

Development of real-time cost analysis application for irrigation construction projects using extreme programming methodology

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ABSTRACT

This research aims to address the challenges of cost management in irrigation construction projects by developing a real-time cost analysis application. Key issues involve information delay, complexity of cost factors, and limitations of traditional development models. The research method consists of three crucial stages: data collection, application development using the Extreme Programming method, and user acceptance analysis. Data was collected through interviews, field observations, and document analyses. The application was developed with features such as budget management, real-time cost monitoring, risk analysis, project team management, and project financial reports. The pilot test involved test scenarios involving active users. The results showed success in managing budgets, real-time cost monitoring, and risk analysis, with a high success rate. The contribution is developing a responsive and adaptive application that meets the needs of irrigation construction projects, overcomes the limitations of traditional development models, and improves the efficiency and responsiveness of project cost management.

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INTRODUCTION

The importance of efficient and accurate cost management in irrigation construction projects must be considered. These projects involve highly complex and large-scale infrastructure, encompassing a network of aqueducts, dams, and other installations that serve irrigation needs. In this context, efficient cost management is crucial as every financial decision directly impacts the viability and success of the project (Ali & Hassan Ali, 2023; Barbón et al., 2023; Pereiro et al., 2023; Varriale et al., 2023). Given the factors involved, such as material purchases, labor wages, and infrastructure maintenance, rigorous cost analysis is necessary. This complexity creates the need for applications that provide real-time cost information so that decision-making can be done quickly and accurately (Abushanab & Alnahhal, 2023; Khan et al., 2023; Van Lancker et al., 2023).

The extensive scale and complex infrastructure require in-depth cost analysis in large-scale irrigation construction projects. The success of irrigation projects depends on technical aspects and the efficiency of financial resource management. Therefore,

meticulous cost analysis is crucial to ensure optimal fund allocation and accurate monitoring of the entire project's elements. Facing irrigation projects with significant impacts on the environment and society, the sustainability and success of the project heavily rely on the ability to manage costs carefully. The decision-making process in irrigation projects requires fast and timely access to cost information. However, delays in delivering information can often hinder an efficient response to changes or challenges. Therefore, the primary goal is to overcome information delays by developing a real-time cost analysis application. This application is expected to provide instant cost data, enabling stakeholders to make the right decisions at the right time, thus enhancing overall responsiveness and efficiency in dynamic irrigation projects.

In addition to information delays, the complexity of the unique cost factors in irrigation infrastructure projects poses a serious challenge. These projects involve various elements, including the construction of water channels, pump installations, and water resource management. These factors have their dynamics, such as material price fluctuations, weather changes, and shifts in water requirements. Therefore, in-depth cost analysis is needed to understand and effectively manage these factors. The development of a cost analysis application that considers this complexity is expected to provide a viable solution, aiding in identifying and managing financial risks and optimizing budget allocation for irrigation infrastructure projects. The importance of up-to-date cost information becomes the primary focus in the decision-making context of irrigation construction projects. The success of a project heavily depends on stakeholders' ability to make timely decisions based on accurate cost data. Changes can occur anytime in a dynamic project environment, and information delays can lead to suboptimal decisions. Therefore, the primary goal of this research is to enhance the availability of real-time cost information by developing a cost analysis application. This application is expected to provide stakeholders instant access to current cost data, enabling them to make informed and strategic decisions (Alzahrani & Emsley, 2013; Fredriksson & Huge-Brodin, 2022; Lai et al., 2016; Marzouk, 2011; Pan, 2008).

The positive impact of real-time applications in addressing cost management challenges is highly significant. The application is designed to meet irrigation construction projects' fast and dynamic needs, where every financial decision has significant consequences. By providing cost information immediately, this application can overcome data collection delays, lack of transparency, and insufficient responsiveness to project condition changes. Thus, the goals of this research include implementing information technology solutions that not only optimize decision-making but also positively impact the efficiency and sustainability of irrigation construction projects (Choi & Ha, 2022; Gao, 2022; Guo et al., 2023; Jato-Espino et al., 2014; Nieto-Morote & Ruz-Vila, 2012; Zhang et al., 2022).

