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Building information modeling (BIM) for safety risk identification in construction projects

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Abstract

A significant number of fatal accidents and injuries are still reported in construction projects worldwide inducing consequent socioeconomic impacts. A crucial factor in construction safety is to properly identify possible hazards at any stage of the construction process. Existing research has not focused much on the automatic detection of risks associated with the inexistence or misplacement of protective safety equipment. This paper presents a method for detecting safety risks (to which workers may be exposed in a construction project) concerning the inappropriate placement or handling of protective equipment. In this approach, the construction site is dynamically modeled employing Building Information Modeling (BIM) technology. In particular, the project status is recorded at regular intervals using a camera. The data provided by the camera are transferred to BIM software and the site plan view is processed via a Matlab pattern recognition module to observe protective equipment misplacement or removal. The software compares the current image with the anticipated safety protection plan of the construction work and automatically detects the safety potential hazards areas along the work area. Within the extracting results, visual representation and labeling of the work areas that present unsafe conditions for the workers are developed and prompt alerts are forwarded to the project supervisor by e-mail specifying the location and type of hazard. The employment of the presented methodology could enable participants in the construction process to promptly identify and restore safety deficiencies, improving thus work safety and minimizing the number and/or the impact of accidents in construction sites.

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1. Introduction

Construction has become one of the most unsafe industries due to the harsh work environment and high risks involved [1]. According to global statistical data, its accident death and injury rates are three and two times higher respectively than the average of other industries [2]. In spite of more attention being paid to safety management in recent years, the accident rate of the construction industry continues to be high. Risks are gradually growing due to the increasing structural complexity, project size, and the adoption of new and complex construction methods [3, 4]. Therefore, improving safety has become an absolute priority.

According to British Standards Institution [5], safety management can be defined as a systematic and comprehensive process for managing safety risk, to provide safe and healthy workplaces, prevent work-related injury and ill health.

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Construction safety management can be divided into the preconstruction stage and construction stage [6]. In preconstruction, potential safety hazards are normally identified based on the safety officers' or project managers' experience and eliminated via safety training and safety planning. During construction, accidents are prevented by monitoring workers and the environment on site [7].

The current approach to construction safety management, summarized as follows:

- a) Traditional safety planning is carried out by means of manual observations, which result to be labor-intensive, error-prone, and often highly inefficient. The link between safety planning and work task execution lacks accuracy due to the massive use of two-dimensional (2D) drawings and, not less relevant, the extensive use of software which loses the connection with the real site simulation. Moreover, building designers and Health and Safety (H&S) coordinators still lack a collaborative working approach and the choices of the H&S Coordinator do not affect project design [8].
- b) Safety training is traditionally based on indoor teaching, which lacks interaction, intuition and hands-on training, and therefore marginally improves the safety consciousness of workers [9].
- c) Safety officers often apply inappropriate site monitoring as they simply use a checklist to manage construction safety by identifying and recording violations. In the absence of technological support, however, it is impractical to monitor the whole site simultaneously due to its large size and dynamic environment [10].

Current research is making some efforts to solve these problems with the help of visualization technology, which makes information digital and visual while depicting the construction environment with contribution to improving construction safety management.

2. Background

2.1 Overview of the literature

There are different research methods that focus on job hazard area identification during design and construction phases. Getuli et al have presented an H&S BIM-based design and validation workflow, specifying the minimum level of requirements and mandatory informative content for the submission of construction site layouts and safety plans, analysing construction phases and identifying potential safety issues in a virtual environment [8]. Shuang et al have presented a framework for systematic personal safety performance and participation assessment through obtaining real-time locations [11]. Hongling et al have introduced a BIM and safety rules integrated approach developed to implement the automated identification of the unsafe factors in design and automatically rectify them to aid in construction safety management on site [12]. S. Zhang et al have investigated how potential fall hazards, which are unknowingly built into the construction schedule, can be identified and eliminated early in the planning phase with a framework that includes automated safety rule-checking algorithms for BIM [13]. L. Zhang et al have presented an innovative approach of integrating BIM and expert systems (B-RIES), composed of three main built-in subsystems (BIM extraction, knowledge base management and risk identification), which is developed to provide real-time support for decision making in traditional safety risk identification process in tunnel construction. [14]. Kim et al have introduced a safety planning platform (implemented in BIM) to simulate and visualize spatial movements of work crews using scaffolding [15]. Computational algorithms in the platform automatically identify safety hazards related to activities working on scaffolding and preventive measures can be prepared before the construction begins. In terms of visualization, a number of works have been reported in the literature regarding construction safety management (e.g. [16, 17]).

