A Mathematical Model to Predict Optimal Risk Response Budget using Genetic Algorithm

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Received: 23 March 2024 | Revised: 11 April 2024 | Accepted: 17 April 2024

ABSTRACT

Construction projects encounter a variety of risks, which require a thorough risk response phase to identify, evaluate, and determine solutions. This study presents a methodology for effectively choosing an appropriate risk response strategy and allocating suitable funds for the risk response phase of building projects. The framework employs optimization approaches and evolutionary principles, specifically utilizing the Genetic Algorithm technique. The objective of the model is to reduce costs and determine a suitable fund allocation strategy with minimum risk. The effectiveness of the framework is assessed in an actual building project involving a ventilation and air conditioning system, demonstrating its ability to optimize risk response and assist decision-makers in making well-informed choices.

Keywords-risk management; risk response; optimization model; genetic algorithm

I. INTRODUCTION

A project is a series of activities with defined objectives, managed effectively through planning, directing, and controlling resources [1]. Each project inherently carries potential risks, and a crucial responsibility of project management is to reduce or eradicate these risks. Project risks refer to unpredictable occurrences that have the potential to affect project goals [2-5]. The latest developments in construction projects have resulted in higher complexities and possible threats. The complexity of risk analysis and assessment is increasing, with a greater emphasis on understanding the interrelationships between threats and the project environment. Frequently, enhancements fail to consider the risk attributes and interconnections, the complicated details of the project, and the experience of the management team. The evaluation of project complexity involves assessing the level of differentiation, dependency, and impact on decision-making within the various components of the project. Project complexity arises from the integration of individuals from diverse organizations and the utilization of various technological combinations. The complexity of a project is directly correlated with the level of uncertainty associated with its components [6-8].

Risk Management (RM) is a crucial knowledge area addressed by the Project Management Institute (PMI), enhancing construction project management and resource efficiency. RM is a methodical process that identifies, analyzes, and responds to risks, minimizing adverse effects and maximizing positive impacts. It is applied in various fields like safety, enterprise management, environment, and health. RM consists of four major phases: risk identification, risk assessment and analysis, risk response planning, and risk monitoring and control. It is essential for recording risks and managing them for future projects [9-13]. The Risk Response (RR) stage is a crucial part of RM, involving developing a plan, proposing responses, and determining treatments for each risk event to minimize risk occurrence and negative impacts, maximize opportunities, and achieve project objectives [14-15]. The research on risks affiliated with construction projects frequently prioritizes identification and assessment, while overlooking the risk response phase. This stage encompasses the formulation of plans, the identification of solutions, and the determination of treatments for each risk occurrence. The main objective of RR is to mitigate risks and their adverse consequences, optimize opportunities, and accomplish project goals by reducing negative results [4].

Through the years, many techniques and instruments have been created to assist project managers. One of the techniques available is the Genetic Algorithm (GA) [16, 17]. GA is an evolutionary algorithm that utilizes crossover, selection, and mutation procedures. They are employed in construction endeavors to manage intricate, multi-modal, and distinct assignments and optimize project management. The process of selection is responsible for driving natural selection, whereas the process of crossover involves dividing a parent string into segments and exchanging them with corresponding segments. Mutation is responsible for maintaining genetic variation within a population. GAs possess several benefits, including straightforward conceptual understanding, wide-ranging applicability, the capacity to be combined with various methodologies, resilience to dynamic alterations, and adaptability. In addition, they do not enforce mathematical prerequisites on optimization problems, enabling them to address non-linear challenges in continuous, hybrid, or limited search domains [18-19].

The objective of this research is to construct a mathematical model that can identify efficient strategies for managing risks in construction projects. Additionally, the model will be used to predict the expected budget for risk response and employ the GA to find it.

II. RESEARCH METHODOLOGY

The research technique comprises two discrete components: theoretical and practical. The theoretical component entails a comprehensive examination of risk and RR, along with an evaluation of relevant prior research on these subjects. The practical component involves the construction of a mathematical model, the collection of data, and the execution of the model using the GA to accomplish the intended research objective. These two components are crucial for achieving the research purpose, which is to predict a suitable RR budget to assist decision makers in their responsibilities (Figure 1).

