Expert Systems with Applications 41 (2014) 7565–7578

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Construction scheduling using Genetic Algorithm based on Building Information Model

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ARTICLE INFO

Article history:
Available online 9 June 2014

Keywords:
Construction project schedule
Building Information Model
Genetic Algorithm
Stability relations

ABSTRACT

The construction project schedule is one of the most important tools for project managers in the Architecture, Engineering, and Construction (AEC) industry that makes them able to track and manage the time, cost, and quality (a.k.a. Project Management Triangle) of projects. Developing project schedules is almost always troublesome, since it is heavily dependent on project planners' knowledge of work packages, on-the-job-experience, planning capability and oversight. Having a thorough understanding of the project geometries and their internal interacting stability relations plays a significant role in generating practical construction sequencing. On the other hand, the new concept of embedding all the project information into a 3-dimensional representation of a project (a.k.a. Building Information Model or BIM) has recently drawn attention to the construction industry.

In this paper, the authors demonstrate a novel approach of retrieving enough information from the BIM of a project and then develop construction sequencing for the installation of the project elements. For this reason a computer application is developed that can automatically derive a structurally (statically) stable construction sequence, using the concept of the Genetic Algorithm (GA). The term "structurally stable sequencing" in this article refers to the sequencing order of erection in which the structure remains statically stable locally and globally during the entire installation process. To validate the proposed methodology, the authors designed 21 different experiments and used the proposed method for generating stable construction schedules, which all were successfully accomplished. Therefore, this methodology proposes a novel approach of construction project application of the GA, as an Expert System tool.

1. Introduction

The development of project schedules is a critical part of all types of projects including engineering, manufacturing, construction, and others. However, engineering education, whether at the graduate or undergraduate level, typically provides little instruction on how to develop good construction or fabrication schedules. Construction engineers and managers on projects learn on the job how to visualize the sequence of activities that will lead to good, feasible schedules, without formal training. By integrating project scheduling with virtual three-dimensional geometric modeling, students could learn through hands-on interaction with the system how to generate more effective project networks and schedules. The literature review performed by the authors (Faghihi, Nejat, Reinschmidt, & Kang, 2014) showed that other researchers were mainly focusing on scheduling with respect to resource handling and usage. This research intends to show how the geometric information of a project can be used directly to generate construction sequence. This direct use of the geometric information and the list of all the components from the BIM of the project can eliminate the potential occurrence of errors in transcription of the 3D data.

The main purpose of this research is to create an environment for construction planners to have a visually interactive communication between the planning process and 3D models of the project at each increment of time. This environment uses an algorithm that simulates the natural evolutionary process in a rule-based approach to reach a feasible project schedule. The natural evolutionary process in this research considers the relationships and dependencies of the project elements from the Matrix of Constructability Constraints (MoCC), presented by the authors (Faghihi, Reinschmidt, & Kang, 2014a) and shown in Eq.(1), and uses previous knowledge gained through experience from similar works. The determination and calculation of the relationships and dependencies of the project elements are handled through a

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http://dx.doi.org/10.1016/j.eswa.2014.05.047
0957-4174/

well-developed mathematical algorithm reading all the geometric information on the project elements from the 3D project file. The necessary common knowledge and previous experience would help the initial phase of developing the algorithm by defining sets of rules to express element dependences. The geometry reading algorithm and common knowledge used in this paper is described briefly in the "Reading the Geometry" section and detailed description is provided in another paper by authors (Faghihi et al., 2014a). Using this algorithm, a project planner can change the work strategy using predefined parameters and the 3D model, as a visual representation of the entire project, to see the effects of different strategies on the schedule. These work strategies can be, but not limited to, determining crane locations, material unloading spots, installation direction priorities, and finding workaround solutions.

The proposed algorithm can potentially extend to have a two-way interactive environment between project geometric model (BIM) and its schedule. This environment can bring new dimensions to the management team of the project in which changing the design of the 3D model directly and immediately results in a new and updated project schedule. Also, when the project schedule is manipulated, the extended algorithm can detect which parts or elements of the project may not be constructible regarding the updates in the project schedule by highlighting them. The extended version of this algorithm (Faghihi, Reinschmidt, & Kang, 2014b) and the managerial usage of the entire proposed algorithm (Faghihi, Reinschmidt, & Kang, 2014c) is described in details in other research papers.

