29 Visualisation of Risk Information in BIM to Support Risk Mitigation and Communication: Case Studies

Yang Zou, Lari Tuominen, Olli Seppänen, and Brian H. W. Guo

Abstract

In recent years, Building Information Modelling (BIM) has been attracting increasing research interest for construction project risk management. However, very few studies exist that explore how to manage and visualise risk information within BIM environment. To overcome this gap, this paper introduces a method that establishes an active link between risk data and BIM, and illustrates and tests the proposed linkage approach by using two case studies to gain a practical understanding on the existing technical limitations and future research opportunities. The first case describes the presentation of risk information as visual objects in a 3D BIM of a highway project in Finland. The second case discusses potential of integrating and visualising risk information into 4D BIM of a footbridge in the UK. Results show the proposed linkage approach could facilitate better communication of risks within multi-disciplinary team; understanding of exact locations of risks, and transparency of risk communication and information management.

Keywords

Building information modelling (BIM) • Risk management • Construction engineering and management

29.1 Introduction

Construction projects are exposed to various risks (e.g. financial, health and safety, cost, environmental related risks) during their project lifecycle and the importance of risk management for any projects has been recognised worldwide. To identify and mitigate any risks successfully, it is important to establish a common understanding and communicate the project and risk information throughout the multi-disciplinary project team before any adverse consequences of the risks come up [1]. However, in current practice risk information has not been communicated, used and recorded effectively. For example, 2D drawings only contain limited information but are often used as design and construction solutions by engineers for risk identification and communication [2]. In addition, risk register as a master document containing information about identified risks and corresponding mitigation solutions is created at an early stage of a project but often has no linkage to the design and construction solution [3, 4].

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Building Information Modelling (BIM) is a new technology in the construction industry that refers to the process of generation and management of digital representations of physical and functional characteristics of a building, and in recent years it has been attracting increasing research interest for project risk management [2–4]. The main advantage of integrating BIM with risk management are twofold. Firstly, the visualisation features of BIM enable the project team to identify foreseeable risks and discuss possible solutions based on a better understanding of the project details, construction activities and sequences [5]. Visualising risks in 3D/4D BIM will help distribute knowledge of risks as widely as possible. Secondly, BIM is a shared data platform and repository serving the lifecycle of a project, and can be extended for risk information analysis and management [6]. However, very few studies [4, 7, 8] exist that can explain how to manage and visualise risk information within BIM environment and what benefits can be achieved.

To overcome this gap, this paper presents a method that stores risk information in a separated database and establishes an active link between risk data and 3D/4D BIM. The method is examined in two case studies—a highway project in Finland and a bridge project in UK—to gain a qualitative understanding on the existing technical limitations. Based on the proposed method and case studies, the paper also discovers a number of new research topics and opportunities.

29.2 Literature Review

29.2.1 BIM-Based Risk Management Research

Risk is an event that has either positive or negative impacts on the set goals [9]. In recent years, risks in construction projects have gradually increased due to the complexity of the structures and the size of the project, as well as the introduction of new and difficult building methods. There is a wide scale of project risks such as structural, construction, health and safety, financial and environmental risks. As a result, all project participants need to improve their ability, knowledge and experience to manage the risks throughout the project lifecycle to ensure a safe, successful and sustainable project [10]. Risk management is critical to the success of any construction projects and current risk management methods are highly dependent on multidisciplinary knowledge and experience [8]. In recent years, the use of information modelling has grown rapidly. It provides potential for cooperation and communication, improving productivity and quality, reducing project cost and implementation time [11]. A data-based collaboration and communication environment could facilitate early identification and reduction of risks [12, 13].

Several studies [5, 14–16] have shown challenges in current risk management methods that are largely dependent on experience and multidisciplinary knowledge. BIM has become a systematic method and process that changes the presentation of the project [17], design [18], and communication [19]. Many publications utilize BIM as a tool for managing project risks, related to design errors, occupational safety, quality and budget, but they often do not refer directly to the concept of risk management. Risk management will play a more valuable role when project participants start using these latest technologies as part of their daily work. Most current BIM-based risk management efforts are technology-driven. Only a few studies (e.g. [10, 14]) show how new technologies, traditional risk management methods and processes can be integrated systematically and efficiently into information-based risk management.