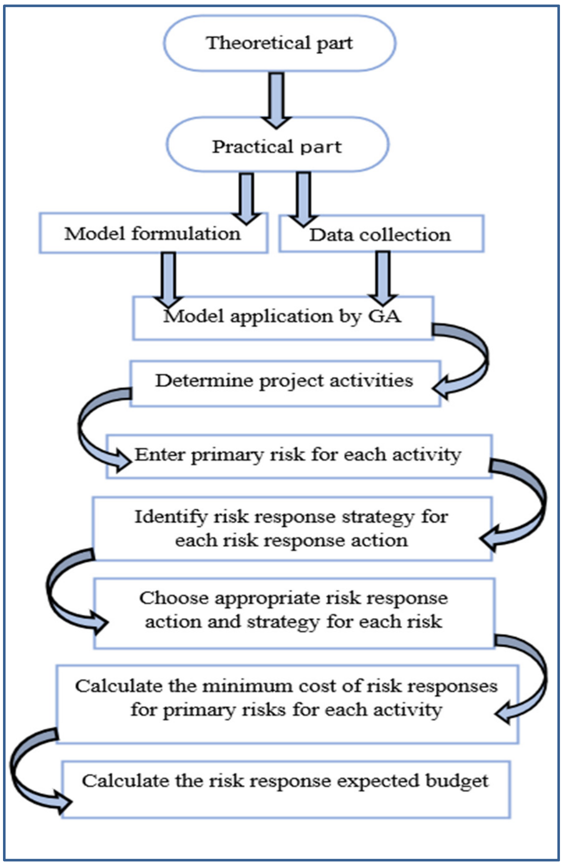

Fig. 1. Research methodology.

III. LITERATURE REVIEW

This study’s objective is to examine, comprehend, plan, and create a suitable approach for managing risks in different project categories. Optimization modeling approaches have been extensively deployed to provide various models for efficiently managing RR plans in construction projects [20]. Authors in [1] categorized the RR strategies into preventive and adaptive ones, taking into account factors, such as the controllability of the risk, the cost of the response, and the features of the project. A mathematical model was devised to assist managers in selecting cost-effective solutions for mitigating risks. A mathematical model was formulated in [21] to address the issue of scheduling a project in the presence of risk. The model consists of two goal functions: (1) minimizing the predicted makespan and (2) minimizing the projected overall cost. The study indicated that GA was a rapid and efficient strategy that could be utilized.in solving this problem. Authors in [22] employed a matrix-based methodology to effectively handle risk interactions and risk networks. They formulated an optimization problem and utilized the GA to discern pivotal places that contribute to project delays. The study determined that the presence of uncertainty regarding important tasks does not necessitate their inclusion on the critical path. Moreover, the effectiveness of the algorithm was mostly influenced by the complications of the project rather than the quantity of tasks.

Authors in [23] developed a model that uses multi-objective and Binary Integer Programming (BIP) to select suitable solutions for risk events in projects, with a particular focus on risk interactions. The Saba tower project was the case study of this paper and delay and failure costs were minimized whereas the efficiency of the project was maximized. A mathematical model was developed in [24] to quantitatively evaluate the effectiveness of RRs. The efficacy of each solution was determined by utilizing the probability distribution of the number of days of delay after implementing RRs. Authors in [25] introduced an approach which employs multiple objectives and BIP to choose appropriate reactions to risks with the goal of maximizing their measurable effects. Authors in [26] presented a study with three stages: (1) Identifying risks, responses, and their interrelationships, (2) assessing the importance of risks and responses employing the Analytical Network Process (ANP), decision-making trial and evaluation laboratory (DEMATEL), and Fuzzy theory, as well as (3) utilizing BIP. The framework proposed in [27] analyzes the influence of risks on the objectives of the projects, the interaction among threats, and the criteria and characteristics of managing risks. The proposed model is an optimization framework designed for determining RR operations. It consists of three techniques: fuzzy TOPSIS, Ant Colony Optimization (ACO), and Multi-Criteria Decision-Making (MCDM).

IV. RISK RESPONSE STRATEGIES

Risk events must be managed through a plan to minimize their impact on a project's success. Researchers have explored various risk reduction strategies, including avoidance, acceptance, mitigation, transfer, sharing, and removing. Avoidance involves implementing a risk-free plan, whereas acceptance acknowledges potential risks. Mitigation involves implementing measures to reduce risks, whereas transfer includes transferring risk-related work to a third party. Sharing encompasses multiple partners handling risk, and removing entails diminishing risk causes to achieve risk elimination [28-30].

