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Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules

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ABSTRACT

Construction safety is a national and worldwide issue. This paper contributes in solving this problem by applying automated safety rule checking to Building Information Models (BIM). Algorithms that automatically analyze a building model to detect safety hazards and suggest preventive measures to users are developed for different cases involving fall related hazards. As BIM is changing the way construction can be approached, the presented work and case studies extend BIM to include automated hazard identification and correction during construction planning and in certain cases, during design. A rule-based engine that utilizes this framework is implemented on top of a commercially available BIM platform to show the feasibility of the approach. As a result, the developed automated safety checking platform informs construction engineers and managers by reporting, why, where, when, and what safety measures are needed for preventing fall-related accidents before construction starts. The safety area reviewed is fall protection. An example case study of such a system is also provided.

1. Introduction

In the past two decades more than 26,000 U.S. construction workers have died at work. That equates to approximately five construction worker deaths every working day. Of these fatalities, 40% involved incidents related to falls from height [1,2]. Inadequate, removed, or inappropriate use of fall protection equipment contributed to more than 30% of the falls [3]. A case study by Frijters and Swuste [4] demonstrated that awareness of safety during design can influence the risk of falling.

As these statistics indicate, safety in construction remains a big problem. The sad reality of frequent loss of life, injuries, near-misses, and collateral damage is that they pose liabilities that can be prevented. Safe construction requires care and planning throughout the project lifecycle, from design, through construction planning, through construction execution and extending into operations and maintenance. As good safety practices and records create a positive, hazard free, and productive work environment, planning for safety at the front-end of a project is not only the first but also a fundamental step for managing safety [5].

Failures in hazard identification are often due to the limited expertise or oversight of engineers or safety staff when planning or executing safety practices, or poor training of construction staff. Examples are tasks in design for safety, safety inspection, and monitoring safety. Failure in any of these can result in increased risk of exposing workers to hazards in the construction environment.

Planning for safety typically consists of the identification of all potential hazards, as well as the decision on choosing corresponding safety measures [6]. Precisely and accurately identifying the potential safety hazards is critical to the safety planning process. Safety planning in construction is generally done separately from project execution planning and involves different actors. This separation and the resulting lack of communication create difficulties for safety engineers to analyze what, when, why, and where safety measures are needed for preventing accidents. The industry is in need of improving the inefficiencies of the existing paper-based and manual safety processes in place. Further improvements can be gained in construction safety through the use of technology.

The growing implementation of Building Information Modeling (BIM) in the AEC/FM industry is changing the way safety can be approached. This research takes advantage of the potential that BIM provides for safety in construction (building) design and planning, and further facilitates the integration of construction safety and health practices in BIM. It does so by automatically detecting and eliminating hazards. It is based on the recognition that a building model and associated schedule means that the construction site changes daily, with new safety issues emerging (and others being removed) as the project progresses. The construction process may include activity sequences that are inherently dangerous, without proper corrective actions and that these activity sequences can be identified at the planning stages and corrected.

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This paper presents an automated rule-based checking system for BIM and how future safety planning can be integrated in work breakdown structures and project schedules. The scope of this paper focuses on developing the rule implementation for fall protection. Deciding what fall protection system to apply, where, and when are part of the research questions that are to be answered. As rules from safety regulations are interpreted, and used to check the design model at the early project stages, the results can then be visualized in BIM.

The current state of safety planning and need for an automated safety checking system is addressed in Section 2 of this paper. The review in Section 3 presents information on the technologies used in this study, construction safety control, and computational rule-based checking language. In Section 4, the framework and methodology for the proposed rule-based safety checking system and rule checking process are presented. Section 5 presents the safety rule interpretation and rule-based algorithms platform for fall protection. A case study is presented in Section 6. The results demonstrate the benefits of the developed safety-rule checking platform in assisting designers, engineers, safety managers, and workers in the efficiency of designing safe work processes, and reducing errors in site layout plans and execution of work tasks. A summary of the contributions and discussions about future research are in the final section that concludes this paper.

2. Background

2.1. The current status of safety planning

The complex and dynamic nature of the construction industry and its on-site work patterns is widely recognized. This separates it from the manufacturing industry, which has mostly stationary fabrication settings. Safety planning in an unstructured construction environment is thus more challenging. The most severe consequence from bad safety planning and execution is loss of life. Significant time and economic resources are lost when workers are injured on the jobsite. Some practitioners even claim that construction sites are often under-resourced and under-planned when it comes to safety planning [7].

