BIM-BASED PLANNING OF TEMPORARY FACILITIES FOR CONCRETE CONSTRUCTION

Kyungki Kim[1] **and Jochen Teizer**[2]

[1] Ph.D. Student, School of Civil and Environmental Engineering, Georgia Institute of Technology, U.S.A.
[2] Associate Professor, School of Civil and Environmental Engineering, Georgia Institute of Technology, U.S.A.
Correspond to kkim369@gatech.edu

ABSTRACT: Concrete construction requires utilization of many temporary facilities such as formwork, shoring, and scaffolding. Appropriate use of these temporary facilities greatly impacts the quality, cost, schedule, and safety of concrete construction. The current practice in design and planning of temporary facilities is often manual, error-prone, and re-active based on construction site layout, status, and progress in the field. Early design and planning of temporary facilities for concrete construction using Building Information Modeling (BIM) technology offers a potential solution. Although some commercially-available software exists that assists in the generation of temporary facility designs, the construction industry lacks tools that support detailed planning and design of many other temporary facilities. This research presents our early work in automating the design and planning of temporary facilities utilizing BIM. Algorithms were developed to automatically assess geometric conditions of work space to detect required temporary facilities and design them. The proposed methodology was implemented in a test model. By automatically incorporating temporary facilities into BIM, more realistic construction models can be created with less effort and errors. Temporary facilities-loaded models can finally be used for communication, bill of materials, scheduling, etc. and as a benchmark for field installation of temporary formwork, shoring, and scaffolding systems.

Keywords: Building Information Modeling; Concrete construction; Construction planning; Formwork; Scaffolding; Shoring; Temporary facility

1. INTRODUCTION

Temporary facilities are frequently used in most construction projects and greatly impact construction cost, safety, speed, and quality of the entire construction project [1]. Temporary facilities can cause spatial conflicts between other temporary facilities or activities [2]. According to Ratay [3], failures of temporary facilities during construction are the main causes of most construction disasters. Also, a recent research conducted by the Construction Industry Institute (CII) identified temporary facilities as one of the four primary categories of indirect construction cost [4]. Thus, temporary facilities should be planned as a part of construction planning.

For concrete construction, many types of temporary facilities are used. The concrete formwork provides a desired shape until the poured concrete gains enough strength to free stand. Shoring system supports the concrete structure in the formwork to prevent collapse. And, the scaffolding system provides construction workers access to the work areas. The construction plan for concrete construction should describe how each temporary facility will be used considering its simultaneous use with other temporary facilities. The plan should assist the construction manager to prevent prematurely detaching formwork and shoring, optimize re-uses of formwork and shoring, and provide construction workers with proper scaffolding. Improper planning of these temporary facilities can cause safety problems and loss of productivity.

Despite the importance of temporary facilities, they suffer from several problems in planning and management by the AEC industry. First, temporary facilities lack effective front-end planning and management. Bid drawings do not typically include temporary facilities except for extremely complex temporary facilities such as cofferdam [5][6]. Some construction plans incorporate important temporary facilities later in the process, but field installations of temporary facilities often take place without any planning after the needs arise during the construction. Apparently, there are several code-compliance problems that appear to result from this lack of temporary facility planning. Occupational Safety and Health Administration (OSHA) reported that the standards related to scaffolding systems and ladders are listed respectively as the first and fourth most frequently cited standards in 2011 according to federal inspections [7]. Also, a survey conducted on 73 formwork sites and 246 scaffolding sites in Australia for code-compliance showed that the rates of non-compliance of scaffolding and formwork were 59% and 18%, respectively [8]. These statistics suggest that the current practices in planning temporary facilities should be improved by better management or technology.

In addition to lack of front-end management, temporary facility planning suffers from heavily reliance on the knowledge and experiences of individual engineers. Even though software programs exist that are specialized in designing temporary facilities (e.g. formwork, scaffolding), the functions of the software programs are often limited to supporting rapid generation of temporary facility designs and do not take into account simultaneous uses with other temporary facilities. Only human cognition, based on visual analysis of the building designs or the construction sites, provides the basis for detecting locations where temporary facilities are required, determining proper types of temporary facilities, and generating corresponding designs. Due to complex nature of construction projects and imperfect human judgment, there are chances of generating erroneous temporary facility plans: necessary temporary facilities are omitted from the construction plan; improper types of temporary facilities are selected; and temporary facilities designs do not properly reflect the design requirements. Taking into account the significant impact on the entire construction project and the deficiencies of the current practices in planning temporary facilities, the industry needs to overcome these drawbacks by enabling thorough and front-end planning of temporary facilities.