29.2.2 Highlighting Risks in 3D BIM

Research about the presentation of risks or hazards in BIM is often focused on occupational safety. Virtual reality (VR), 4D CAD, BIM, sensitivity/warning technologies or their combinations are often used to manage hazards and prevent accidents [14, 20]. According to a study by Enshassi et al. [21], BIM is currently one of the best available application tools to improve workers safety in the building industry. Fall hazards can be checked against computer readable algorithms and visualized objects of risk can be automatically generated in BIM [22]. The benefits of BIM on site safety were already reported in 2009, including safety planning, identification of hazards and risk assessment, work guidance and information on topical work, dangers and security arrangements [23]. Visualisation of safety risks enables designers and engineers to better understand the importance of 'Design for Safety' (or 'Safety in Design' and 'Prevention through Design').

The most recent observation is the Publically Available Specification (PAS) 1192-6 standard issued by the British Standards Institute in February 2018 [24]. The PAS defines the requirements for sharing work safety information throughout the project lifecycle. Its appendix "Representation of risk information" contains examples of how to store the risk information in the element attribute and visualize hazards using the objects in the BIM. According to this PAS, visualisations should be used to emphasize the elevated risks.

29.2.3 Promoting Risk Visualisation in 4D BIM

Four-dimensional (4D) model is an important concept of BIM, where the fourth dimension refers to the time- and schedule-related information [25]. Risks in construction are highly relevant to particular tasks or activities, and visualising risk information in 4D BIM throughout the construction process could effectively facilitate the understanding and communication of what and when any risks may come to place. It is also an effective way to help recall previous knowledge and experience for identifying and mitigating potential risks [4, 26, 27]. For example, Sacks et al. [28] proposed a model that informs risk levels of each floor of a building in a 4D animation using different colours to help plan and filter tasks for safety risks. In order to facilitate the risk identification and communication process in 3D/4D BIM, Zou et al. [4, 8] developed a framework that integrates a project's Risk Breakdown Structure and Work Breakdown Structure into BIM environment. In addition, Ding et al. [7] successfully implemented linking risk knowledge and information to BIM objects in 4D in a tunnel project to support its risk mitigation and communication.

29.3 Method and Case Studies

29.3.1 The Proposed Linkage Approach

To enable the visualisation and management of risk information in BIM, this paper proposes a method that stores risk information in an external database and establishes an active link between the risk data and BIM. Specifically, 3D/4D BIM can provide a visual information-rich environment for the multi-disciplinary team to understand and communicate the project goals, construction logics, and potential risks, etc. A user interface within 3D BIM environment can be established to help end users to input and manipulate risk data. The risk data is then stored in an external database, which, at the same time linked to BIM objects and construction schedule. Integrating the risk information needed into 3D BIM will help the project team to extract their best knowledge and experience to communicate the potential risks in a visualised 3D environment. Risk data can be then further visualised and highlighted in 4D BIM. The following two sections will present two case studies of implementing this method, and the next chapter will connect recent literature and technologies to discuss benefits and technical obstacles summarised from the two case studies, and a number of promising research directions in this area.

29.3.2 Case Study 1: Managing Risks in 3D Highway BIM

A highway project in Finland, called E18 Kausela-Kirismäki was selected as the first case study. The use of BIM in risk management was based on experiences from the Finnish Transport Agency in two railway projects in 2016. The experiences were positive, and all project partners realized that BIM improved the risk management. In those two railway projects, however, there was no link between the risk database and the BIM models. Instead, data were manually transferred to the BIM as objects. As a result, the workload was big and the implementation was time-consuming. In this case study, a link was created between the risk information and the BIM and hence the previous workload issues were largely resolved. The main purpose was to explore the benefits of presenting risk information as visual objects in a BIM model and identify the practical challenges related to implementation.

The project is located a one and half hour drive away from Helsinki to the west. The state-owned road section called E18 Kausela-Kirismäki is 9 km long and improvement work will be carried out during years 2018-2021. The road section is part of the international TEN-T Scandinavian-Mediterranean core corridor. The project involves a four-lane TEN-T road. Construction costs are estimated at about EUR 65 million.

Implementing risk assessment and modelling was done by Finnmap Infra Company. The company developed a plugin for Bentley PowerCivil software that transfers information between the modelling software and the risk database which is described in Fig. 29.1. A total number of 41 project risks were identified and added to the risk database, and 20 of these risks could be located and identified with a visual object in the BIM. The plugin retrieves the risk information from the database based on the risk number on the user's screen so that the user can also update the information via the plugin.