The limitations of sequential-based development models, such as the Waterfall model, become a significant obstacle in dynamic irrigation construction projects. In the context of irrigation infrastructure involving numerous variables and dynamically changing challenges, the linear and sequential nature of the Waterfall model often needs to respond

quickly to changes. This process takes a long time to complete development stages, and midway changes can result in significant delays. Therefore, this research aims to overcome the limitations of the Waterfall model by adopting a more adaptive and responsive development method, accommodating the dynamics of changes frequently occurring in irrigation construction projects. Adaptive and responsive applications to changes become essential in the dynamic environment of irrigation construction projects (Dingsøyr et al., 2012; Najihi et al., 2022; Santos et al., n.d.; Serrador & Pinto, 2015; Shrivastava & Rathod, 2014). Changes in conditions, weather alterations, or other factors that can substantially impact the project require a system that can quickly adapt. Adaptive applications can integrate changes into the development process without disrupting the workflow. Furthermore, responsiveness to changes is crucial in addressing challenges that arise suddenly.

Therefore, this research aims to develop a cost analysis application that is not only adaptive to the dynamics of irrigation projects but also responsive to changes quickly to support effective cost management. Especially in irrigation projects, where conditions can affect the application's functionality, continuous testing becomes crucial in ensuring the application remains responsive and reliable. Therefore, this research emphasizes the need for continuous testing to guarantee the quality of irrigation applications, ensuring that the developed solutions can be implemented and function well in various conditions and dynamic changes in irrigation projects. This research aims to enhance responsiveness and timeliness in cost analysis for irrigation construction projects. Irrigation projects often involve numerous variables that can change rapidly, such as weather changes or soil conditions. Therefore, it is crucial to have a cost analysis system capable of providing information quickly and accurately. By improving responsiveness, stakeholders are expected to respond to changing conditions and make informed decisions promptly. Timely accuracy in cost analysis is also crucial to ensuring optimal budget allocation and efficient financial resource management in dynamic irrigation projects (Akhtar et al., n.d.; Alami et al., 2022; Hasan et al., 2013; Mishra & Alzoubi, 2023; Tøndel et al., 2022).

Furthermore, this research aims to minimize delays in cost decision-making in irrigation projects. Delays in data collection and cost analysis can result in crucial decision-making delays for project sustainability. Minimizing these delays is expected to create a more efficient system, enabling stakeholders to make decisions quickly and in a timely manner. Thus, this research aims to develop a solution that can optimize the cost decision-making process in irrigation projects, making the project more adaptive and responsive to potential dynamics.

METHODS

The research process comprises three crucial stages, as illustrated in Figure 1. The first stage involves data collection, commencing with identifying cost information needs for irrigation construction projects. A carefully designed data collection plan is implemented in this stage, incorporating interviews, field observations, and document analysis. The second stage centers on application development using the Extreme Programming (XP) Method. A

development team is assembled, and the development plan encompasses selecting critical features and feature-based development stages. Pair programming and continuous testing are applied to ensure the quality and responsiveness of the application. Finally, the third stage entails user acceptance analysis. Thorough testing preparation is conducted, involving user participation to gather valuable feedback. The test results are analyzed comprehensively, and necessary changes are implemented, followed by a final evaluation. These stages form a holistic research framework, from data collection and application development to user acceptance analysis to deliver a responsive and tailored cost analysis solution for irrigation construction projects.

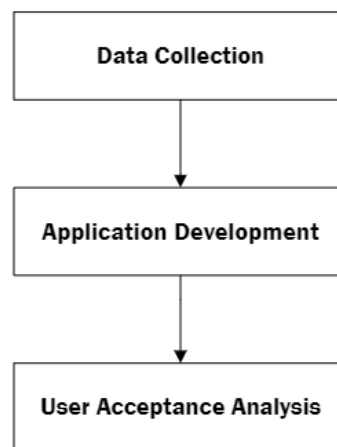


Figure 1. Research Stages

Data Collection

Firstly, the activities commence with identifying cost information needs for irrigation construction projects. In-depth analysis is conducted to comprehend the information required by stakeholders. Subsequently, the design of the data collection structure takes place, encompassing data collection methods and relevant information sources. The implementation of data collection involves executing the prepared plan, including interviews with experts, field observations, and analysis of related documents. This process forms the foundational data necessary for developing the cost analysis application for irrigation projects.

