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Semi-automated site equipment selection and configuration through formal knowledge representation and inference

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ABSTRACT

The selection and configuration of site equipment is a fundamental part of construction preparation. Suitable site equipment supports the timely, cost-efficient and qualitative execution of the construction process. The use of planning tools based on formal knowledge management methods can both speed up the process of construction site planning and lead to better results. In this paper, we propose a rule-based knowledge inference system to support site equipment planners in a semi-automated manner using input data from building information models and working schedules. The knowledge-based system is built using the business rule management system *Drools*. Using a sample construction site, the feasibility of the proposed approach has been proven.

1. Introduction

Inappropriately selected construction site equipment (SE) can slow down the construction process, generate unnecessary costs and constitute actual safety risks, making the process of equipment selection an indispensable step in execution planning. The purpose of the SE is to ensure an orderly, productive and safe execution of all tasks necessary during construction, reconstruction or demolition of a building or structure. The selection and generation of the SE provide the basis for performing construction site layout planning (CLSP).

Site layouts are especially relevant during shell construction, as most heavy equipment is used in this phase. A prerequisite for creating reasonable site layout plans is to identify all needed SE and to determine the necessary dimensions of each element of the SE. To generate a site layout plan, these SE elements are placed in the available areas on site.

The necessary SE varies widely depending on the conditions of the specific construction project. Due to the large deviations in the circumstances and specific requirements of construction projects, the SE has to be selected and configured individually for each project. However, according to current literature, despite the large impact of SE on the on-site overheads and construction productivity, the site planning process has not been well formalized [1,2]. Usually, planners conduct both selection of the SE and CSLP manually, without technological support. Oral conversation with practitioners confirmed this observation [3,4].

The dimensioning of the individual elements of the SE is mostly realized based on the experience of the planners and rules of thumb, without qualitative or quantitative reviews. The results of the manual SE selection and CSLP planning thus depend solely on the expert knowledge and practical experience of the executing planner.

A large set of information, traditionally acquired in late planning stages, has to be considered during the CSLP process. Changes in the construction design and construction methods usually require the adjustment or re-planning of the SE. To reduce the planning efforts and prevent repetitive re-planning phases, the CSLP is usually conducted only after decisions on the design and construction are final, depriving the possibility to include information about the necessary SE in the process. This way, potentially expensive and inconvenient solutions might be condoned because the SE was not taken into account during the design phase.

To be able to include aspects of the SE selection in the planning considerations, a fast and easy way to support planners in their decisions by partly or even completely automating the planning of the construction site is necessary. This becomes even more relevant as numerous regulations and guidelines for SE selection exist. To support the planners during the generation of individual site facilities, knowledge-based systems (KBS) form a suitable basis. These systems are computer programs that formalize human knowledge in a strict, logical and computable manner, allowing them to infer conclusions from given facts.

KBS have been chosen for the problem at hand, as they allow the direct representation of the rules stipulated by the aforementioned regulations and guidelines. On the contrary, alternative technologies,

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such as case-based reasoning or machine learning, rely on the implicit derivation of knowledge from provided examples. They require a large set of training data and a human-assisted training phase. As, however, rules on SE selection are made available explicitly through textbooks, guidelines, etc., a KBS approach seems to be more promising and is investigated in this paper.

This paper presents rule-based knowledge inference systems to perform the SE selection process in a semi-automated manner using input data from building information models and working schedules. In the first part of the paper, we concentrate on the fundamentals of SE planning and KBS and give an overview of the related work. In the second part of the paper, we present a system for semi-automated SE selection and generation. In the third part of the paper, we formulate rules applying to SE selection and generation, followed by the implementation of a prototype. Finally, we present a case study and conclude the paper.

2. Background

Up to now, construction site equipment is generally selected and configured by hand. However, there has been effort by several research groups to automate the planning process. In the next sections, a short overview over the traditionally SE planning and the state of the art in computer-aided SE planning is given.

2.1. Fundamentals of SE planning

The SE is used to prepare and conduct all individual construction processes in the best possible way in order to enable a fluent and continuous construction progress. The construction SE includes all producing and non-producing facilities required on site for the construction or renovation of a structure [5].

With the construction method applied, the conditions on site, neighbouring properties and local characteristics, the boundary conditions and requirements for the construction site facilities vary from construction project to construction project. These boundary conditions cause deviations in the required material, storage spaces, construction machines and processes, so that the planning has to be conducted for each new project. Changes to the construction project or the construction process must also be followed by repeated calculations and planning, which requires extra effort. The SE can be classified into seven basic groups (see [2,6]).