This research addresses the problems above through the integration of temporary facilities into Building Information Modeling (BIM)-based construction planning. A growing number of construction projects are utilizing BIM technology in order to create more realistic construction models and develop reliable construction plans. By integrating temporary facilities in BIM, we can take advantage of rich information available from BIM model to automate the process of assessing the construction site condition, generating required temporary facility design, and visualizing the designs in the main BIM model.

In order to automate BIM-based temporary facility planning, we developed an automated rule checking system focusing on concrete construction. Considered temporary facilities are formwork and shoring system and scaffolding system. The rule checking system detects all the construction site situations that need the targeted temporary facilities, and then automatically generate the design according to OSHA regulation.

This is an on-going research and presented is the background reviews, the framework of the rule checking system, preliminary results, and expected long-term contribution to the construction industry.

2. BACKGROUND

2.1 Current industry practices in temporary facility designing and planning

The need for temporary facilities is one of the factors that distinguish the construction planning from the production planning of manufacturing industries. Manufacturing planning of mechanical components involves the application of mechanical tools to process desired shapes [9]. On the other hand, construction projects, constructed by construction workers and human-driven equipment, require construction plans that involve usages of temporary facilities that assist the activities of construction workers and equipment. Construction projects are more complex and dynamic than manufacturing processes and involve multidisciplinary participants. Bad planning of temporary facilities can result in schedule delay, worker safety problem, and increased uncertainty of cost estimation.

The efforts made by the construction industry include the implementation of regulations related to temporary facilities and industry best practices that go beyond the regulatory requirements. OSHA provides guidelines on how to design, use, and inspect temporary facilities. Construction companies apply more strict rules and use technology for planning temporary facilities. BIM technology is used by several construction companies to visualize important temporary facilities and to acquire more accurate quantities of material [4] [10] [11].

The current state of temporary facilities design and planning can be summarized:

1) Traditionally temporary facility planning is conducted manually based on visual observation of engineers. Usually, engineers identify required temporary facilities and design them based on field observation or using the drawings. Since the assessment of the construction site condition is subject to the experience and knowledge of an individual engineer, the results can be erroneous [12].

2) Temporary facility designs are not properly reviewed by project participants. After temporary facility designs are prepared by temporary facility vendors, designer and engineers are responsible for reviewing the designs. However, the designers and engineers do not have sufficient time to thoroughly review the drawings and calculations submitted by the vendors [5]. Therefore, the temporary facility designs are reviewed only for the impact on the permanent part of the construction project.

2.2 IT-based approaches to temporary facility design and planning

Research studies suggested approaches utilizing advanced IT technology to solve existing problems of designing and planning temporary facilities. Based on the review, we identified six areas of concern that researchers considered important for temporary facility design and planning. The Table 1 summarizes the review.

Detection of required temporary facilities: Kim and Fischer conducted a research study to establish a theoretical foundation for automatically selecting a proper type of temporary facility [12]. This research provides a theoretical basis for automatically detecting required temporary facilities. They suggested a method of recognizing the geometric condition of construction projects based on the relationship between a work face (the face where the effect of an activity is applied to) and a base face (a face where a temporary facility is place on). Kim and Ahn developed a tool that recognizes the perimeter of a building model and design and install a scaffolding system around it [6]. However, their research does not present any machine-readable rules that can be used for geometric recognition in the complex building geometry.

Table 1. IT-based approaches to designing and planning temporary facilities

No.	**Areas of concern**	Kim and Fischer (2007)	Kim and Ahn (2011)	Sulankivi et al. (2009)	Akinci et al. (2002)	Jongeling et al. (2008)	Scia scaffolding (2009)	CADS (2012)	Lee et al. (2007)	Nagi et al. (2007)
1	Detection of required temporary facilities	●	●							
2	Design generation		●				●	●	●	●
3	Structural stability						●			
4	Incorporation into the main model or 4D simulation	●	●	●	●	●				
5	Inclusion of safety features (i.e. guardrail)		●	●						
6	Space occupied by temporary facilities				●					

Lee et al. developed a formwork layout planning tool considering the prioritized design requirements [13]. Nagi et al. developed a tool for optimizing the aluminum formwork system layout by maximizing the area of standard formwork elements compared to the area of customized formwork elements [14]. Even though the results showed improved usage of standard formwork elements, the developed program does not have a capability to recognize geometric information from the building models and requires users to manually specify corners of the formwork elements. From the review, it can be seen that there is no research study that presents comprehensive method of automatically assessing the project situations in order to identify required temporary facilities.