The mandate of the construction industry is to provide a safe and healthy work environment. The existing safety management culture in a construction company focuses on checking regulations from the Occupational Safety and Health Administration (OSHA). Often companies apply more stringent best practices in safety and health that go beyond providing education, training, and personal protective equipment (PPE) to workers [8].

The current state of safety planning in construction can be summarized:

- *Traditional safety planning relies on frequent manual observations, is labor-intensive, time-consuming, and thus highly inefficient.* Safety planning together with project execution planning can convey what is to be built, what safety measures are necessary when, where and why [9]. The link between planning for safety and work task execution is often weak: for example, many contractors use two-dimensional drawings (2D) or field observations to determine hazard prevention techniques. Since their approach is manual and based on experience, the observed results are often error-prone due to subjective judgments of the decision maker.
- *Safety knowledge is difficult to transfer by safety regulations alone.* Existing safety rules, regulations, and best practices have demonstrated impact. A trend towards zero accidents can be shown in indices such as the Total Recordable Incident Rate (TRIR) published by the Construction Industry Institute [10]. Even though safety records have improved compared to ten years ago, improvement in recent years has slowed down, or in the last few years began again to get worse. One main contributor for the recent increase in incidents is knowledge transfer of safety best practices. As companies hire new personnel it becomes difficult for them to adapt to a new safety culture. Though many job sites require safety orientation and training, it is demanding for workers to acquire the knowledge in a short time and stick to the rules accordingly when performing design, planning, and work tasks.
- *Construction site safety often remains the sole responsibility of the contractor.* Design choices often determine construction methods and schedule; while limited attention is given to safety during the design phase [11]. Often designers do not understand the impact their work has on construction methods, schedule, and most importantly on safety. To date, the cooperation and communication among project stakeholders (owners, contractors, subcontractors, etc.) in regards to safety is quite limited at the front-end [12].

All of these are barriers and unintentionally create hazards at the project planning and execution stages. The following section summarizes some of the research conducted for new and improved safety planning approaches based on historical data.

2.2. The traditional approach of safety analysis and control

Many efforts at safety analysis and control have been based on historical safety statistics. Yi and Langford [13] analyzed historical safety records and presented a theory on safe planning by estimating the risk distribution of a project. The approach works by estimating situations of concentrated risk and then adjusting the schedule to avoid the risk peaks. Saurin et al. [14] integrated a Safety Planning and Control Model (SPC) into the production planning and control process. Three hierarchical levels were defined: long-, medium-, and short-term safety planning. Safety control and evaluation is based on both proactive and reactive performance indicators relying on percentage of safe work packages and actual accident data. A specific Construction Job Safety Analysis (CJSA) tool was developed by Rozenfeld et al. [15]. The method focused on the identification of potential loss-of-control events for detailed staging of construction activities. The assessment of the probability of occurrence for each event was determined through interviews. The goal was to predict the fluctuating safety risk levels and to support safety conscious planning and safety management. Tam et al. [16] applied Non-Structural Fuzzy Decision Support System (NSFDSS) to evaluate safety management systems and prioritize the measures with the consideration of various decision criteria, and further to facilitate more realistic decision making.

Analysis and causation of accidents and historical data provide valuable but general information for safety planning. These are, however, not sufficient to predict when and where accidents occur on unique construction projects. This has led to the advent of information technology-enabled approaches for construction safety using virtual designs and simulations of construction operations. The following section outlines some of these initiatives.

2.3. Information and communication technologies (ICT) for construction safety

Information and communication technologies such as Building Information Modeling (BIM) [17], Virtual Design and Construction technology (VDC) along with Geographic Information Systems (GIS), etc. have become established tools in the Architecture, Engineering, and Construction (AEC) industry. Detecting spatial conflict or congestion of construction operations is one issue addressed using 4D visualizations [18]. Hadikusumo and Rowlinson [19] adopted Virtual Reality for construction safety by creating a design-for-safety-process (DFEP) database. The VR-based DFEP tool helps to identify safety hazards based on manual selection during the building design phase. Mallasi [20] developed the Patterns Execution and Critical Analysis of Site Space Organization (PECASO). It aims at developing a methodology and tool to assist planners with the assignment of activities in the execution