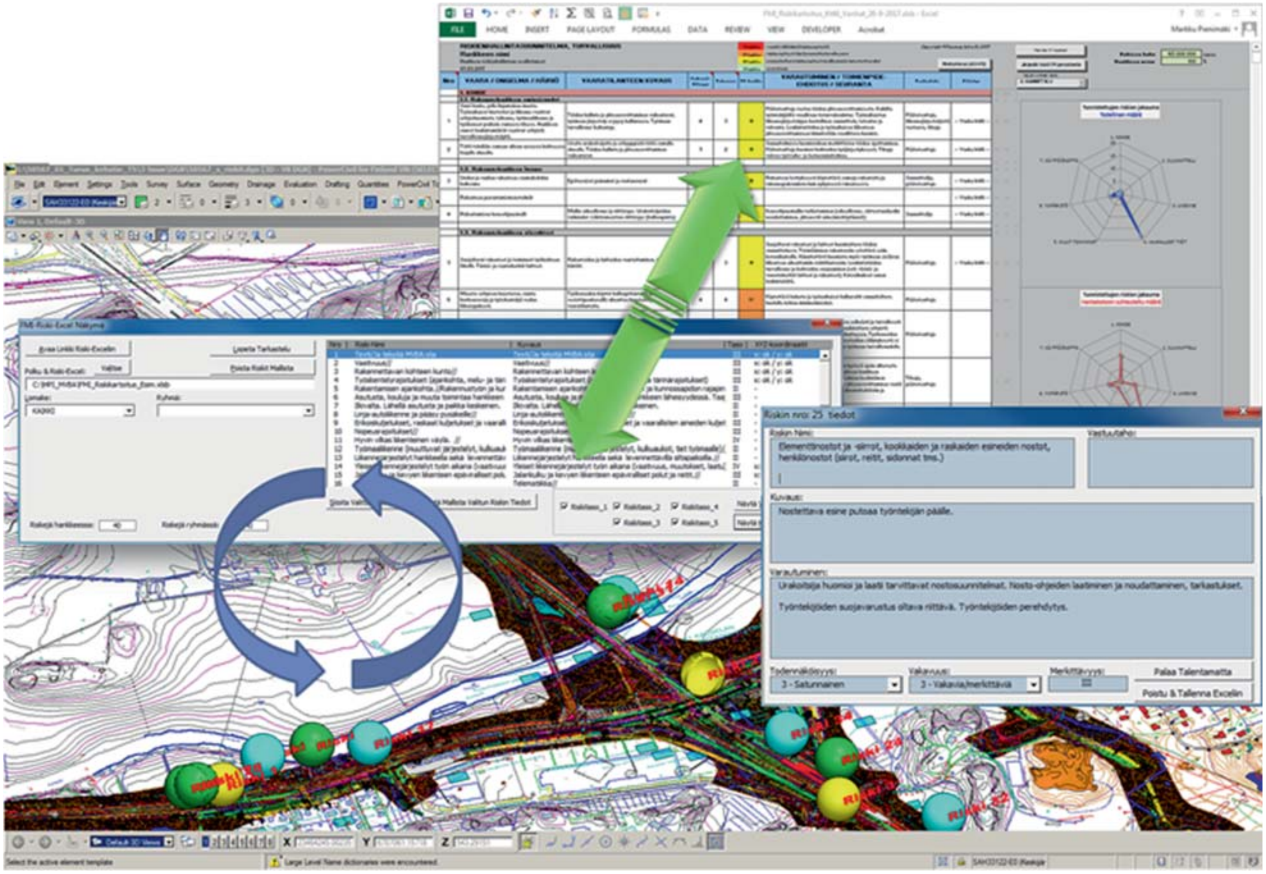

Fig. 29.1 Plugin communicates between the design software and the risk database

The targeted risks were described in the BIM with a vector-type ball object. The shape of the balls was designed based on a simple rule to assist easy risk visualisation and model producing. The colour of the ball was determined by the classification of each risk. The classification and colour scheme are based on guidelines issued by the national Finnish Transport Agency. Additionally, the plugin adds a text object to the ball object, where the number of the targeted risk is described. This way, the information model can be used to read the risk locations and risk number information on other design platforms as well without plugins (Fig. 29.2).

