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METHODS AND TOOLS USED FOR MANAGEMENT OF GEOTECHNICAL RISKS IN CONSTRUCTION PROJECTS

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Decisions taken in the process of organizing and managing construction structures pose various risks and can adversely affect people's lives. Geotechnical risks constitute a large part of the risks of construction projects. Technical problems related to soil characteristics can lead to delays in the schedule and cost overruns in the budget of the projects. Geotechnical risks with the potential to cause major damage to projects must ultimately be prevented before they happen. Recently, many technological tools are available to use strategically for the management of such risks. The integration of various numerical methods with different technological tools might be effective for this purpose. The use of the right method or tool will greatly contribute to geotechnical risk management. Since the management of these risks can directly and/or indirectly affect the work program, the healthy progress of the project depends on the adoption of correct risk management approaches and strategies. With the aim of o determine the effect of technological tools in the management of geotechnical risks in this study, literature review about the management of geotechnical risks in construction projects was examined, and the methods used were compiled. The results of this study are expected to be a guide in terms of introducing technological tools to practitioners in the sector and improving risk management in their course.

Keywords: Geo-risk management, Risk assessment, Project administration, Systematic literature review.

1 INTRODUCTION

Every construction project, regardless of its size, includes various risks. Risk management in construction projects is a process that needs to be carefully managed by the relevant experts due to factors such as determining the project budget accurately, ensuring the desired quality of the project, and completing the project on time. But even with expert planning, projects in the construction phase of the lifecycle always fail to meet planning, budget, and schedule estimates. Especially for megaprojects, excessive contingency allocations, reduced scope, low-quality work, missed schedule and cost targets and stressed contractors have become normal. Therefore, proper management of material, energy, information, and documentation flows is essential. These multiple aspects pose the problem of the implementation of interoperability tools between the actors and the overall risk management (Benachenhou *et al.* 2016). In building projects, risks come from unpredictable failures. And one of the most unpredictable failures in construction projects is geotechnical hazards. That is why, while leading Project Risk Management (PRM), Geotechnical Risk Management (GRM) can be more focused on. The geotechnical part is the crucial point in the projects as significant design and construction risks are inextricably linked to a geological

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setting. What is more, as it is known, because of the incomplete knowledge of subgrade layers and their properties, soil uncertainty is frequently a significant predictor of project uncertainty (Van Staveren 2013). There is a lot of evidence in the literature that projects should focus more on GRM. As an illustration, in the Dutch construction sector, hazard expenses account for about 10% of the industry's total revenue, approximately 5 billion euros linked to failure costs. Assuming 20% of failure costs are attributed to geotechnical conditions, the estimated annual geotechnical failure cost is around 1 billion euros solely in the Netherlands (Van Staveren 2018). Another example is, as stated by the US National Committee on Tunnelling Technology, inadequate site investigations lead to various site conditions states averaging 28% of the total contract price (Smith 1996). Hence, there are plenty of justifications for the field of construction engineering to be more meticulous about their risk management, especially in GRM practices, particularly considering their presence in the current era of worldwide crises, such as climate, economic challenges, and others. Exploration of GRM should take place throughout the entire project, not only at the very beginning. Also, Geotechnical Reports must be examined by not only related engineers, but also construction management team, contractor, even by senior management. The purpose of the study is to compile the geotechnical risks that are likely to be encountered in construction projects, to determine the current-technological tools used in the determination and prevention of these risks by literature review and to present them to the relevant experts. It will be emphasized that GRM is an issue that needs to be more focused on in construction projects. Thus, it can be managed more ideally, and solution proposals can be revealed in a shorter time.