Design generation: Some research studies developed methods to assist temporary facility design generation. The tool developed by Kim and Ahn automatically creates scaffolding systems around a building model. The scaffolding designs automatically incorporated safety features such as guardrails [6]. Scia scaffolding (2009) provides functions to design scaffolding systems manually [15]. CADS (2012) automatically generates several types of scaffolding systems according to manually generated geometry [16].

Structural stability: Structural stability of temporary facilities should be insured for safety of construction workers. As stated by Sulankivi et al, the current approaches of planning temporary facilities rely on utilization of libraries of pre-modeled models and it is extremely difficult to prepare all the types and sizes of temporary facility designs for complex construction projects [17]. Among the existing approaches, Scia scaffolding provides automated code checking and structural analysis for scaffolding systems [15].

Incorporation into the main model or 4D simulations: Several researchers recognized the benefits of incorporating the temporary facility models into the main building models or 4D construction simulations. The benefits include realization of more realistic construction planning by visualization.

Sulankivi et al [17] and Kim and Ahn [6] identified that temporary facilities have great influence on construction safety and incorporated *safety features* into the temporary facility designs.

Akinci et al. specified project-specific work spaces occupied by construction. In this study, an important idea of *equipment spaces* was used for analyzing spatial conflicts between spaces occupied by a scaffolding system and a work crew [18].

2.3. Need for an automated rule-based checking system for temporary facility design and planning

Front-end planning of temporary facilities is needed by the construction industry since it provides an opportunity for the project stakeholders to pro-actively manage temporary facilities. In spite of the efforts and advancements made by the industry, manual and text-based practices of current construction industry have limited capabilities to cope with the industry needs. Previous research indicates that temporary facilities lack effective front-end planning and management and temporary facility planning suffers from heavily reliance on the knowledge and experiences of individual engineers. This research addresses these drawbacks by integrating temporary facilities into BIM-based construction planning. We develop a rule-based checking system for temporary facility planning focusing on concrete construction.

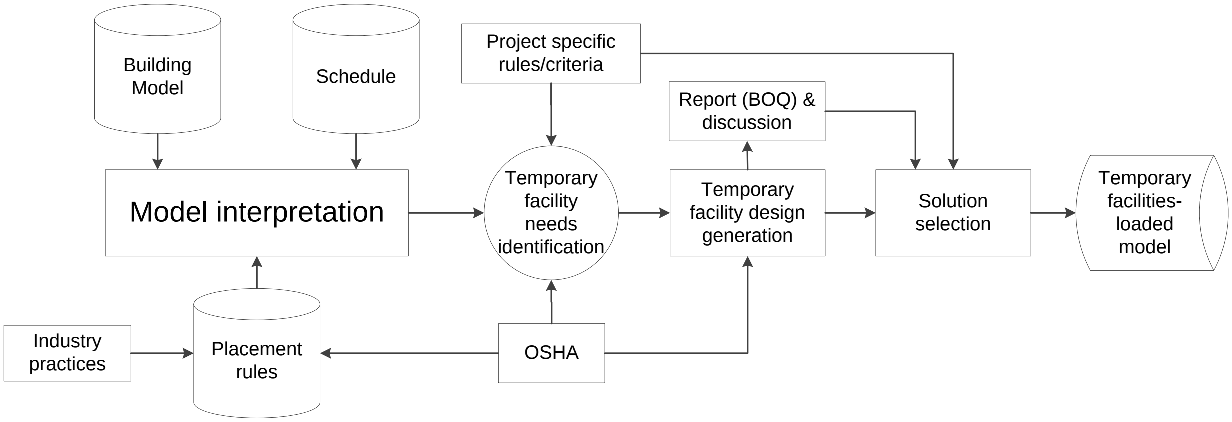


Figure 1. Framework of the proposed rule-based temporary facility design and planning system

A rule-based checking system assists building model users by evaluating the building model based on pre-defined rules and returning the checking results such as pass or fail [19]. Zhang el al. [20] developed a rule-based checking system for construction safety focusing on prevention of fall protection. Our research will contribute to the development of more realistic and feasible construction planning by incorporating important temporary facilities. Various regulations and best practices related to temporary facility design and placement can be automatically reflected into the plan. Visualization of BIM can be used as the platform for communication and as the benchmark for field installation. Automatically conducting quantity take-off, expenditures on temporary facilities will become more predictable. In addition, safe management of the construction site will be possible.