Application Development

After the data is gathered, the next step is to plan the application development using the Extreme Programming (XP) method. The development project plan includes defining the application's key features and outlining the development stages. The formation of the development team is carefully done, involving both programmers and clients (users) collaborating directly. The feature-based development process prioritizes key features identified during the data collection. Pair programming is executed to enhance the quality

and accuracy of the implementation, while continuous testing is performed to ensure each feature functions well and meets user requirements.

User Acceptance Analysis

The final stage involves analyzing user acceptance of the developed application. Testing preparation includes formulating a strategy, selecting test users, and creating relevant testing scenarios. Implementing user testing involves active user participation to gather feedback on user experience, usability, and satisfaction levels. After the testing, a thorough analysis of the results is conducted. Findings and input from users are identified and used to adjust the application. This process concludes with implementing necessary changes and a final evaluation to ensure the application meets quality standards and effectively fulfills user needs.

RESULTS AND DISCUSSION

Data Collection

The results of the Data Collection stage demonstrate significant achievements in understanding the cost information needs of irrigation construction projects. In the first sub-stage, in-depth analysis was conducted to identify the information requirements necessary for project stakeholders. The second sub-stage included designing the data collection structure, encompassing the types of data needed, methods, and relevant information sources. A meticulous data collection plan was devised to ensure the completeness and relevance of the obtained information. The final sub-stage, Data Collection Implementation, involved executing the plan through various methods such as expert interviews, field observations, and analysis of relevant documents. This process was carried out according to the plan to ensure the accuracy and quality of the data acquired, supporting the development of the cost analysis application for irrigation construction projects.

Table 1. Identification of Data Requirements

Data Source	Data Collection Results
Expert Interviews	Cost information needs, risk factors. Experts provided in-depth insights into cost information needs and potential project risks
Direct Observation	Soil conditions, topography, existing infrastructure. Direct observations in the field provided actual data on soil, topography, and existing conditions.
Analysis of Relevant Documents	Historical data from similar projects, construction regulations. Documents yielded historical information on similar projects and construction regulations affecting construction costs and price changes.

The data collection process for irrigation construction projects, as outlined in Table 1, involves expert interviews, direct field observations, and analysis of relevant documents. Expert interviews yield profound insights into cost information needs and the identification of risk factors, such as material price fluctuations. Direct observations provide actual data on soil conditions, topography, and existing infrastructure, forming a robust foundation for

accurate cost estimates. Document analysis, including historical data from similar projects and construction regulations, offers the necessary context for cost analysis. Historical data from similar projects serve as a basis for budget estimates. In contrast, understanding construction regulations and projected price changes provides comprehensive insights into external factors that can impact project costs. The combination of various information sources ensures a holistic approach to data collection, supporting robust and accurate cost analysis and effective decision-making throughout the irrigation construction project lifecycle.

Application Development

After collecting data, the next step is to plan and execute the application development using the Extreme Programming (XP) method. The project development plan includes determining the application's key features and outlining clear development stages. The formation of the development team is done carefully, involving programmers and clients (users) in direct collaboration. The feature-based development process prioritizes key features identified during the data collection. Pair programming is implemented to enhance the quality and accuracy of each implementation stage.

Additionally, continuous testing ensures each feature functions well and meets user needs. This approach ensures high-quality implementation and facilitates responsiveness to changes and project needs that may arise over time. The results of this application development are expected to provide an adaptive solution that aligns with the needs of irrigation construction project users.

Table 2. Application Features

Features	Function
Budget Management	Allows users to create and manage detailed budgets for irrigation construction projects, including estimates for material costs, labor wages, and additional expenses.
Real-Time Cost Monitoring	Provides a real-time view of the project's actual costs, enabling users to track current expenditures and compare them against the established budget.
Cost Risk Analysis	Identifies potential cost risks, such as fluctuations in material prices or changes in field conditions, and offers solutions or alternatives to manage them.
Project Team Management	Offers collaboration tools for project teams, including pair programming features and task management, to enhance efficiency and communication among team members.
Project Financial Reports	Generates detailed financial reports encompassing expenditures, remaining cost estimates, and overall financial progress of the project.