Eq.(1). Matrix of Constructability Constraints

$$\textit{Matrix of Constructability Constraints (MoCC)} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} A_1 & A_2 & \dots & A_n \end{array} \\ \begin{bmatrix} s_{1,1} & s_{1,2} & \cdots & s_{1,n} \\ s_{2,1} & s_{2,2} & \cdots & s_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ s_{n,1} & s_{n,2} & \cdots & s_{n,n} \end{bmatrix} \end{array} \quad (1)$$

where:

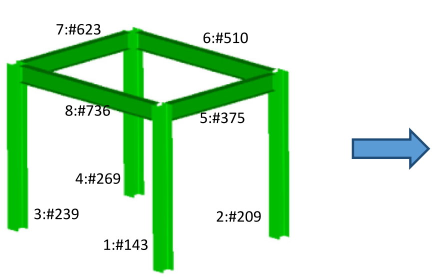
A_i: is the project tasks (geometric elements in the 3D model or the activities to be scheduled),

$s_{j,i}$: is dependencies between elements (that could be either 0 or 1 showing not dependent or dependent respectively).

Considering Graph Theory and definitions of the matrices, the MoCC is a Directed Adjacency Matrix or a Directed Design Structure Matrix (Directed DSM). The Directed DSM is a matrix representing the project network (Kanda, 2011) and has been in use since the 1960s (Steward, 1962). The spatial translation of 3D BIM to the MoCC and then to the project network is shown in Fig. 1. The Genetic Algorithm will later use this project network (or MoCC) to generate construction schedule for the given 3D model. The novel approach of decoding the 3D model stability rules into a Directed DSM is briefly mentioned in this article and mainly described in another article written by the authors (Faghihi et al., 2014a). In the current article, a new approach of generating and developing construction schedules using the Genetic Algorithm and the MoCC is described, tested, and verified. In the mentioned figure, the matrix in the middle, MoCC, is generated based on the spatial relations of the geometry elements in the 3D model considering the previously mentioned common knowledge of stability. By having this matrix, as a numerical representation of the stability relations in a BIM, the next step will be generating a constructible and stable project schedule for that specific 3D model. To reach a set of fully stable project schedules, the stability score can be assigned to each possible solution. This stability score will be the percentage of the project elements that are scheduled for installation in a stable order (i.e. obeying the constructability constrains calculated in MoCC). Then, the target score will be 100% of the stability that should be reached. This approach brings the environment of optimization methods where the stability score should be maximized. To accomplish that outcome, one of the best methods is the Genetic Algorithm (GA), which has already been proven to be useful in project management and in Expert Systems as an optimization tool. In addition, since the proposed matrix consists of zeros and ones, representing stability relations, it is very well suited for the GA fitness function. The entire methodology process is summarized in the following schematic view (Fig. 2). More about the process will be described later in this paper.

2. Reading the geometry

In this paper, the 3D model input to the algorithm is in a standard text-based format, called Industry Foundation Classes (IFC).



$$MoCC = \begin{array}{c} \\ 1:\#143 \\ 2:\#209 \\ 3:\#239 \\ 4:\#269 \\ 5:\#375 \\ 6:\#510 \\ 7:\#623 \\ 8:\#736 \end{array} \begin{array}{c} \begin{array}{cccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \end{array} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

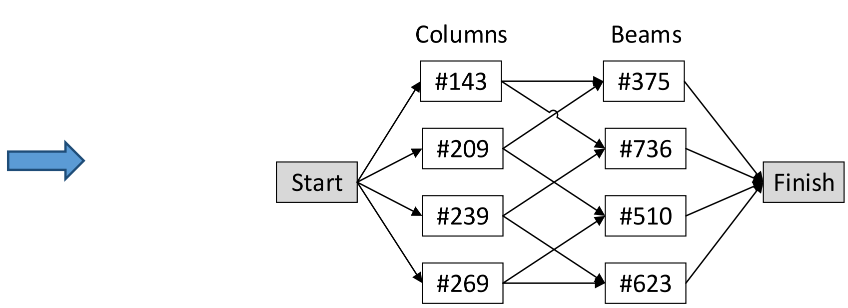


Fig. 1. BIM to project network.