.

3.2 *Base platform implementation*

Conclusions from first phase lead to decision about using appropriate programming libraries. Requirement about geometry is ability of accession into geometry of VRML geometry structure.

Openness and flexibility are very important application properties and must be assured with suitable technology and application architecture (figure 3), based on Java technology. Figure 3 depicts the application architecture, recognition process and both input data models like:

- 4D model and
- image model.

3.2.1 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 [21] (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 and DXF. CAD tools can export the geometry model (3D design model) into at least one of these formats.

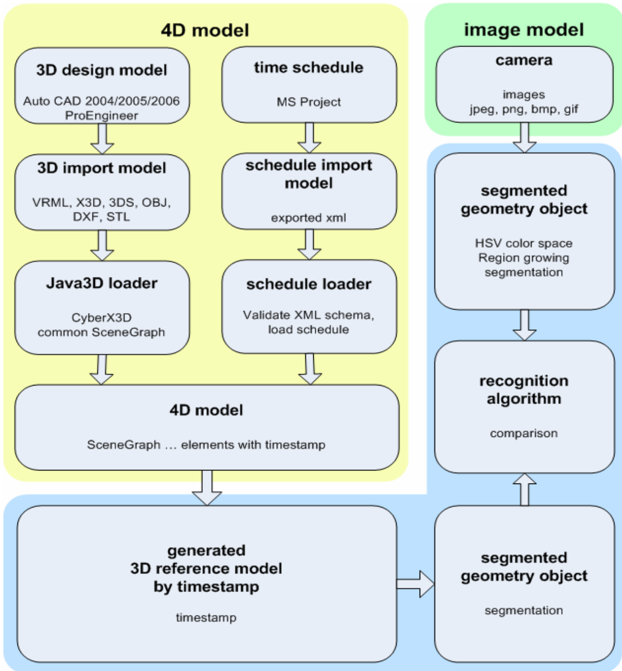

Figure 3. Architecture scheme for 4D-ACT application.

3.2.2 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* [5] 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 [17] 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.

3.2.3 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 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.

3.2.4 Constructing 4D model

4D models cannot be written in the standard form. For this reason we have develop a tool with ability of linking the elements with activities from both models. Current implementation supports construction of 4D model with GUI. The connections between building elements and activities are saved in the configuration file in the XML form.

3.3 *Development of building element recognition*

The recognition algorithm has been divided into two phases. Segmentation of the whole building object from site images presents the first phase [12]. In second phase, after segmentation, recognizes individual building elements of building object and identifies them, using knowledge from 4D model.

3.3.1 Segmentation building object

The *image model* from figure 3 establishes repository of images with required information like: camera position, look at vector, up vector and timestamp. All these data are needed for generating *3D reference* model from 4D model, which presents 3D geometry model for specific timestamp.

Pixel presentation

Before segmentation each image has to be transformed into HSV color space, where pixel component presents:

- H – hue
- S – saturation and
- V – value.

For each pixel, recognition algorithm calculates values for:

- texture,
- contrast and
- gradient.

Calculated pixel contains twelve values, written in vector:

$$p = [col(H,S,V); t(H,S,V); c(H,S,V); g(H,S,V)], \qquad (1)$$

where *col* presents color in HSV color space, *t* texture, *c* contrast and *g* gradient of pixel.

Learning phase

For successful automation activity tracking the algorithm has recognized the building elements from site images. Recognized buildings elements are compared with the elements from 3D reference model, which presents 3D design model in time. First phase of recognition process is segmentation, where algorithm separates the useful information from other on images. Before segmentation process the algorithm have to contain criterions for segmentation. The "teacher" has interactively marked the areas on site images, which present the building elements. From these areas an algorithm teaches itself and generates the base knowledge of element features. Average values of elements features are compounded into universal criteria function for segmentation process.

Algorithm region growing

Elementary principle based on region growing from one or more *starting pixels* or *region* has to be members of grown region. For these areas the algorithm checks, if a neighbor pixels (down, up, left and right directions) corresponds of universal criteria function and includes only the corresponding pixel into region. The process of growing is finished when is no neighbor pixels corresponding of universal criteria function. The result is an area on site image with similar properties as values from base knowledge. Figure 4 depicts the results of segmentation process on experimental images.

3.3.2 Building elements identification

The identification of particular building elements of building object is necessarily for automatic findings accordance between planed and performed activities during building process on building site. The algorithm from segmented image tries to identify elements, by using 3D reference model. Identified building element can be connected with different messaging systems and thus improve the project information flow.