The integrated features, as outlined in Table 2, contribute to effective cost management throughout the irrigation construction project. From detailed budget planning to real-time monitoring, risk analysis, team collaboration, and comprehensive reporting, this

application aims to enhance project success by ensuring financial transparency, control, and adaptability to the evolving project dynamics. The Budget Management feature allows for meticulous planning and control over project finances. Users can create a comprehensive budget, ensuring detailed breakdowns related to material costs, labor wages, and other expenses. This feature enhances transparency and accuracy in financial planning. The Real-Time Cost Monitoring feature provides a dynamic view of the project's financial health. Users can track expenses as they occur, enabling proactive decision-making and immediate response to budget deviations. This real-time visibility enhances overall financial control.

The Cost Risk Analysis feature is crucial for identifying and addressing potential financial risks. By assessing factors such as material price fluctuations or unforeseen field conditions, the application empowers users to proactively manage challenges, reducing the impact of unforeseen events on the project budget. Project Team Management facilitates efficient collaboration among team members. Including pair programming features and task management tools enhances cooperation and communication. This improves a cohesive work environment, increasing productivity and project success. The Project Financial Reporting feature provides a comprehensive overview of the project's financial status. Users can access detailed reports, including cost breakdowns and remaining cost estimates. These reports serve as valuable tools for informed decision-making and communication with stakeholders.

User Acceptance Analysis

The final stage of the project involves analyzing user acceptance of the developed application. Test preparation includes formulating a testing strategy, selecting test users, and creating relevant testing scenarios. Implementing user testing involves active user participation to gather feedback on user experience, usability, and satisfaction levels. After the testing, a thorough analysis of the results is conducted. Valuable findings and input from users are discovered, serving as the basis for adjustments to the application. These findings cover the user interface, functionality, and application performance. The use of appropriate testing scenarios aids in identifying potential improvements and additional development. This process concludes with implementing necessary changes based on the user acceptance analysis. A final evaluation ensures the application meets the desired quality standards and fulfills user needs. Thus, the user acceptance analysis stage not only serves as the project's conclusion but also forms the foundation for future development and the implementation of continuous improvements.

Table 3. Application Feature Testing

Features	Scenario	Results
Budget Management	Users input project budget details, including material cost estimates and labor wages. The testing scenario includes validating the system's ability to perform automatic calculations and validate against invalid budget inputs.	successfully
Real-Time Cost	Users view real-time cost displays and	

Features	Scenario	Results
Monitoring	compare them with the established budget. The scenario also includes testing automatic notifications when a significant deviation from the budget occurs.	
Cost Risk Analysis	Users identify and manage cost risks using this feature. Testing involves simulating risk scenarios and checking the system's response to proposed solutions or alternatives.	successfully
Project Team Management	The project team uses collaboration tools for pair programming tasks. Testing includes verifying the availability of task management features and team communication in a virtual environment.	successfully
Project Financial Reports	Users generate project financial reports using actual data. The scenario involves verifying the accuracy of reports, including expenditure details and remaining cost estimates.	successfully
User Acceptance Analysis	Faced with a change in the team structure, a manager wants to use the application to manage workforce role changes. Test the change management feature for smooth process execution.	successfully
Employee Performance Evaluation	Active user participation in trial testing to provide feedback. The scenario involves testing the user interface, application usability, and measuring user satisfaction.	successfully

Testing the features of the Real-Time Cost Analysis application for Irrigation Construction Projects shows that each feature has undergone comprehensive testing. The Budget Management feature successfully handles budget inputs accurately and validly. At the same time, Real-Time Cost Monitoring provides a dynamic view of the project's actual costs with automatic notifications for significant deviations from the budget. Cost Risk Analysis tests the application's effectiveness in addressing potential risks, while Project Team Management successfully provides an efficient collaboration tool. Project Financial Reporting generates accurate and detailed reports, validating the reliability of information for decision-making. User Acceptance Analysis identifies areas for improvement and enhancements based on user feedback, ensuring optimization of the user interface, application usability, and overall user satisfaction. With these results, the application is ready for implementation in irrigation construction projects using the Extreme Programming (XP) method, ensuring adequate quality, readiness, and responsiveness to user needs.