V. THE MATHMATICAL MODEL CONSTRUCTION

An RR approach encompasses various alternatives, such as risk avoidance, risk acceptance, risk mitigation, risk transferring, risk sharing, and risk removal. The overall expenditure associated with implementing these strategies, known as the Total RR Cost for the project (TRRCp), is calculated by summing the costs linked to each form of response: risk-avoidance cost (C_v), risk-sharing cost (C_s), risk-removing cost (C_r), risk-acceptance cost (C_a), risk-mitigation cost (C_m), and risk-transferring cost (C_t). It is necessary to assess the cost of each specific action. Table I provides a comprehensive explanation of every parameter employed in the proposed model. The model constraints include the following:

- Fitness (cost) Constraint:

  Fitness= total cost = Σ(selected responses)cost (1)

- Strategy Constraint 1: states that strategies S_i and S_i' exclude each other:

  $$x_{ij} + x'_{ij} \leq 1 \quad (2)$$

- Strategy Constraint 2: guarantees the selection of a single strategy:

  $$x_{ij} + x'_{ij} = 1 \quad (3)$$

- Strategy Constraint 3: implies the condition that choosing a particular strategy necessitates the selection of another specified method as well:

  $$x_{ij} - x'_{ij} \leq 0 \quad (4)$$

- The objective function will calculate the TRRCPp while minimizing the total cost for each category:

  $$\text{Min } RC_a = \sum_{e=1}^{E}\sum_{i=1}^{6} PC_{eij}\, x_{eij} \quad (5)$$

  $$TRRCPp = \left(\sum_{e=1}^{E} C_a + \sum_{e=1}^{E} C_v + \sum_{e=1}^{E} C_m + \sum_{e=1}^{E} C_t + \sum_{e=1}^{E} C_s + \sum_{e=1}^{E} C_r\right) \quad (6)$$

TABLE I. PARAMETER DESCRIPTION

Parameter	Description
Ae	A project activity, e=1,……,E
PRj	Primary risk event, j=1,…..n
S_i	Set of risk response strategies where i=1,….,6 or m if risk response actions were considered
PC_{eij}	Primary Cost for the implementation of the i^{th} primary RR for activity Ae
x_{eij}	Decision variable, it is equal to 1 for the i^{th} RR strategy for the j^{th} risk in the e^{th} activity, otherwise is equal to zero
RC	Total cost of response strategies (actions)
TRRCp	Total risk response cost for the project
Min RCa	Minimum RR cost for each activity

VI. DATA COLLECTION

The effectiveness of the proposed RR selection model is confirmed by its application in an actual building construction project. The data used to verify the accuracy of the model were obtained from [20]. This study examined the construction project of a ventilation and air conditioning system. The project expenditure amounts to $4.7 million. The entire project is organized into eight key work activities. The researchers determined 10 significant risks that could potentially affect the vital activities of the project as depicted in Table II. They have also proposed 20 potential actions to respond to these risks. Table III presents the description and anticipated cost of every possible response available for each individual risk.

TABLE II. PROJECT ACTIVITIES AND RELATED RISKS

Project activities	Related PRs	Related RRAs
Ventilation duct making (A1)	Corrosion (PR1)	RRA1, RRA2, RRA3
	Wear (PR2)	RRA4
Drainage pipe making (A2)	Corrosion (PR1)	RRA1, RRA2, RRA3
Support making (A3)	Corrosion (PR1)	RRA1, RRA2, RRA3
Installation of a system and ventilator ducts (A4)	There are sundries in the ventilation duct (PR4)	RRA7, RRA8
	Looseness (PR5)	RRA9, RRA10, RRA11
	Condensation (PR8)	RRA13, RRA14, RRA15
Implementation of a drainage pipe and system (A5)	Looseness (PR5)	RRA9, RRA10, RRA11
	Sewage residue (PR6)	RRA12
	Condensation (PR8)	RRA13, RRA14, RRA15
Air leakage test (A6)	Valve interfaces are not tight (PR3)	RRA5, RRA6
	Too much noise of ventilation system (PR9)	RRA16, RRA17, RRA18, RRA19
Pipe pressure test (A7)	High resistance of drainage system (PR10)	RRA20
Installation of air-conditioning equipment (A8)	Corrosion (PR1)	RRA1, RRA2, RRA3
	Rustiness (PR7)	RRA1, RRA2, RRA3

VII. MODEL APPLICATION

The proposed model was applied to the specified construction project via GA. Consequently, distinct results were achieved for each risk, including the effect of PR1 (Corrosion) on the activity of Ventilation duct making (A1). To resolve this problem, the implementation of the RRA3 treatment can be considered. This treatment was evaluated alongside other approaches (RRA1 and RRA2 treatments) considering the cost criterion, and was ultimately chosen. The chosen RR action is a subordinate component of the mitigation strategy. This methodology has been implemented for every project task and for every potential risk, subsequently proposing to an estimated total budget to carry out the RR strategy for managing the risks associated with the project equal to $56,571. Table IV shows the detailed results of the model.

