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Recognition of process patterns for BIM-based construction schedules

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ABSTRACT

Construction scheduling is a very demanding and time intensive process. Building information modeling (BIM) is becoming increasingly important for planning and scheduling, as it provides significant support for this difficult assignment. Further improvements can be achieved by applying predefined process templates for BIM-based schedules. It can reduce the planning time and thus increase the productivity. However, a manual definition of proper and application-specific process templates is very challenging. The automatic detection of recurring similar configurations of construction processes, called process patterns, would greatly support this complex task. Identified process patterns can be subsequently generalized, supporting the design of process templates. This contribution presents an overall concept for process pattern recognition in BIM-based construction schedules by applying graph-based methods. Due to the fact that graph matching algorithms are in general very time- and resource-consuming, an indexing technique based on features is used to solve this problem more efficiently. The paper focuses on the estimation of similarity in construction schedules, describing feature-based methods and similarity measure definitions in detail. Another emphasis is the preparation of schedules for the recognition of process patterns, including decomposition of schedules into smaller parts, referred to as subschedules, and normalization of features. The potential of this concept is demonstrated by two different case studies. The proper results of the evaluation show that the proposed method and similarity metrics are sufficient for the recognition of process patterns in construction schedules.

1. Introduction

The success of construction projects as well as their compliance with budgets and timelines is directly related to the quality of construction scheduling. Indeed, the determination of valid and efficient schedules is extremely challenging and time-consuming [1]. Current software tools provide only partial support for this demanding assignment. For example, linking building elements of a 3D model with the corresponding construction processes, known as 4D Building Information Modelling (BIM), enables a visual analysis of construction schedules [1]. Nevertheless, this alone does not sufficiently simplify the check for completeness and correctness of the schedules. Furthermore, the definition of construction processes and their dependencies are still performed manually. The possibility to automate construction scheduling has been recognized and addressed in some research projects in recent years [2–9]. The required information is automatically extracted from a BIM-model to enable the generation of a schedule.

However, the choice of construction processes, execution sequences, as well as decisions for one or another alternative method must be done by a responsible planner or a planning team and is based on their own knowledge and experiences. In many cases such decisions are not explicitly documented, which makes it difficult to verify them and to reuse the gained experience for future projects. Nevertheless, there are a lot of recurring tasks that can be performed in the same or a similar way and it would be of great advantage to have some predefined process templates for this. Such process templates could be applied to other projects immediately or, more common, after an adaptation. This would enormously reduce the time for schedule generation and thus increase the productivity. It could also help to understand the precedent decisions and improve the quality of schedules by taking into account previous knowledge and experience.

Unfortunately, a manual definition of adequate process templates is also very challenging. Templates have to be designed application-specific and represent frequent or approved solutions. The automatic detection of recurring similar configurations of construction processes would greatly support the creation of process templates. The search for the recurrences and regularities in general is known as pattern recognition and is widely used in many

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application areas [10–14]. In order to recognize process patterns in construction schedules it is appropriate to use graph-based methods, as schedules can be represented in the form of precedence graphs. For this purpose, it is necessary to examine the given graphs for similarities with respect to the content information contained in the processes (nodes) and structural composition given by process interdependencies (edges).

The term *pattern* has a great variety of meanings and the terminology used in different research domains is not uniform. In the context of process workflows, civil engineering, architecture, product development, software engineering, and many others the word *pattern* is used in the sense of template, original object to make copies or reusable solution (cf. [15]). In the field of machine learning pattern recognition means the recognition of regularities in the data,"[...] how machines can observe the environment, learn to distinguish patterns of interest from their background, and make sound and reasonable decisions about the categories of the patterns [...]" [14]. Because of the widespread use of both meanings the terminology is preserved in the paper. However, attention is paid to the usage of uniform terms when describing the developed concept and the evaluation. A distinction is made here between a defined process template and a recognized process pattern.