3. FRAMEWORK AND METHODOLOGY

Figure 1 illustrates the framework of proposed rule-based temporary facility design planning system. The initial step is to collect project data from a building model and construction schedule. BIM models provide geometric data (building object shapes and relative relationship between the building objects) and non-geometric information (material, related schedule task, and the stakeholder in charge of the task) that are useful analyze the condition of dynamically changing construction site.
Then, the rules for detecting required temporary facilities from the model are established based on the industry practices and regulatory rules available from OSHA. Development of the rules for the three types of temporary facilities is under progress and only basic usages of the temporary facilities were used to develop preliminary rules in this research.
For detection of required scaffolding systems, the relative relationship between building objects should be considered. Kim and Fischer [12] proposed a method to analyze the relationship based on the configuration of a work face and a base face. The basic configuration applied in this research is illustrated in Figure 2. A work face is a combination of faces from several building objects where a construction worker can apply construction activities to it without ceasing. In order to implement this method, we developed an algorithm that detects all the work faces from the model. Then, the height of each work face is used to determine if the project location needs a scaffolding system. Schedule information of the objects in a work face is used to determine when to install and demobilize the scaffolding system.

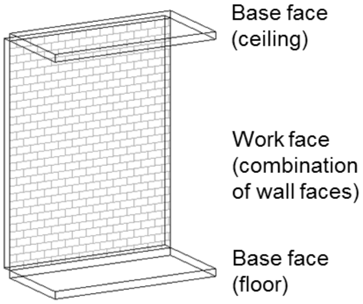
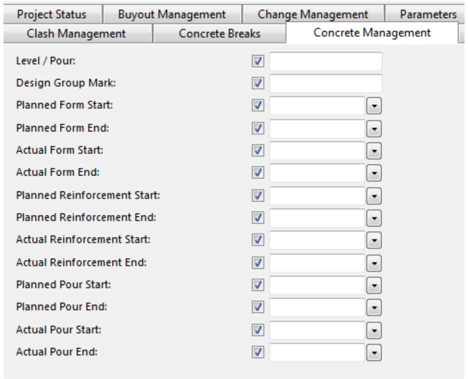


Figure 2. Configuration for scaffolding installation

Building objects that require formwork and shoring system can be detected using object properties. All the concrete objects are first detected from the model. Then, pre-determined dates for concrete management can be used to determine when formwork and shoring system will be placed. Figure 3 illustrates the concrete management interface of Tekla structure.



Level / Pour: ☑
Design Group Mark: ☑
Planned Form Start: ☑
Planned Form End: ☑
Actual Form Start: ☑
Actual Form End: ☑
Planned Reinforcement Start: ☑
Planned Reinforcement End: ☑
Actual Reinforcement Start: ☑
Actual Reinforcement End: ☑
Planned Pour Start: ☑
Planned Pour End: ☑
Actual Pour Start: ☑
Actual Pour End: ☑

Figure 3. Concrete management interface of Tekla

As a result of the interpretation process, all the needed temporary facilities are identified and geometric information is obtained for each location that needs temporary facilities. For each temporary facility, corresponding design can be generated based on the geometric information, OSHA design guidelines, and best practices. Final decisions can be made by a construction planner based on automatically generated bill of quantities and visualization of the temporary facilities.

4. IMPLEMENTATION AND RESULT

The proposed rule checking system for concrete construction was implemented in Tekla structure. A test model created for the test implementation is a four-story building that includes concrete walls and slabs (see Figure 4).