This framework may be characterized as a beneficial, efficient, and uncomplicated tool for users or decision makers.

TABLE III. RISK RESPONSE ACTION INFORMATION

RRA ID	Description	Est. cost $	Strategy
RRA1	Implementing moisture-proof and anti-corrosion procedures at the building site	156900	Mitigation
RRA2	Enhancing the degree of equipment safety throughout the equipment purchase process	65350	Mitigation
RRA3	Purchasing the dehumidifier	7845	Mitigation
RRA4	Organising fibre boards at the storage facility	1569	Mitigation
RRA5	Conducting a pressure test prior to valve installation.	785	Mitigation
RRA6	Before valves installation, it is necessary to clean the valves	313	Mitigation
RRA7	Sealing duct holes when installation of the ducts is stopped temporarily	120	Mitigation
RRA8	Attaching steel meshes to the ends of the ducts during their installation in the structural air ducts.	470	Mitigation
RRA9	Conducting a bearing test on the fixed anchors and supports	627	Mitigation
RRA10	Enhancing the quality of the supports and employing supports of vibration dampening.	12600	Mitigation
RRA11	Using an electric drill to create bolt holes on the supports, instead of using gas welding.	7800	Mitigation
RRA12	Cleansing the pipes with air purge after the pressure test	450	Mitigation
RRA13	Playing hoops outdoors the layers of insulation	4800	Mitigation
RRA14	Making improvements to the insulation quality of the plenum chamber that houses the air conditioning supply	78450	Avoidance
RRA15	Implementing insulation measures on the internal walls of the equipment room.	21500	Mitigation
RRA16	Cleansing the ducts interiors before installation	350	Mitigation
RRA17	Temporarily closing duct holes after duct installation	120	Mitigation
RRA18	Installing sound-absorbing materials on the inner walls of the equipment room.	785	Mitigation
RRA19	Placing the silencer in the ventilation pavilion	7060	Mitigation
RRA20	Installing automated drainage valves and exhaust valves	3920	Mitigation

TABLE IV. RESULT

Act.	Primary risks	RR actions	Min RC	Strategy
A1	PR1	RRA3	7845	Mitigation
	PR2	RRA4	1569	Mitigation
A2	PR1	RRA3	7845	Mitigation
A3	PR1	RRA3	7845	Mitigation
A4	PR4	RRA7	120	Mitigation
	PR5	RRA9	627	Mitigation
	PR8	RRA13	4800	Mitigation
A5	PR5	RRA9	627	Mitigation
	PR6	RRA12	450	Mitigation
	PR8	RRA13	4800	Mitigation
A6	PR3	RRA6	313	Mitigation
	PR9	RRA17	120	Mitigation
A7	PR10	RRA20	3920	Mitigation
A8	PR1	RRA3	7845	Mitigation
	PR7	RRA3	7845	Mitigation

VIII. CONCLUSION

The current study introduces a model that follows optimization techniques to choose efficient actions and strategies for responding to risks. The GA was employed to optimize the model, with the objective of minimizing costs connected to addressing risks. The efficacy of the framework was showcased in an actual building construction endeavor, with its advantages succinctly outlined as follows:

- The use of GA in combination with optimization strategies can effectively address the RR challenges.
- The proposed model enables decision-makers to evaluate possible responses and reach optimal decisions.
- This approach is applicable to various building projects due to the GA characteristics.

Implementing the proposed strategy has specific limitations and challenges, including the lack of comprehensive documentation regarding the risk management process in completed or ongoing construction projects, from risk identification and assessment to risk response. Additionally, it is crucial to assess and consider the probability and consequences of secondary risks.

ACKNOWLEDGMENT

The authors express their gratitude to the study participants, the expert committee responsible for evaluating this work, and the personnel of the Civil Engineering Department at the University of Baghdad for their valuable recommendations.