1. Construction machinery (e.g. hoists, concrete pumps).
2. Social and office facilities (e.g. office/sanitary containers).
3. Storage areas (e.g. tool sheds, outside/inside storage).
4. Traffic areas, transport routes (construction roads, entrances/exits).
5. Media supply and disposal (e.g. waste disposal, power/water supply).
6. Site security (e.g. fences, illumination, scaffolding).
7. Excavation support.

Different groups of SE entail different degrees of freedom concerning the planning task. While the media supply, site security and excavation support are highly restricted by the circumstances on site, the construction machinery, social facilities and storage areas are more variable. With ongoing progress, the requirements and conditions at the construction site change. The construction process is typically divided into several construction stages, where some facilities may not be required in each construction stage. Therefore, a dynamic construction site plan is required. At the beginning of each construction stage, items that are no longer needed are disassembled and replaced by other facilities [7].

Depending on the state in which a construction project is to be carried out, different laws and regulations have to be applied. This work is primarily concerned with legislation in Germany. Construction-related regulations can be found, for example, in the workplace ordinance [8] and various ISO and DIN standards (e.g. DIN 4124 [9] for excavations, ISO 668 [10] for containers, and DIN 30734 [11] for interchangeable silos).

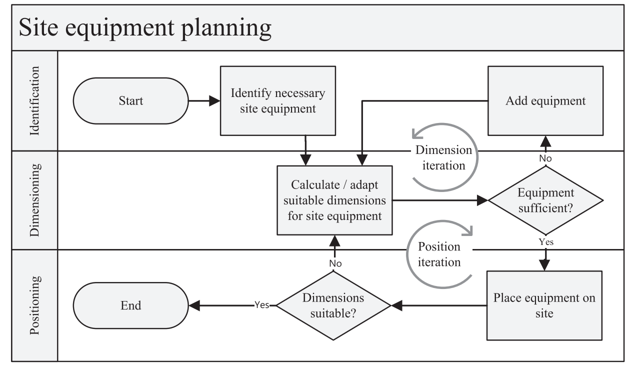

Fig. 1. Site equipment planning and interdependencies of different planning stages.

During the planning process, all needed SE is identified, dimensioned, and finally placed on the construction site. Following this consideration, we split the SE planning into three interdependent tasks: identification, dimensioning, and placement of the SE (Fig. 1). In this paper, we seek to support the planner in the first two steps, the identification and dimensioning of necessary SE. The placement process will be subject of future publications.

The required SE can be identified explicitly—e.g. the planner demands the use of a concrete pump—or implicitly—e.g. if a concrete pump is demanded, most likely a tower crane is required to place formwork. In this paper, we propose connecting BIM models with detailed working schedules, where a construction method is explicitly given for each building element. Each construction method is linked to SE, so that a timed list of necessary equipment can be generated. Nevertheless, additional SE might be required and implicitly identified.

Dimensioning, the determination of necessary and economic dimensions according to the specific conditions and requirements of a construction project, is especially important for producing, transporting and storing facilities. Under-dimensioned elements can lead to a delay in construction progress (e.g. insufficient storage areas), or individual work steps could become impractical (for example if a tower crane's reach is too small). Over-dimensioned elements increase the costs (for example if the crane is higher than needed) and the travel times on site (if storage areas are too large and need to be crossed frequently).

2.2. Knowledge-based systems

Knowledge-based systems are computer programs using methods from the field of artificial intelligence. They are used to assist humans in solving complex problems and tasks that are usually conducted by specialized decision makers. To that end, the algorithms mirror human thought processes and attempt to draw intelligent conclusions and action recommendations from given information [12].

2.2.1. Characteristics and architecture of knowledge-based systems

KBS are characterized by the strict separation of knowledge (stored in a knowledge base) and techniques to retrieve information from that knowledge (called inference engine). Further components are needed to fill the knowledge base (expert interface and knowledge acquisition component) as well as to retrieve solutions for a specific problem (user interface, working memory and explanation facility) [13]. The typical structure of a KBS is shown in Fig. 2.

The core functionality of a KBS lies in the knowledge base and the inference engine. The *knowledge base* contains the permanent knowledge, which can be structured in rules and facts. Human knowledge