2 METHODOLOGY

This research employs a comprehensive literature review to investigate the utilization of technological tools, including established and state-of-the-art ones, for geotechnical risk management. The primary objectives are to examine their impact on project management as a whole and project risk management specifically, in the context of geotechnical risk management practices. The primary purpose was to reach as many related studies as possible in academic papers such as articles, books, conference proceedings etc. Scopus was selected for literature review since it is one of the largest and most reputable academic search engines. The references of the identified studies were scrutinized using the snowball sampling approach to ensure the inclusion of pertinent documents relevant to the study area, and the necessary studies were also included in the review. Since new studies are likely to cite at least one paper from the prior relevant studies already carried out in the subject field, snowballing is useful for extending literature studies (Wohlin 2014). Different research was done with two different word combinations in Scopus. The first was specific to “tools” to identify and deal with geotechnical risks, and the second was a GRM survey in general in “project management”, to assess which tools identified in the first search were also applicable and influential in the broader context of project management, thereby assessing their overall impact on project outcomes. In the first combination of codes, the following were provided: (1) "geotechnical risk management," however, "geotechnical risk assessment" and "geotechnical disputes" were also used as synonyms to explore additional studies related in the literature; (2) "construction industry" was initially used to focus on the industry, but it was later modified to "construction" to ensure inclusivity of related studies; and (3) "tools" was used in the last code, however snowballing also led to the inclusion of "methods", "digital" and, "technology". The analysis steps of the research are illustrated in Figure 1.

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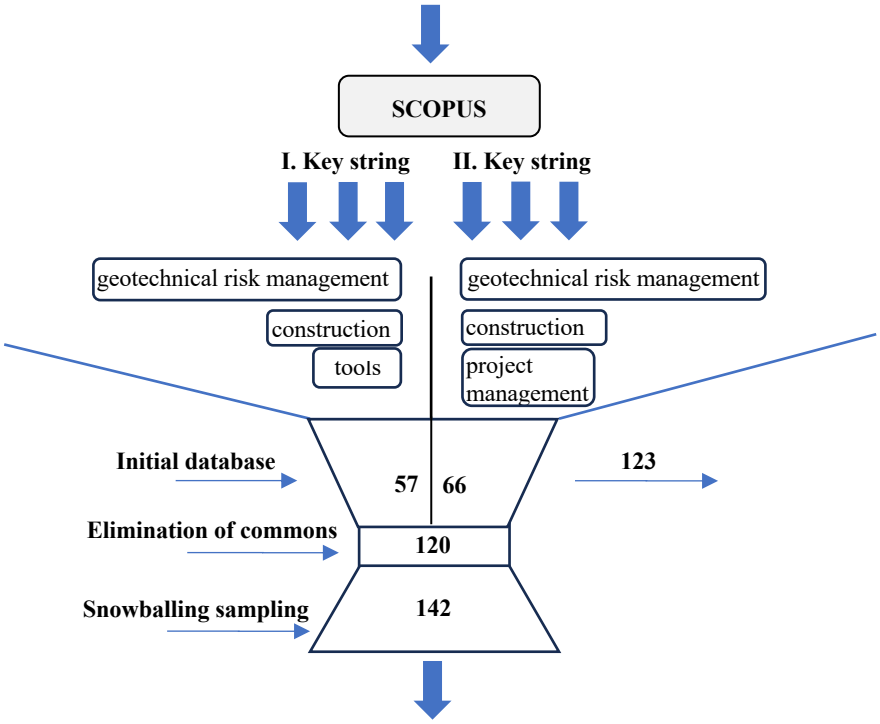


Figure 1. Flowchart of the methodology.

From two query strings containing geotechnical risk management, construction, and tools keywords, a total of 57 studies (research articles, reviews, books, etc.) were found in the first search and 66 studies in the second search. Among these, three articles were common to both searches. Non-English articles were superficially examined through translations. The investigations focused exclusively on geotechnical risk management and tools, following two inclusion criteria: (1) articles aiming to prevent and/or minimize geotechnical risks, and (2) articles implementing technological tools for managing geotechnical risks. In total, 142 papers were used for comprehensive content analysis.