REFERENCES

[1] M. Fan, N.-P. Lin, and C. Sheu, "Choosing a project risk-handling strategy: An analytical model," *International Journal of Production Economics*, vol. 112, no. 2, pp. 700–713, Apr. 2008, https://doi.org/10.1016/j.ijpe.2007.06.006.

[2] A. M. Burhan, *Risk management in construction projects*. Baghdad, Iraq: University of Baghdad, 2003.

[3] E. K. Rasheed, "Development of a Blueprint Impact System of the risks on construction projects Implementation," *Journal of Engineering*, vol. 21, no. 8, pp. 28–49, Aug. 2015, https://doi.org/10.31026/j.eng.2015.08.12.

[4] H. O. Ghaeb and A. M. R. Mahjoob, "Risk Response in Construction Project: A Review Study," *Journal of Engineering*, vol. 29, no. 8, pp. 121–137, Aug. 2023, https://doi.org/10.31026/j.eng.2023.08.09.

[5] A. A. Alfahad and A. M. Burhan, "BIM-Supporting System by Integrating Risk Management and Value Management," *Engineering, Technology & Applied Science Research*, vol. 13, no. 6, pp. 12130–12137, Dec. 2023, https://doi.org/10.48084/etasr.6427.

[6] H. E. Hossny, A. H. Ibrahim, and A. Elnady, "Assessment of Construction Project Complexity," *The Open Civil Engineering Journal*, vol. 15, no. 1, pp. 414–423, Dec. 2021, https://doi.org/10.2174/1874149502115010414.

[7] R. J. K. Jalhoom and A. M. R. Mahjoob, "An Extensive Literature Review on Risk Assessment Models (Techniques and Methodology) for Construction Industry," *Journal of Engineering*, vol. 29, no. 8, pp. 76–93, Aug. 2023, https://doi.org/10.31026/j.eng.2023.08.06.

[8] A. Alameri, A. S. A. M. Alhammadi, A. H. Memon, I. A. Rahman, and N. A. N. Nasaruddin, "Assessing the Risk Level of the Challenges Faced In Construction Projects," *Engineering, Technology & Applied Science Research*, vol. 11, no. 3, pp. 7152–7157, Jun. 2021, https://doi.org/10.48084/etasr.4020.

[9] T. Zayed, M. Amer, and J. Pan, "Assessing risk and uncertainty inherent in Chinese highway projects using AHP," *International Journal of*

Project Management, vol. 26, no. 4, pp. 408–419, May 2008, https://doi.org/10.1016/j.ijproman.2007.05.012.

[10] E. K. Rasheed, "Valuation the Impact of Risks on the Goals and the Safety of Construction Projects in Iraq," *Journal of Engineering*, vol. 21, no. 4, pp. 1–19, Dec. 2015, https://doi.org/10.31026/j.eng.2015.04.10.

[11] A. D. Nandagavale and B. A. Konnur, "Risk Management in the Construction Project: Review," *International Research Journal of Engineering and Technology*, vol. 6, no. 4, pp. 4003–4006, 2019.

[12] P. K. Jain and S. T. Qadri, "Identification of Risk in Construction Projects," *International Research Journal of Engineering and Technology*, vol. 7, no. 11, pp. 253–260, 2020.

[13] S. H. N. Alani and A. M. R. Mahjoob, "Corruption Risk Analysis at the Project Planning Stage in the Iraqi Construction Sector using the Bowtie Methodology," *Engineering, Technology & Applied Science Research*, vol. 11, no. 3, pp. 7223–7227, Jun. 2021, https://doi.org/10.48084/etasr.4060.

[14] S. H. Fateminia, N. G. Seresht, and A. R. Fayek, "Evaluating Risk Response Strategies on Construction Projects Using a Fuzzy Rule-Based System," in *36th International Symposium on Automation and Robotics in Construction*, Banff, AB, Canada, Dec. 2019, pp. 282–288, https://doi.org/10.22260/ISARC2019/0038.

[15] A. Nieto-Morote and F. Ruz-Vila, "A fuzzy approach to construction project risk assessment," *International Journal of Project Management*, vol. 29, no. 2, pp. 220–231, Feb. 2011, https://doi.org/10.1016/j.ijproman.2010.02.002.