Many existing and well-executed studies have focused on risk identification methods mainly at preconstruction stage (design and planning). No practical approaches exist to date on how the data of unsafe conditions can be used by practitioners in order to improve safety during the construction of a project. In this paper, such a methodology is presented, which can enable participants in the construction process to promptly identify and restore safety deficiencies.

2.2 Need for an automated safety checking system

A construction site is a very dynamic environment in which the workspace related to construction activities changes continuously according to project-specific construction data. The planning and design phases provide a vital opportunity to eliminate or mitigate hazards before they appear on-site. Inefficiencies are witnessed in predicting all possible health and safety risks for workers in the project development and operation phases. During project construction, the safe working practices specified in Safety and Health Plan (SHP) and safety construction drawings are not fully implemented, as shown in national and international practice. Visual technology can offer a 3D and automatic approach to identify job hazard areas and potentially play a key role in reducing current incident rates. Vision-based detection of safety risks in real time can resolve safety issues during construction work. Other potential contribution of automated tools to assist safety management in construction is the development of an enhanced framework to facilitate the communication between contractor and designer for safety issues [18].

3. Research method

The proposed methodology for implementing automated rule-based safety checking is illustrated in Fig. 1 and consists of the following elements.

3.1 Image capturing and project data transferring

The methodology starts with capturing the project status at regular intervals appropriately specified (e.g., every 30 minutes). The imaging laser scanner BLK 360 by Leica Geosystems is employed for this purpose. The scanner performs spherical imaging with HDR support. A complete full-dome laser scan, 3D panoramic image capture and wireless transfer to the Autodesk ReCap 360 Pro application takes approximately 3 minutes. In the current application, the scan data are filtered and registered in real-time. ReCap 360 Pro enables point cloud data transfer to a number of BIM applications.

The project site instantaneous image data (taken by the scanners every thirty minutes) are wirelessly transferred to the Autodesk ReCap 360 Pro application. The image focuses mainly on job hazards areas of the project (e.g., warning signs, fences, protective equipment, scaffoldings, excavations, slab edges, portable ladders, holes, construction machinery etc). Then the image data are transferred to Autodesk Revit for better display and processing. The site plan view is inserted as an image from Autodesk Revit to Matlab code with the detection algorithm described below. The file transfer and conversion from tool to tool is done automatically (see Fig.1). Alternatively, the images from a simple camera could be entered into the Matlab code directly, in image file format “.png”, without processing by Autodesk Revit.

Fig. 1: Automated rule-based safety checking implementation framework

3.2 Algorithm operation

The algorithm for the detection of job hazard areas in a construction site is developed by a programming code using the application Matlab R2018a. The algorithm operation includes three modules, as illustrated in Fig. 2.

At the upper module ("Data entry"), all necessary information, as original and temporary images, e-mail address and defined check areas, is introduced and recorded at the Matlab code. All the necessary information is introduced by the respective selection from the "options window" of the code. The original image illustrates the ideal safety protection plan while the temporary images illustrate the real conditions over time at the work areas of the construction site. All images are taken from the same optical angle. Each check area is characterized with an integer identification number in ascending order.

Fig. 2: Illustration of algorithm operation

At the "Execution" stage, the code performs the comparison of the two images (ideal and current) with "pixel by pixel" searching procedure and determination of deviations between the two images. Each image consists of 3,600 pixels on the x axis and 2,580 pixels on the y axis (in total 9,288,000 pixels). Once the execution cycle has completed, the code finds and recognizes the areas of the worksite where there are differences between the images and thus unsafe working conditions.

At the "Reporting results" stage, results from execution stage are displayed, recorded and sorted. Both images are displayed with marked areas where changes have been detected. At the same time, a warning notice is generated to the site manager (or other responsible person), with the respective image, specifying the areas with unsafe working conditions. The notification is automatically transmitted through e-mail electronic message.