Most of the project risks were distributed over the whole project. However, in some cases, the locations of the risks were very close together. Closed ball objects almost overlap if two or more risks are closely related to each other. This may cause challenges for users to read. The factors affecting this are the size and shape of the object. With a smaller object, the information is more readable, but it is more difficult to notice when viewed from a large perspective. If the three-dimensional object consists only planar surfaces, then the locally accumulating information can be more readable.

It was observed from this study visualising risks in 3D BIM can facilitate the risk identification process. Previously, the risk location was not accurately defined and a risk management expert needed to analyse all risks in order to locate it in a specific location of the BIM. Around half of the location-based risks had more than one location associated with them. The most frequently repeated risk occurred in ten different locations in BIM. But this case study did not investigate how risks that are non-location-based in nature can be taken into account in the project. In the next project phase, BIM will provide a visual overview of the risks of the project to the new project team. The risks information can be easily transferred from one phase and team to another.

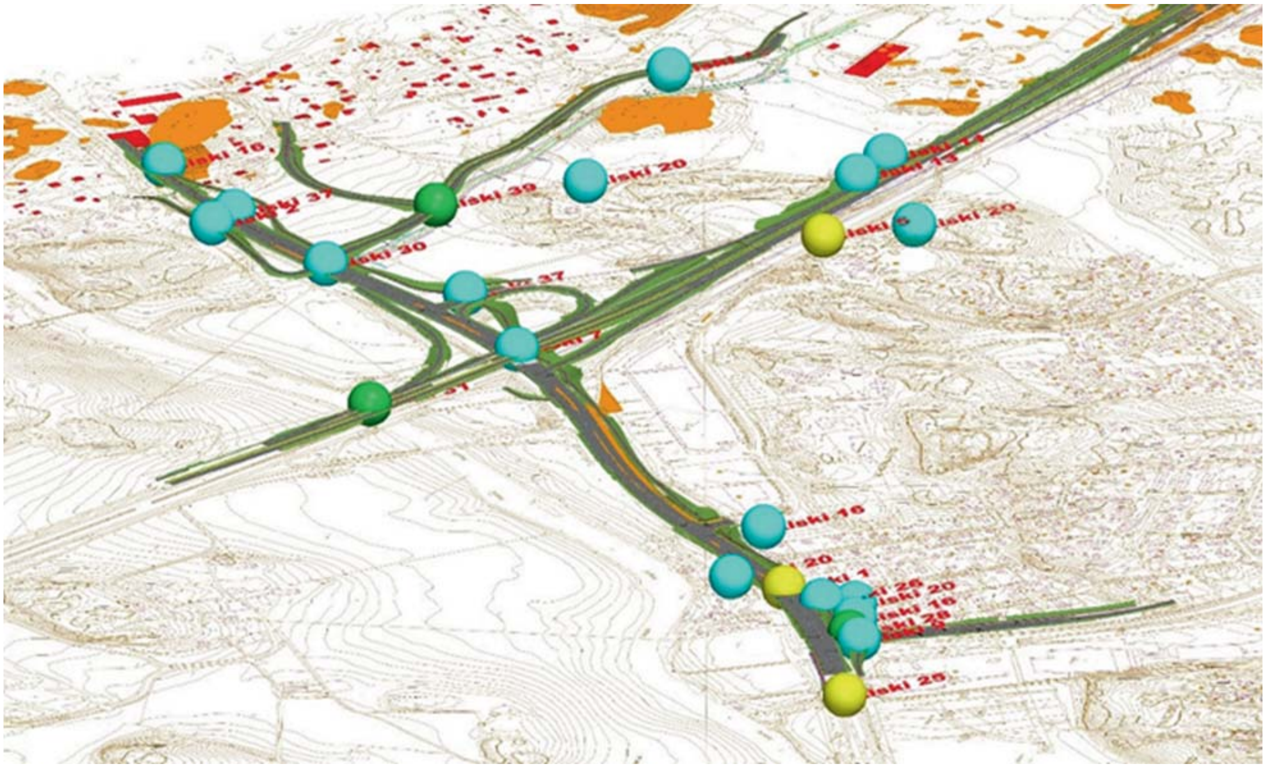

Fig. 29.2 Visualised risks of the E 18 Kausela-Kirismäki project

29.3.3 Case Study 2: Visualising Risks in 4D Steel Bridge BIM

A footbridge named Dunmow Footbridge was selected as the second case. This bridge has a span of 56 m and is a steel tied-arch bridge spanning over the M60 motorway in the UK. The bridge has been completed in 2004 as part of a large motorway widening project and there is no existing 3D graphical model available.

