Automation in Construction 57 (2015) 132–145

Contents lists available at ScienceDirect

Automation in Construction

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

Managing repetitive construction in a dynamically changing project environment: Conceptualizing the system–model–simulator nexus

Magdalena Hajdasz

Poznań University of Technology, Piotrowo 5, 60-965 Poznań, Poland

ARTICLE INFO

Article history:
Received 8 January 2014
Received in revised form 5 May 2015
Accepted 19 May 2015
Available online 18 June 2015

Keywords:
Artificial intelligence
Expert systems
Construction process
Modeling and simulation
Repetitive construction projects
Knowledge management

ABSTRACT

This paper presents a methodology for modeling repetitive construction projects by introducing a modeling procedure based on the system–model–simulator nexus, with the aim of developing an intelligent tool to facilitate decision-making in the construction implementation phase. The study offers a conceptualization of the construction processes designed for the monolithic construction computer-aided system (MoCCAS) that enables a flexible approach to managing repetitive projects within a dynamically changing construction environment. The discussion deals with the art of modeling the construction process and introduces a repetitive construction process formulated as (1) a dynamic construction process model in a temporal perspective (DCPM-TP), which is a construction process representation in a three coordinate system; and (2) a managing assumed goals (mag_811) module, designed to simulate process behavior and to create execution strategies. Both models are capable of handling variability during the construction process execution and address the complexity of the relations among the production system components, including resource mutual constraints. A case study is discussed which involves the execution of construction processes by means of a slip formwork system, which exhibits a large degree of repetition and, therefore, is a particularly useful example for illustrating the effectiveness of the modeling approach proposed. The original contribution of this research lies in (i) representing construction process by acknowledging the specificity deriving from the nature of repetitive projects and technological regime; (ii) developing flexible structures (DCPM-TP and mag_811) that enable the construction process complexity to be addressed; (iii) designing a representation of the construction process within the system–model–simulator nexus developed for MoCCAS. A significant outcome of the overall study is the development of a system capable of harnessing the cyclic nature of the repetitive processes and converting the repetitiveness into a vital asset in the construction management.

1. Introduction

The complex, dynamic, and unpredictable nature of construction poses challenges as regards modeling construction processes. There has been an immense amount of research in this field. Developing intelligent tools, which are based on advanced process abstraction and symbolic models, with the aim of facilitating decision-making in the construction implementation phase, has become one of the means of alleviating the uncertainty and complexity that surrounds construction management. The rationale behind management modeling as a scientific discipline per se is to enhance the decision-making and control processes [31]. Notably, the quality of the decisions undertaken by managers is determined by the quality of the models they use (cf. [6]).

This paper presents a methodology for modeling repetitive construction projects by introducing a modeling procedure for developing an intelligent decision-support tool that facilitates decision-making in the construction execution stage. The discussion deals with the art of the construction process modeling and offers a novel approach to modeling repetitive construction projects by focusing on the system–model–simulator nexus in designing Monolithic Construction Computer Aided System (MoCCAS), which is a system that supports the management of repetitive projects. The development of the modeling formula proposed in this study is based on a description and abstraction of the key features of the construction process and its environmental qualities, which is fundamental for the purpose of MoCCAS. A case study is discussed which deals with the construction processes carried out by a slip formwork system that exhibits a large degree of repetition and requires rigorous technological procedures. The article focuses on the repetitive construction process formulation and conceptualizes this process by presenting: (1) DCPM-TP, that is a construction process representation in a three coordinate system, and (2) the mag_811 module, which is part of MoCCAS

E-mail address: magdalena.hajdasz@put.poznan.pl.

http://dx.doi.org/10.1016/j.autcon.2015.05.005

and which is designed to simulate process behavior and to create effective execution strategies.

2. Challenges in repetitive projects modeling, scheduling, and management: literature review

Modeling and simulation (M&S) techniques have been widely recognized to be useful analytical instruments for reducing complexity and advancing the understanding, control, and management of construction processes (cf. [1]). In particular, M&S has been recognized as well-suited for projects with repetitive tasks (e.g. [2,11,15]).

As Kamat et al. [20] point out, construction can be planned, monitored, and controlled at 1) the activity or schedule level and 2) the operation or process level. Each level involves differences in relation to concepts, form, and content in developing graphical construction visualizations. At the activity level, visualizing construction entails the depiction of the construction product by presenting what kind of physical components are built, where and in which time frame. Visualization methods at the operations level allow the product development to be visualized, including visualization of the interactions of the various resources as they build the product.