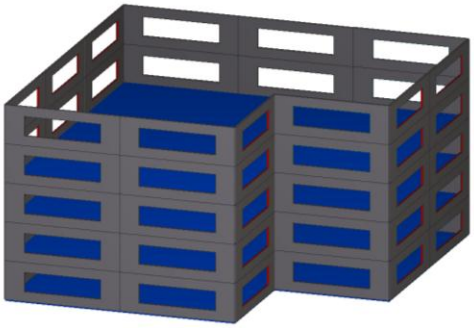


Figure 4. Modeling without temporary facilities

Figure 5 illustrates an intersection of the test model with traditional pipe and board scaffolding systems automatically generated by the proposed system. The scaffolding system design reflects OSHA design guidelines and the edges are processed automatically to prevent overlapping or voids between scaffolding systems. By the use-defined model interpretation rule, scaffolding systems were installed for work faces that are greater than 20 feet in height. The result shows that scaffolding systems are installed for the building exterior and fourth floor while remaining work faces in the lower three floors are highlighted. This approach can support the application of project-specific rules for different heights and lengths of work faces and visualization of work spaces.

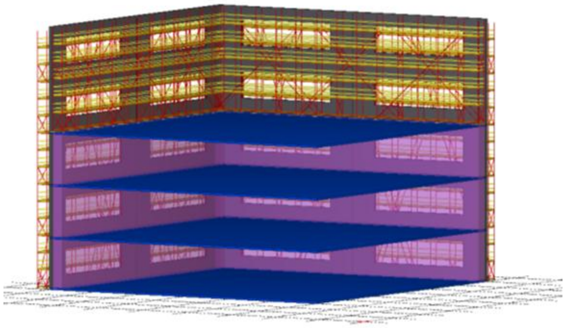


Figure 5. A test model with scaffolding system

Figure 6 show an intersection of the test model with the formwork and shoring systems for concrete floor, Figure 7 shows the model with formwork and shoring system and scaffolding system. Figure 8 and 9 show the different details of scaffolding systems depending on the floor materials.

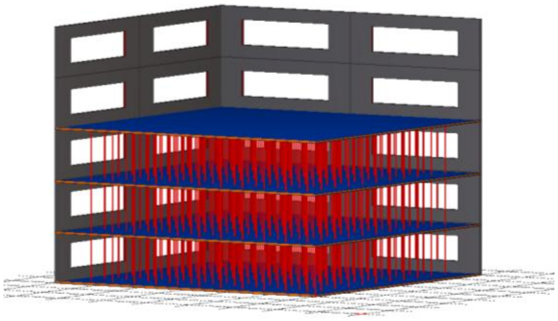


Figure 6. A test model with formwork and shoring system

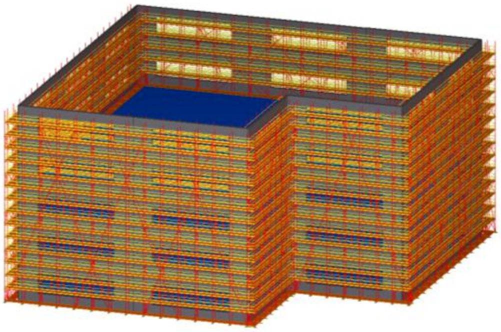


Figure 7. A test model with formwork and shoring system and scaffolding system

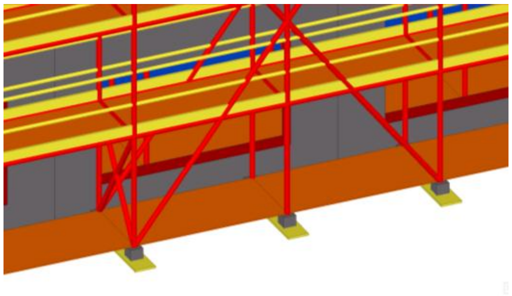


Figure 8. A scaffolding system placed on the ground

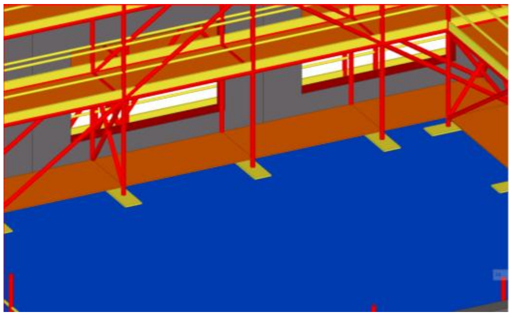


Figure 9. A scaffolding system placed on the concrete floor

5. CONCLUSIONS AND DISCUSSIONS

This research presented the framework for automated temporary facility design and planning system focusing on concrete construction. The developed system implementing the framework recognizes the geometric conditions of a building model, generates required temporary facilities, and incorporates them into the building model for construction planning. This approach allows the user to establish a thorough plan for temporary facilities before the construction begins and allow rapid application of best practices and project-specific rules to designing the temporary facilities.