The purpose of this case is to examine the feasibility, benefits and technical obstacles of integrating and visualising risk data into 4D BIM. Autodesk Navisworks 2017 was selected as the main BIM platform for implementation, and a plugin was developed within Navisworks environment to help users to input and manipulate risk data and link risk data to BIM objects and construction activities, where risk data is stored in Microsoft SQL Server database.

In the initial stage, a set of construction drawings were obtained and a 3D BIM was created manually by using Autodesk Revit 2016. The Revit model was then exported to Navisworks as a 3D BIM and the construction schedule information of the bridge was brought into Navisworks to develop the 4D model. The construction of this bridge consists of three main processes: (1) on-site fabrication of the arch and deck, (2) construction of the bridge abutments, and (3) move and installation of the bridge structure.

With the 3D/4D BIM, several industry experts were invited to review the project, its surroundings, and construction schedule in the computer-based virtual environment, and a number of risks were identified associated with their affected construction activities. Risk information was manually input into 3D/4D BIM through using the proposed plugin tool. In this process, each risk's information was stored in the database and a link was established between the risk data and BIM. By taking the on-site fabrication of the arch and deck as an example, three risks relating to time, personnel safety and the structure respectively were identified according to the authors' and invited experts' experience. As the risks had been linked to their affected construction phases in the data input stage, they were then visualised in 4D scheduling (see Fig. 29.3). Specifically, risk information were linked to existing objects or new risk objects. For those risks (e.g. time-related) that are not easily linked to any objects, they were summarised in a popped up tabular form.