Based on user assessments of various features of the Real-Time Cost Analysis application for Irrigation Construction Projects, it is evident that the application has achieved a high level of success with an overall average score of 87. Features such as Budget Management, Real-Time Cost Monitoring, and Project Financial Reporting received the highest ratings, demonstrating effectiveness in planning, managing, and providing accurate financial information. Users also gave positive ratings to Cost Risk Analysis and Project Team Management, indicating the application's success in addressing project risks and improving team collaboration. The user acceptance results reaching a score of 90 in User Acceptance Analysis illustrate that the user interface, application usability, and overall user satisfaction have met or exceeded expectations. Thus, this high level of success confirms that the application is ready for implementation in the irrigation construction project environment using the Extreme Programming (XP) method.

CONCLUSION

This research addresses cost management challenges in irrigation construction projects by developing a real-time cost analysis application. User acceptance analysis results indicate that the application has been well-received, with high satisfaction regarding the user interface, clarity of features, and user-friendliness. The application provides budget management and real-time cost monitoring and offers additional features such as risk analysis, project team management, and project financial reporting. The success of the test scenarios confirms that the application effectively manages budgets, cost monitoring, and risk analysis, achieving a high level of success. The primary contribution of this research is developing a responsive and adaptive application that meets the specific needs of irrigation construction projects, serving as a relevant and efficient solution. These findings are anticipated to enhance the management of irrigation construction projects and contribute positively to the overall efficiency and responsiveness of the construction industry.

REFERENCE

- Abushanab, A., & Alnahhal, W. (2023). Life cycle cost analysis of sustainable reinforced concrete buildings with treated wastewater, recycled concrete aggregates, and fly ash. *Results in Engineering*, 20. <https://doi.org/10.1016/j.rineng.2023.101565>
- Akhtar, A., Bakhtawar, B., & Akhtar, S. (n.d.). EXTREME PROGRAMMING VS SCRUM: A COMPARISON OF AGILE MODELS. *International Journal of Technology, Innovation and Management (IJTIM)*, 2, 2022. <https://doi.org/10.54489/ijtim.v2i1.77>
- Alami, A., Krancher, O., & Paasivaara, M. (2022). The journey to technical excellence in agile software development. *Information and Software Technology*, 150. <https://doi.org/10.1016/j.infsof.2022.106959>
- Ali, K., & Hassan Ali, M. I. (2023). Energy and cost analysis of a multiple channel direct contact membrane distillation module: Case study. *Case Studies in Chemical and Environmental Engineering*, 8. <https://doi.org/10.1016/j.cscee.2023.100449>