Overall, with this algorithm it is possible to determine the type and location of potential risks arising in the construction site. The most noticeable benefit of the process is the capability of automatic and instant notification at any time of the day, which makes immediate problem settlement feasible.

3.3 Case study: applying the automatic work hazard identification process in a roadwork construction site

The typical site (3D view) of the arrangement is shown in Fig. 3 (from Autodesk Revit with file type "png"). The construction work is supposedly carried out along the pavement width and partly on the carriageway. Warning signs, fencing, and safety barriers are required (according to the legislation) to prevent accidents due to the coexistence of workers, machinery, pedestrians and vehicles traveling along the road. In the Figure, one can also see the check areas with numbers in yellow boxes, as they had been defined in the first algorithm module.

It has been observed that, in such projects, warning signs, fencing, and safety barriers are not typically placed in accordance with the safety standards or are being moved during the project implementation from their proper position to make work easier, at the expense, however, of increased likelihood of accident occurrence. To reduce the frequency or fully avoid such hazardous circumstances, the proposed methodology is used for automatically detecting the lack or misplacement of warning signs, fencing and safety barriers in the work site. Following data entry and code execution, the results are produced in both forms, a report (Fig. 4) with the image frames where differences between the original and current images (in the example frames 26, 27, 44, 45 & 46) and a graphical form of the two images in contrast (Fig 5) with clearly marked deviations.

Fig. 3: Site view of the project site with check areas

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Command Window
[27-Feb-2019 00:37:07] User selected to compare images (with areas masks)
[27-Feb-2019 00:37:14] Image "P 23.png" was selected for comparison
[27-Feb-2019 00:37:14] Comparing images "GENERAL COMPLETE 3D VIEW.png" and "P 23.png". Please wait, this may take a while..
[27-Feb-2019 00:37:20] Our tool has detected 5 changes in the following areas:

- Changes have been detected in area: 26
- Changes have been detected in area: 27
- Changes have been detected in area: 44
- Changes have been detected in area: 45
- Changes have been detected in area: 46

[27-Feb-2019 00:37:22] Sending report with email is not enabled
[27-Feb-2019 00:37:22] The tool will now terminate

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Elapsed time is 14.909721 seconds.
fx >>
    