3 FINDINGS AND DISCUSSION

After evaluating 142 academic studies, 17 geotechnical risks were identified, along with 14 specific technological tools. Table 1 shows the number of studies mentioning geotechnical risks (64 out of 142), and 26 studies specified the risks in detail. Water-related issues, such as groundwater rise and sewer overflows, emerged as the most common geotechnical risks. On the other hand, geotechnical risks like complexity, weak layers, deformations in foundations, soil permeability, and soil nail stability were mentioned the least. Table 2 lists the 14 technological tools mentioned in the studies, with modeling software being the most frequently used for addressing geotechnical risks. Interestingly, project management software like machine learning, image capture technologies, and resource planning software were also found to have applications in geotechnical risk mitigation. Table 3 summarizes definitions of technological tools, their associated geotechnical risks, and their contributions to risk mitigation. The impact of resolving these risks on the project process is also listed.

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Table 1. The frequency of geotechnical risks.

	Geotechnical Risks	Frequency
1	Water Problems (High Groundwater Level)	28
2	Landslide	23
3	Settlement	19
4	Uncertainties	16
5	Slope	13
6	Collapse (Cave in collapse)	7
7	Liquefaction	5
8	Seepage & Leakage	5
9	Shear Strengh	4
10	Loss of Bearing Capacity	3
11	Swelling/Shrinking	3
12	Unknowns	3
13	Complexity	1
14	Discontinuity (weak layers)	1
15	Deformations	1
16	Permeability	1
17	Soil Nail Stability	1

GRM must be well-integrated within PRM. A complete GRM application that is integrated with PRM, seems not yet common practice in a lot of projects and countries (Van Staveren 2014). The integration of construction components should be seamless, ensuring transparent connections and the harmonization of their borders, while considering them as interdependent constituents of a cohesive whole. In projects embracing a holistic approach, geotechnical risk management can be effectively incorporated within the framework of project risk management.

Table 2. The frequency of technological tools.

	Technological Tools	Frequency
1	Modeling Design / Analysis Software (Plaxis, K-REA, etc.)	20
2	Machine learning/ Artificial intelligence	8
3	Image capture technologies: Laser scanning, LIDAR/LADAR	7
4	Spatial technologies: GIS (Geographic Information System), etc.	6
5	BIM	6
6	Fuzzy Logic	5
7	Augmented reality / Virtual reality / Mixed reality	5
8	Internet of things (IoT)	5
9	Robotic applications	4
10	Mobile apps for phone / tablet	3
11	Optimization Methods	1
12	Cloud computing technologies	1
13	Wearable technology (ECG/EKG sensors, UV light sensor)	1
14	Resource Planning& Data Management Tools (ERP, SAP)	1

Efficient use of tools for design, simulation and data management is linked to the quality of preparation of project, also quality of the risk management (Šedivý *et al.* 2013). Identifying risks and properly managing them are two different stages (Van Staveren 2013). The selection of the tools that will be used will allow stakeholders to have a smooth and effective transition between these stages.

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Table 3. The effects of technological tools based on geotechnical risk within the scope of the project.