[16] A. H. Beg and M. Z. Islam, "Advantages and limitations of genetic algorithms for clustering records," in *11th Conference on Industrial Electronics and Applications*, Hefei, China, Jun. 2016, pp. 2478–2483, https://doi.org/10.1109/ICIEA.2016.7604009.

[17] V. Bhosale, D. S. S. Shastri, and M. A. Khandare, "A Review of Genetic Algorithm used for optimizing scheduling of Resource Constraint construction projects," *International Research Journal of Engineering and Technology*, vol. 4, no. 5, pp. 2869–2872, 2017.

[18] A. B. Senouci and N. N. Eldin, "Use of Genetic Algorithms in Resource Scheduling of Construction Projects," *Journal of Construction Engineering and Management*, vol. 130, no. 6, pp. 869–877, Dec. 2004, https://doi.org/10.1061/(ASCE)0733-9364(2004)130:6(869).

[19] S. N. Sivanandam and S. N. Deepa, *Introduction to Genetic Algorithms*. New York, NY, USA: Springer, 2008.

[20] Y. Zhang and Z.-P. Fan, "An optimization method for selecting project risk response strategies," *International Journal of Project Management*, vol. 32, no. 3, pp. 412–422, Apr. 2014, https://doi.org/10.1016/j.ijproman.2013.06.006.

[21] M. Kilic, G. Ulusoy, and F. S. Serifoglu, "A bi-objective genetic algorithm approach to risk mitigation in project scheduling," *International Journal of Production Economics*, vol. 112, no. 1, pp. 202–216, Mar. 2008, https://doi.org/10.1016/j.ijpe.2006.08.027.

[22] C. Fang, F. Marle, M. Xie, and E. Zio, "An Integrated Framework for Risk Response Planning Under Resource Constraints in Large Engineering Projects," *IEEE Transactions on Engineering Management*, vol. 60, no. 3, pp. 627–639, Aug. 2013, https://doi.org/10.1109/TEM.2013.2242078.

[23] E. Cheraghi, M. Khalilzadeh, S. Shojaei, and S. Zohrehvandi, "A mathematical Model to select the Risk Response Strategies of the Construction Projects: Case Study of Saba Tower," *Procedia Computer Science*, vol. 121, pp. 609–616, Jan. 2017, https://doi.org/10.1016/j.procs.2017.11.080.

[24] H. Fukuda and H. Kuwano, "The Mathematical Model of Project Risk Responses in Project Risk Management," *Journal of the Operations Research Society of Japan*, vol. 60, no. 2, pp. 192–200, 2017, https://doi.org/10.15807/jorsj.60.192.

[25] R. Soofifard, M. Bafruei, and M. Gharib, "A Mathematical model for selecting the project risk responses in construction projects," *International Journal of Optimization in Civil Engineering*, vol. 8, no. 4, pp. 601–624, Jan. 2018.

[26] A. Ghassemi and A. Darvishpour, "A novel approach for risk evaluation and risk response planning in a geothermal drilling project using DEMATEL and fuzzy ANP," *Decision Science Letters*, vol. 7, no. 3, pp. 225–242, 2018.

[27] S. Shoar and A. Nazari, "An optimization framework for risk response actions selection using hybrid ACO and FTOPSIS," *Scientia Iranica*, vol. 26, no. 3, pp. 1763–1777, Jun. 2019, https://doi.org/10.24200/sci.2018.20225.

[28] A. A. Mahmoud al-Mukahal, "Risk Management of Construction Projects," *Engineering Management Research*, vol. 9, no. 1, pp. 15–27, May 2020, https://doi.org/10.5539/emr.v9n1p15.

[29] W. Bransah, "Discovering Project Risk Management Practices in Construction Industry of Ghana," *Dama Academic Scholarly Journal of Researchers*, vol. 5, no. 3, pp. 1–14, 2020, https://doi.org/10.15373/22501991.

[30] N. H. Kadum, "The integration of Risk management and BIM to Manage the duration of construction projects," M.S. thesis, University of Diyala, Baqubah, DI, Iraq, 2021.

[31] M. Singh, S. Deep, and R. Banerjee, "Risk management in construction projects as per Indian scenario," *International Journal of Civil Engineering and Technology*, vol. 8, no. 3, pp. 127–136, Mar. 2017.

[32] I. Ben-David and T. Raz, "An integrated approach for risk response development in project planning," *Journal of the Operational Research Society*, vol. 52, no. 1, pp. 14–25, Jan. 2001, https://doi.org/10.1057/palgrave.jors.2601029.