In order to improve the efficiency of repetitive construction projects, a variety of modeling and scheduling methods have been proposed, for instance, the critical path method (CPM), line of balance (LOB), the linear scheduling method (LSM), horizontal and vertical scheduling, and time versus distance diagrams (T–D charts), among many others ([21]). LOB and bar chart techniques enable simple estimation of the total project duration via the location–time relationship, as well as easy process updates. In addition, they are able to calculate a productivity rate relating to the concept of natural rhythm. However, they make the relationships among activities difficult to identify. The CPM enables a clear representation of activity relationships and easily addresses the project management via the critical path, but it does not deal effectively with repetitive cycles and is not capable of maintaining work continuity. Compared to bar charts, network scheduling is not time scaled, which creates difficulties for practitioners [5,7,44].

Even though these methodologies account for resources, research indicates the shortcomings of traditional scheduling methods, such as bar charts, LSM, or CPM, as a result of their inability to include a wide range of aspects that are crucial at the project planning stage, and because these methods consider planning processes in one-dimensional ways, e.g., they focus only on time [17,24].

With the aim of making scheduling more effective, researchers have combined CPM and LOB scheduling methods by defining logical relationships between overlapping activities [3] or by introducing heuristic rules [41]. These methods have been integrated with artificial intelligence (AI) and operations research (OR) techniques [27], and object-oriented or genetic algorithm (GA) methods [7,8] to minimize project duration, improve construction work efficiency, maintain work continuity, and optimize project scheduling.

Zhou et al. [45] provide a comprehensive overview of construction schedule optimization methods. They identify three categories: mathematical, heuristic, and meta-heuristic. With regard to repetitive projects, some example approaches according to the above classification have been offered, for instance, a dynamic programming model that introduces a cost variable into the optimization process [28], a heuristic method for scheduling a multiple-mode construction project that is subject to resource constraints [40], or a GA-based method for scheduling construction projects, by considering project duration and/or cost [26].

2.1. Insight into the difficulties of repetitive project management

Within repetitive projects, resource management represents a flow-optimization problem [21]. Repetitive construction projects are resource-driven, multi-unit projects characterized by activities which need to be performed in a sequence from unit to unit repeatedly. These activities need to be scheduled in such a way that construction crews go over the same work in various locations of the project [19] and such that resources assigned to them are utilized continuously once they reach the construction site [16]. Therefore, ensuring an uninterrupted deployment of resources assigned to similar activities between different units is one of the most important issues in scheduling these projects [34]. The activities' intricacy and simultaneity, combined with the changing resource requirements as they move through the site, pose significant challenges for the modeling, planning, scheduling, and management of repetitive projects. Bragadin and Kahkonen [4] highlight that construction process modeling for repetitive projects creates the need for advanced scheduling techniques and comprehensive models 'of resource flows through project activities' in particular.

The characteristics of activities and crews in repetitive projects have been summarized by Yang and Ioannou [36], who highlight a series of possible variations within these projects and focus on the practical concerns in regard to their scheduling. Thus, in repetitive projects, 1) activities may start and finish at different locations, not be present in all working locations, require space-buffers and time buffers, and have multiple predecessors and successors, with a possibly wide range of relationships between predecessor successor pairs, whereas 2) crews may change progress direction and have complex work sequences, affect the unit production rates during progress, and perform multiple activities with an activity possibly employing multiple crews simultaneously working at different locations (cf. [36]: 621–622). This is further complicated by the fact that resources in general have time–space requirements that are not constant and that change along with the construction progress, which may result in temporal and spatial collisions or idleness of resources. Unforced resource idleness is associated with imbalanced production rates, uncertainty concerning the production rate in the planning phase and variability during the execution phase [37]. The flow of resources can be protected with time buffers, which cushion the production process from the negative impacts of variability and uncertainty [10,18,22,23,30].

Furthermore, in project scheduling, it is crucial to differentiate between relationships involving hard and soft logic. As Fan and Tserng [7] and Tamimi and Diekmann [33] notice, in the real world, two types of relations among activities can be distinguished: fixed logic and soft logic (which take place, respectively, between technically dependent and independent activities). 'Hard or fixed logic is network logic requiring an "only link" definition due to inflexible constraints while soft, preferential, or discretionary logic is network logic configured with more flexible constraints' ([25]: 484).

Also, other activity-based classifications have been offered. For example, Hegazy and Kamarah [46] define two types of activities: structural core activities that form the physical high-rise structure, and other activities that are not part of the structural core when one is developing a scheduling and cost optimization model. For the purpose of developing a repetitive project scheduling and work continuity-maintenance model, Fan and Tserng [7] provide a further distinction in regard to soft logic: between semi-soft logic and fully-soft logic.

This brief review of repetitive project management problems reveals that effective management of these projects requires a precise identification of the size and degree of repetitiveness of the work units, and an accurate recognition of the relations among activities and their possible sequencing, as well as an accurate recognition of the scope of resource manipulation, in order to ensure work continuity, meet deadlines, and maximize resource utilization.

2.2. Difficulties arising from the formwork system specificity: selecting a case study

This study attempts to address the difficulties related to the modeling and management of specific construction processes conducted by