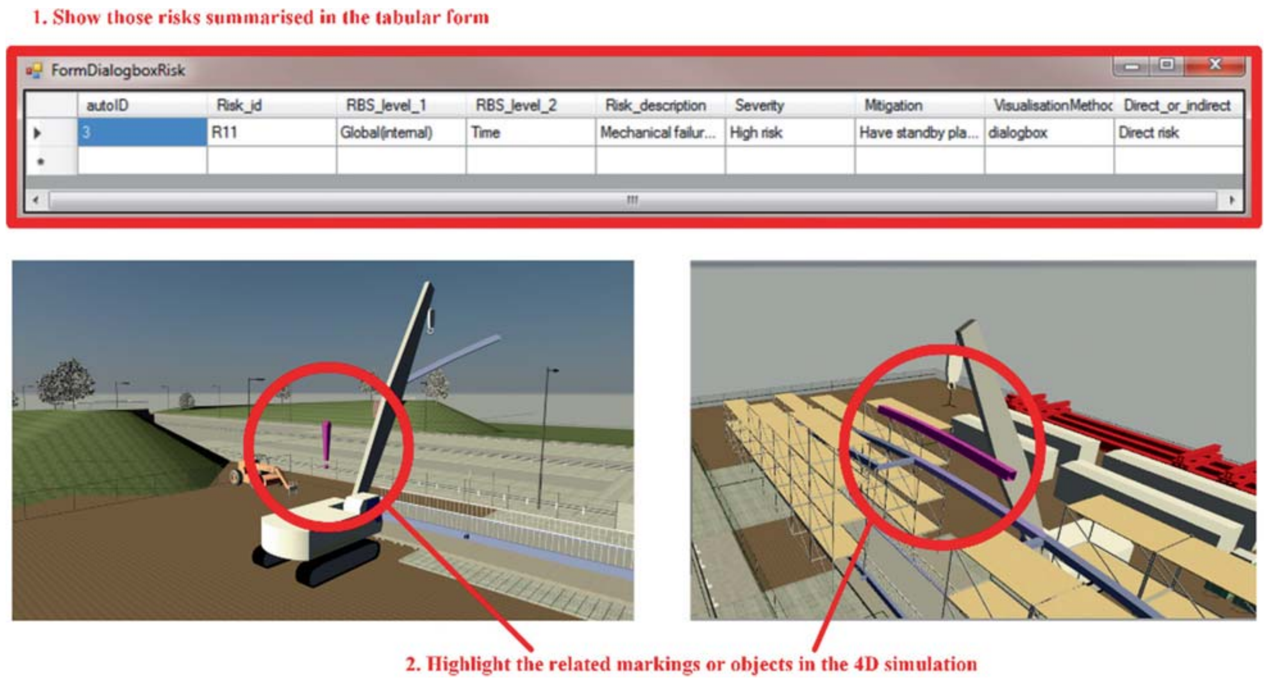

Fig. 29.3 Examples of visualising different types of risk in 4D BIM

29.4 Discussion and Conclusion

This paper presents a method for risk information management in BIM that a linkage can be established between risk data and 3D/4D BIM. It further illustrated and tested the proposed approach through using two case studies. To better understand the benefits and challenges of the proposed approach, this paper conducted a SWOT (Strengths, Weaknesses Opportunities, Threats) analysis on the case studies and its results are presented in Fig. 29.4. Specifically, main strengths of the linkage approach include, for example: (1) risk information can be visualised and highlighted in 3D BIM environment and 4D animation for better communication of risks within multi-disciplinary team; (2) visualising risks in BIM could facilitate the understanding of exact locations of risks, (3) it facilitates the concept of identifying risks at an early stage and improves the transparency of risk communication and information management. The main weakness observed from the two case studies is the lack of a well-accepted method for visualising different types of risk in BIM. For example, some structural risks can be linked to structural elements directly; however, some other types of risks such as potential coordination risks between different design teams are not object-dependent and therefore difficult to be linked to any BIM objects. To overcome this weakness, the next step of this research will investigate the use of applied semiotic to develop a general method or framework for risk signs in BIM [29]. Future opportunities of the proposed method include: (1) the quality of risk management will be improved, (2) risk documentation can be enhanced, and (3) risk management can be facilitated to support the development process of a project. The main threat behind the proposed method is currently there is a lack of method that can update linkage when BIM models are progressing. For example, when a BIM is transferred from one platform to another platform, the established linkages are not transferred.

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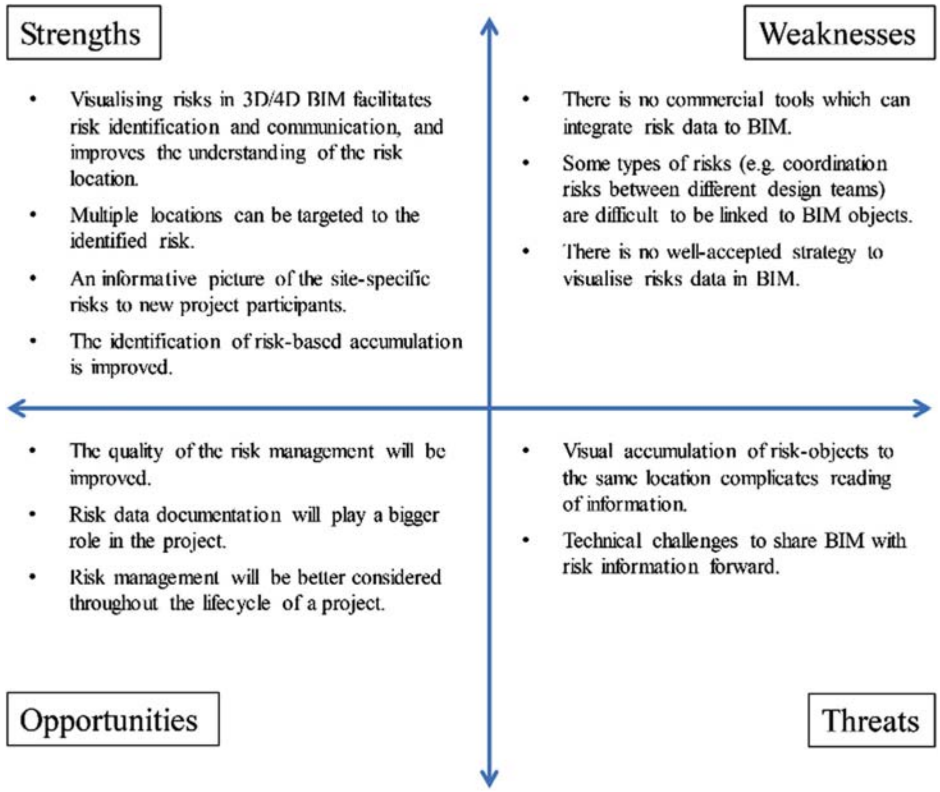

Fig. 29.4 SWOT analysis results

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