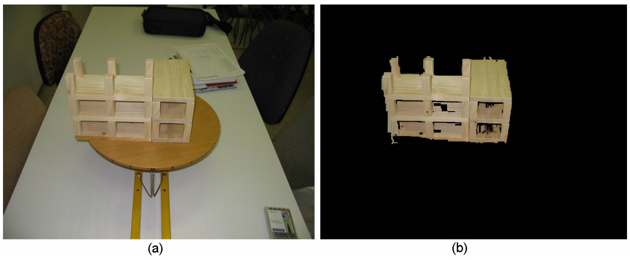

Figure 4. input image (a) and result of segmentation (b).

3.4 *4D-ACT benefits and challenges*

In previous section were mentioned possible benefits of 4D-ACT system. The most important is improvement of project information flow from designing phase to building process and back into information system, as feedback information. Feedback information contains reports like material delivery services, successful finished activities, failure situations, unexpected conflicts, etc. The collection of reports could be as a repository of actions with several advantages:

- easier recalculation of time period activities,
- reconstruction of situation on building site and
- clear presentations for critical events.

4 CONCLUSION

This paper presents the evolution process of 4D-ACT system and separately describes different phases of development. First phase covers inspecting different technologies to be used for implementation. Second phase presents the architecture of systems platform and its development for 4D model construction. The new 4D tool can generates animation of building process. Constructed 4D model is needed as a base knowledge during recognition process. Java3D was used 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.

After image segmentation algorithm has ability to identify particular building elements. Advance messaging system is logical continuation of system development as an integrated application for total information support.

REFERENCES

[1] 3D ACIS Modeler (2007). (available at http://www.spatial.com/products/acis.html).

[2] Akinci, B., Sherly S., Fisher, M. (1997). "Productivity and cost analysis based on a 4D model". CIB W78.

[3] Bonsang, K., Fisher, M. (2000). "Feasibility study of 4D CAD in commercial construction". Journal of construction engineering and management.

[4] IAI (2006). "Industry foundation classes". (available at http://www.iai-na.org/technical).

[5] Java3D (2006). (available at http://java.sun.com/products/java-media/3D).

[6] Kathleen McKinney Liston (1999). "Designing 4D contexts for construction planners". Doctoral consortium.

[7] Chau, K.W., Anson, M., Zhang, J.P. (2004). "Four-dimensional visualization of construction scheduling and site utilization". Journal of construction engineering and management.

[8] Leinonen, J., Kahkonen, K. (2003). "Virtual reality applications for building construction". (available at http://cic.vtt.fi/4D/4d.htm).

[9] Nell, J. (2006). "STEP on a page". (available at http://www.mel.nist.gov/sc5/soap).

[10] Open CASCADE (2007). (available at http://www.opencascade.org/).

[11] Pavešić, N. (1992). "Razpoznavanje vzorcev". Fakulteta za računalništvo in informatiko Ljubljana.

[12] Podbreznik, P., Potočnik, B. (2007), "Segmentacija gradbenih objektov z uporabo algoritma rast regij". Accepted on ROSUS 2. strokovna konferenca, 22. marec 2007, Maribor, Slovenija.

[13] Podbreznik, P., Rebolj, D. (2005), "Automatic comparison of site images and the 4D model of the buiding". SCHERER, Raimar J., KATRANUSCHKOV, Peter, SCHAPKE, Sven-Eric. CIB W78 22nd conference on information technology in construction, July 19-21,2005, Dresden, Germany, (CIB Publication, No. 304). Dresden: Institute for Construction Informatics, Technische Universität, page. 235-239.

[14] Podbreznik, P., Rebolj, D. (2006/6), "Building elements recognition using site images and 4D model", ICCCBEXI, International Conference on Computing and Decision Making in Civil and Building Engineering, June 14-16,2006, Montreal, Canada, page 87.

[15] Podbreznik, P., Rebolj, D. (2006/9), "Modeling conditions required for recognition of building elements from site images ", ECPPM, e-Business and e-work in architecture, engineering and construction , September 13-15,2006, Valencia, Spain, page 109-113.

[16] Primavera (2007). (available at http://www.primavera.com).

[17] Satoshi, K. (2007), (available at http://www.cybergarage.org/vrml/cx3d/cx3djava).

[18] Sherly, S., Fisher, M (1998). "Constructability reasoning based in a 4D facility model".

[19] Sriram, V. (1998). "4D CAD in construction". Fall.

[20] Tong Lu, Chiew-Lan Tai, Feng Su, Shijie Cai (2004). "A new recognition model for electronic architectural drawings".

[21] Žalik, B. (1999). "Geometrijsko modeliranje". Fakulteta za elektrotehniko, računalništvo in informatiko Maribor.