Preliminary results demonstrated the potential capabilities of the BIM-based planning system in detecting and designing required temporary facilities. Since the system automatically analyzes information available from BIM models, thorough temporary facility plans can be established reflecting the industry know-hows with less effort.

The results demonstrated in this paper show our early work in an on-going research. The future tasks include integrating schedule into the temporary facility system based on in-depth investigation into best practices and developing algorithms that generate detailed formwork and shoring. Also, automated material re-use planning system will be developed.

REFERENCES

[1] Ratay, R. T., “Temporary Structures in Construction Operations”, *ASCE Convention*, Atlantic City, American Society of Civil Engineers: pp. 1-8. 1987.

[2] Akinci, B., *Automatic generation of work spaces and analysis of time-space conflicts at construction sites*. PhD thesis, Dept. of Civil and Environmental Engineering, Stanford University, Stanford, California, 2000.

[3] Ratay, R. T., “Temporary Structures in Construction - USA Practices”, *Structural Engineering International*, Vol. 14(4), pp. 292-295(4), 2004.

[4] CII, *Leading Industry Practices for Estimating, Controlling, and Managing Indirect Construction Costs*, Research Summary 282-1, 2012.

[5] Ratay, R. T., *Handbook of Temporary Structures in Construction: Engineering Standards, Designs, Practices and Procedures*, New York, McGraw-Hill, 1996.

[6] Kim, H. and Ahn, H., “Temporary Facility Planning of a Construction Project Using BIM (Building Information Modeling)”, *Proceedings of the 2011 ASCE International Workshop on Computing in Civil Engineering*, pp. 627-634, 2011.

[7] OSHA, “Top 10 Most Frequently Cited Standards.” Occupational Safety & Health Administration. < http://www.osha.gov/Top_Ten_Standards.html > (April 22, 2012), 2011.

[8] WHSQ, Work Health and Safety Act 2011. *Workplace Health and Safety Queensland*, Department of Justice and Attorney-General, 2011.

[9] Vandenbrande, J. H., Requicha, A. A. G., *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 15(12), pp. 1269-1285, 1993.

[10] Tekla, “In Practice: DPR Construction.” References. <http://www.tekla.com/us/solutions/references/Pages/DPRConstruction.aspx> (May 1, 2012)

[11] Tekla (2012). “Tokyo Sky Tree, Japan.” References. <http://www.tekla.com/international/solutions/references/Pages/tokyo-sky-tree-japan.aspx> (May, 2012)

[12] Kim, J., Fischer, M., “Formalization of the Features of Activities and Classification of Temporary Structures to Support an Automated Temporary Structure Planning.” *Proceedings of the 2007 ASCE International Workshop on Computing in Civil Engineering*, Pittsburg, Pennsylvania, pp. 338-346, 2007.

[13] Lee, C., Ham, S., and Lee, G., “The development of automatic module for formwork layout using the BIM”, *ICCEM/ICCPM*, Vol. 3, pp. 1266-1271, 2009.

[14] Nagi, R. S., George, T., and Ashwin, M., “Automation of scheme preparation and BOQ calculation for L&T-aluform” *24th International Symposium on Automation & Robotics in Construction*, pp. 273-280. 2007.

[15] Scia scaffolding, Scia Scaffolding: providing an accurate design and time-saving workflow, *White Paper*, Nemetschek, 2009.

[16] CADS, “Smart Scaffolder” References http://www.smartscaffolder.com (May, 2012)

[17] Sulankivi, K., Mäkelä, T., and Kiviniemi, M., "BIM-based Site Layout and Safety Planning." *VTT Symposium (Valtion Teknillinen Tutkimuskeskus)*, ISSU(259), pp. 125-140, 2009.

[18] Akinci, B., Fischer, M., Levitt. R., and Carlson, R., "Formalization and Automation of Time-Space Conflict Analysis." *Journal of Computing in Civil Engineering*. Vol. 16(2), pp. 124-134, 2002.

[19] Eastman, C., M., Lee, J., Jeong, Y., Lee, J., “Automatic rule-based checking of construction designs, *Automation in Construction*, Vol. 18(8), pp. 1011-1033, 2009.

[20] Zhang, S., Teizer, J., Lee, J., Eastman, C., M., Venugopal, M., “Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules”, *Automation in Construction*, pp. 1-13, 2012.