The main aim of this research is the recognition of process patterns in BIM-based construction schedules by applying graph-based algorithms. Certain preparation steps and adjustments are required to achieve this objective and are the subject of this contribution. In the context of this research work only the structural process patterns are to be examined. Thus, the time and the cost component as well as the required resources are deliberately omitted. The determined process patterns can serve as a basis for the definition of process templates, supporting a human expert during design. Analysis and evaluation of the results of pattern recognition enable the identification of common or best practice solutions. The subsequently created process templates could be applied during the schedule definition for regularly occurring tasks, making construction scheduling more efficient. Another major advantage of the automatic pattern recognition is the possibility of detecting undesired regularities within the schedules in order to avoid such failures in the future. The automatic definition of correct and generally valid process templates by aggregation of detected process patterns is a further important challenge. However, the automatic generation of process templates as well as their application for construction scheduling is beyond the scope of this contribution.

The present paper first outlines the latest research achievements in BIM-based scheduling, pattern-based methods in the domain of construction management as well as the state of the art techniques in this field. After the short description of the underlying BIM-based framework for the automatic generation of construction schedules, an overall developed concept for process pattern recognition is presented in Section 3. Section 4 focuses on the decomposition of modeled schedules into a set of subschedules. Decomposition is necessary for the search of small repetitive substructures and the reasonable applicability of graph-based methods. The similarity estimation of construction schedules is discussed in detail in Section 5, describing the defined similarity measures and the selected methods including the application specific adjustments. Finally, the achieved results of the implementation are evaluated on a test database.

2. State of the art and related work

The traditional method of construction scheduling is the manual definition of processes and their dependences supported only by the Precedence Diagram Method (PDM), including the Critical Path Method (CPM), and the Program Evaluation and Review Technique (PERT). Although this time-consuming and error-prone practice is not outdated, the advantages of 3D modeling for the planning process have been recognized long ago and applied in research and practice. This section gives a survey of current research on computer-aided scheduling with the focus on knowledge-based and especially pattern-based methods. Pattern Recognition in graphs has so far been hardly examined in the field of construction management. However, there are some state of the art techniques in other research areas. Comprehensive surveys of literature on graph-based methods in Pattern Recognition in the last forty years can be found in [10–12]. Most of the existing methods have been proposed in the field of computer vision. Pattern recognition is an extremely large research area, hence only techniques relevant in the context of this paper have been examined and are provided at the end of the section.

2.1. 4D modeling

With the increasing availability of 3D building models, the scheduling process has been supplemented with visualizations of the construction progress. For this purpose, building geometry is linked with temporal information and construction processes of the schedule, which is known as 4D modeling. It enables an early-stage analysis and a visual validation of schedules and helps to explore options and increases the transparency of the planning process. However, in most current 4D applications the schedule is developed separately from the building model and the linking and sequencing of construction processes is realized subsequently during a cumbersome, manual procedure. Because of the identified disadvantages of the manual method [16], further research has investigated the automatic linking between product and process model [17–21]. In [17] the construction order is determined automatically relying on the geometrical position of the building elements. Indeed, the topological alignment is not always decisive for the sequencing of related processes. The approaches presented in [18] allows for the generation of construction schedules applying manually predefined rules and construction methods. Chua and Yeoh [20] and Chua et al. [21] pay special attention to the capturing and modeling of static and dynamic schedule constraints.

There is no definitive preference of the 4D simulation software in the context of construction scheduling. Nevertheless, BIM-based 4D software, especially based on IFC (Industry Foundation Classes), are becoming increasingly important in research and practice [22]. The advantage of the IFC standard is that a lot of the required object definitions are provided. The application of BIM-based methods for the automatic generation of schedules has gained an enormous significance in recent years [5,6,9,23–27]. Considerable scientific effort was made for analyses and automated extraction of construction-specific spatial information from BIM models [9,23,24,27]. In [27] the extracted geometrical information is further used to support construction planning. By means of the derived adjacency relationships between building components the original schedule can be improved. A more advanced approach is presented in [9], where the spatial, geometrical, quantity, material and other information is applied to generate a schedule, considering the user-defined sequencing rules. That means, that for every project and for each building element a set of activities and rules has to be pre-determined manually.

In contrast to rule-based systems, the constraint-based linking method does not require predefinition of any rules. Several approaches, e.g. in [2–8] have been presented. In these approaches processes contain information about building elements, construction methods, and constraints to be fulfilled. The constraints are described by building elements in certain states and are regarded as prerequisites and results of processes. The schedule is then gen-