Tech. Tool	Definition	Geotechnical Risk	How tools are used	Effects to project
Modeling/Analysis Software (Plaxis, K-REA, etc)	used for calculations such as deformation and stability analyze, building damage due to tunneling	• seepage, slope stability, pile stability, rising groundwater, ground freezing etc.	• analyzing the, determined data, interface forces • can be combined with other software	• 3D modelling in the design phase • choose the correct materials • right cost guess
Machine learning	utilizes data and algorithms to mimic human learning and make predictions.	• inconsistency of geotechnical data	• classifications regressions such as Random Forest	• helps managing and control risks for the benefit of stakeholders
Image capture technologies: Laser scanning -radar, LIDAR/LADAR	lead the charge with visualizations available of the built environment	• rock slope, landslide, difficult site settings	• 3D scanning and mapping • use advanced geophysical methods	• enrich geospatial dataset, study on geotech. features in planning phase
Spatial technologies: GIS, etc.	are for environmental data analysis and planning.	• uncertain ground conditions • high slope • landslide	• is composed of database, editing, query, display module • storing, searching	• can be displayed during execution • site decision in planning phase
BIM	provides support for various phases of workflows such as initial design, detailing, documentation, etc.	• changes in soil moisture content due to heavy rainfall • inappropriate management of geotechnical data	• focuses geotechnical data management with BIM for precise project decision-making.	• compares the dynamic model to the physical asset • efficient construction processes
Fuzzy Logic	permits to model uncertainties related to accident databases and the randomness due to environmental natural, engineering, or time changes.	• critical slip surfaces • slope-stability • estimation of parameters (gas, dust, geotechnical hazard, etc.)	• evaluates a deterministic model using sets of random numbers as inputs • uses expert opinions for quantifying the probabilities	• fast and accurate planning phase, controllable throughout execution • long-term cost reduction
Augmented/Virtual/ Mixed reality	IT-based concepts that virtualize objects are blended with real images to test multiple scenarios	• geotechnical uncertainty	• with AR, 4D BIMs compare status of construction site with its intended state	• timely delivery of accurate and robust digital data in project Initiation Phase
Internet of things (IoT)	is applied to various fields of work and life, for example, use of the IoT and road traffic & smart city.	• pile stability	• describes networked physical objects with sensors, software, and gadgets.	• ensures production within transparent control phases and allowable limits
Robotic applications	vehicles such as, aerial vehicle, 3D printer to reduce labor	• inaccurate positioning of underground assets	• map tunnels and transfer the data collected into engineering systems	• accurate, fast project flow • collect hundreds of data per second
Mobile apps for phone / tablet	facilitate site visits and mobile work completion.	• seepage, slope and pile stability, ground freezing	• viewing project and foundation plans	• 24/7 software support, prevent time loss.
Optimization Methods	find solutions that maximize or minimize parameters	• slope stability	• deterministic and probabilistic approaches	• fast workflow, well- prepared planning stage
Cloud computing technologies	web-based applications do not require installation	• rock burst • uncertain geotechnical data	• transfer the hazard estimation index to the concept of cloud	• eliminates the uncertainty in planning, design

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Table 3 (contd)

Tech. Tool	Definition	Geotechnical Risk	How tools are used	Effects to project
Wearable technologies (ECG, EKG sensors, etc.)	monitor bodily postures of workers to tracking accuracy in collaboration tasks	• hydrous sandstone for geotechnical engineers' safety • collapse	• inertial measurement unit bonded to a subject collects dynamic data	• indirectly informs about geotechnical data • reduce accidents
Resource Planning, Data Management	electronic document management systems	• unknown geophysical area • complicated data	• secure, organized, up-to-date documents • accessible anytime	• supervision, monitoring, quality assurance

4 CONCLUSION

The geotechnical parts of the building projects exhibit distinct characteristics owing to their elevated risk of encountering exceptional situations such as the rise of groundwater, landslides, loss of bearing capacity, etc. Such situations may stem from uncertain soil hydrogeological properties to weak ground conditions. Therefore, it is vital for the industry to grasp technological innovations, history, challenges, and risks for future applications. Existing literature often downplays geotechnical risks, and when they do arise, mitigation measures are adopted. Nonetheless, the significant impacts of these risks, including time and cost implications on project management, are now gaining prominence. The main issue here is not a lack of knowledge or resources for solutions, but rather a failure to effectively manage risks. As a result of the study, it was emphasized that there is a serious technical problem on water, landslides, settlement, and uncertainties. Findings indicate the extensive use of known geotechnical software models in managing risks. However, it is evident that resource management tools can also effectively address these risks. Academic research has been conducted to support this, and the number of studies has increased recently. Notably, the successful integration of different technologies plays a crucial role in proper risk management. Project managers, stakeholders, field engineers, and design departments should take these factors into account. Embracing industry 4.0 technologies is vital for accurate risk management.

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