```

Fig.4: Result report instance

Fig.5: Original and current site images with difference indications

4. Conclusion

The research outlines a framework for job hazard area identification employing a rule-based checking system to detect whether the appropriate safety measures are fully and properly implemented in the construction site. Risks are associated mainly with the absence or incorrect placement of warning signs, fencing, and safety barriers, which could create work accidents and injuries/fatalities. The proposed method integrates an imaging laser scanner that monitors the project status at regular intervals, BIM software for developing an electronic temporary image of the project site, and an algorithm that compares the current temporary image with the original one for automatically checking any possible removal or misplacement of the above safety measures. A Matlab code is used to deploy the hazard identification algorithm at a number of predetermined check areas. If differences between the original and current safety measure placements are detected, which indicate improper removal or deviation from appropriate arrangement, the type and the area of the potential risk for workers' safety and health are indicated by displaying the two images in contrast, with the image frames under interest clearly highlighted. An alert is following raised via e-mail message to project or site manager, specifying the point and type of nonconformity. The alerting process can result in prompt response and appropriate restoration of safety measures, preventing thus accidents and reducing the possibility of undesired consequences to project execution.

References

- [1] M.R. Hallowell, Safety-knowledge management in American construction organizations, *J. Manag. Eng.* 28 (2011) 203–211. [https://doi.org/10.1061/\(ASCE\)ME.1943-5479.0000067](https://doi.org/10.1061/(ASCE)ME.1943-5479.0000067)
- [2] V. Sousa, N.M. Almeida, L.A. Dias, Risk-based management of occupational safety and health in the construction industry-part 1: background knowledge, *Saf. Sci.* 66 (2014) 75–86. <https://doi.org/10.1016/j.ssci.2014.02.008>
- [3] Z. Zhou, Y.M. Goh, Q. Li, Overview and analysis of safety management studies in the construction industry, *Saf. Sci.* 72 (2015) 337–350. <https://doi.org/10.1016/j.ssci.2014.10.006>
- [4] C.S. Shim, K.M. Lee, L.S. Kang, J. Hwang and Y. Kim, Three-dimensional information model-based bridge engineering in Korea, *Struct. Eng. Int.* 22 (2012) 8–13. <https://doi.org/10.2749/101686612X13216060212834>
- [5] British Standards Institution, BS ISO 45001:2018, Occupational health and safety management systems – Requirements with guidance for use, BSI Standards Publication, 2018.
- [6] L. Zhang, X. Wu, M.J. Skibniewski, J. Zhong, Y. Lu, Bayesian-network-based safety risk analysis in construction projects, *Reliab. Eng. Syst. Saf.* 131 (2014) 29–39. <https://doi.org/10.1016/j.res.2014.06.006>
- [7] G. Carter, S.D. Smith, Safety hazard identification on construction projects, *J. Constr. Eng. Manag.* 132 (2006) 197–205. [https://doi.org/10.1061/\(ASCE\)0733-9364\(2006\)132:2\(197\)](https://doi.org/10.1061/(ASCE)0733-9364(2006)132:2(197))
- [8] V. Getuli, S. Mastrolembo Ventura, P. Capone, A. Ciribini, BIM-based code checking for construction health and safety, *Proceedings of the CCC 2017, Primosten, Croatia*, 2017 <https://doi.org/10.1016/j.proeng.2017.07.224>
- [9] E.W.L. Cheng, H. Li, D.P. Fang, F. Xie, Construction safety management: an exploratory study from China, *Constr. Innov.* 4 (2004) 229–241.
- [10] M. Golparvar-Fard, F. Peña-Mora, C.A. Arboleda, S. Lee, Visualization of construction progress monitoring with 4D simulation model overlaid on time-lapsed photographs, *J. Comput. Civ. Eng.* 23 (2009) 391–404.
- [11] D. Shuang, Y. Qin, L. Heng, Positive safety participation and assessment by integrating sharing technology with virtual reality, *Proceedings of the CCC 2015, Krakov Poland*, 2015. <https://doi.org/10.1016/j.proeng.2015.10.069>
- [12] G. Hongling, Y. Yantao, Z. Weisheng, L. Yan, BIM and Safety Rules Based Automated Identification of Unsafe Design Factors in Construction, *Proceedings of the CCC 2016, Budapest Hungary* (2016), 586–591. <https://doi.org/10.1016/j.proeng.2016.11.646>
- [13] S. Zhang, K. Sulankivi, M. Kiviniemi, I. Romo, C.M. Eastman, J. Teizer, BIM-based fall hazard identification and prevention in construction safety planning, *Safety Sci.* 72 (2015) 31–45. <https://doi.org/10.1016/j.ssci.2014.08.001>
- [14] L. Zhang, X. Wu, L. Ding, M. J. Skibniewski, Y. Lu, Bim-Based Risk Identification System in tunnel construction, *J. of Civ. Eng. & Manag.* 22 (2016), 529–539. <https://doi.org/10.3846/13923730.2015.1023348>
- [15] K. Kim, Y. Chob, S. Zhang, Integrating work sequences and temporary structures into safety planning: Automated scaffolding-related safety hazard identification and prevention in BIM, *Aut. in Constr.* 70 (2016) 128–142. <https://doi.org/10.1016/j.autcon.2016.06.012>
- [16] H. Guo, Y. Yua, M. Skitmore, Visualization technology-based construction safety management: A review, *Aut. in Constr.* 73 (2017) 135–144.
- [17] J. Seo, S. Han, S. Lee, H. Kim, Computer vision techniques for construction safety and health monitoring, *Adv. Eng. Informatics* 29 (2015) 239–251. <https://doi.org/10.1016/j.aei.2015.02.001>
- [18] S. Zhang, J. Teizer, J.K Lee, C. Eastman and M. Venugopal, Building Information Modeling (BIM) and safety: Automatic safety checking of construction models and schedules, *Aut. in Constr.* 29 (2013) 183–195. <https://doi.org/10.1016/j.autcon.2012.05.006>