- Alzahrani, J. I., & Emsley, M. W. (2013). The impact of contractors ' attributes on construction project success : A post construction evaluation. *JPMA*, 31(2), 313–322. <https://doi.org/10.1016/j.ijproman.2012.06.006>
- Barbón, A., Carreira-Fontao, V., Bayón, L., & Silva, C. A. (2023). Optimal design and cost analysis of single-axis tracking photovoltaic power plants. *Renewable Energy*, 211, 626–646. <https://doi.org/10.1016/j.renene.2023.04.110>
- Choi, J., & Ha, M. (2022). Validation of project management information systems for industrial construction projects. *Journal of Asian Architecture and Building Engineering*, 21(5), 2046–2057. <https://doi.org/10.1080/13467581.2021.1941999>
- Dingsøy, T., Nerur, S., Balijepally, V., & Moe, N. B. (2012). A decade of agile methodologies: Towards explaining agile software development. In *Journal of Systems and Software* (Vol. 85, Issue 6). <https://doi.org/10.1016/j.jss.2012.02.033>
- Fredriksson, A., & Hüge-Brodin, M. (2022). Green construction logistics – a multi-actor challenge. *Research in Transportation Business and Management*, 45(PA), 100830. <https://doi.org/10.1016/j.rtbm.2022.100830>
- Gao, J. (2022). Research on Financial Informatization Construction of Business and Finance Integration. *International Journal of Science and Research (IJSR)*, 11(7), 354–358. <https://doi.org/10.21275/sr22704192347>
- Guo, F., Wang, K., & Cao, E. (2023). *A Digital Twin (DT) Framework at Design and Construction Phases*. <https://www.researchgate.net/publication/371416031>
- Hasan, R., Ta, A.-, & Razali, R. (2013). Prioritizing Requirements in Agile Development : A Conceptual Framework. *Procedia Technology*, 11(Iceei), 733–739. <https://doi.org/10.1016/j.protcy.2013.12.252>
- Jato-Espino, D., Castillo-Lopez, E., Rodriguez-Hernandez, J., & Canteras-Jordana, J. C. (2014). A review of application of multi-criteria decision making methods in construction. In *Automation in Construction* (Vol. 45, pp. 151–162). Elsevier B.V. <https://doi.org/10.1016/j.autcon.2014.05.013>
- Khan, U., Zevenhoven, R., Stougie, L., & Tveit, T. M. (2023). Life cycle cost analysis (LCCA) of Stirling-cycle-based heat pumps vs. conventional boilers. *Cleaner Environmental Systems*, 8. <https://doi.org/10.1016/j.cesys.2022.100105>
- Lai, Y.-Y., Yeh, L.-H., Chen, P.-F., Sung, P.-H., & Lee, Y.-M. (2016). Management and Recycling of Construction Waste in Taiwan. *Procedia Environmental Sciences*, 35, 723–730. <https://doi.org/10.1016/j.proenv.2016.07.077>
- Marzouk, M. M. (2011). Automation in Construction ELECTRE III model for value engineering applications. *Automation in Construction*, 20(5), 596–600. <https://doi.org/10.1016/j.autcon.2010.11.026>
- Mishra, A., & Alzoubi, Y. I. (2023). Structured software development versus agile software development: a comparative analysis. *International Journal of System Assurance Engineering and Management*. <https://doi.org/10.1007/s13198-023-01958-5>
- Najihi, S., Elhadi, S., Abdelouahid, R. A., & Marzak, A. (2022). Software Testing from an Agile and Traditional view. *Procedia Computer Science*, 203, 775–782. <https://doi.org/10.1016/j.procs.2022.07.116>

- Nieto-Morote, A., & Ruz-Vila, F. (2012). A fuzzy multi-criteria decision-making model for construction contractor prequalification. *Automation in Construction*, 25, 8–19. <https://doi.org/10.1016/j.autcon.2012.04.004>
- Pan, N. (2008). Fuzzy AHP approach for selecting the suitable bridge construction method. *Automation in Construction*, 17(8), 958–965. <https://doi.org/10.1016/j.autcon.2008.03.005>
- Pereiro, X., Cabaleiro, M., Conde, B., & Riveiro, B. (2023). BIM methodology for cost analysis, sustainability, and management of steel structures with reconfigurable joints for industrial structures. *Journal of Building Engineering*, 77. <https://doi.org/10.1016/j.jobbe.2023.107443>
- Santos, R., Cunha, F., Rique, T., Perkusich, M., Almeida, H., Perkusich, A., & Icaro Costa, ' . (n.d.). *A Comparative Analysis of Agile Teamwork Quality Instruments in Agile Software Development: A Qualitative Approach*. <https://doi.org/10.18293/DMSVIVA2023-217>
- Serrador, P., & Pinto, J. K. (2015). Does Agile work? - A quantitative analysis of agile project success. *International Journal of Project Management*, 33(5). <https://doi.org/10.1016/j.ijproman.2015.01.006>
- Shrivastava, S. V., & Rathod, U. (2014). Risks in Distributed Agile Development: A Review. *Procedia - Social and Behavioral Sciences*, 133, 417–424. <https://doi.org/10.1016/j.sbspro.2014.04.208>
- Tøndel, I. A., Cruzes, D. S., Jaatun, M. G., & Sindre, G. (2022). Influencing the security prioritisation of an agile software development project. *Computers and Security*, 118. <https://doi.org/10.1016/j.cose.2022.102744>
- Van Lancker, L., Saravanan, A., Abu-Bakra, M., Reid, K., Quijano, C., Goyal, S., Rodrigues, I., Lascaratos, G., Trikha, S., Barwood, C., Combe, E., Kulkarni, A., Lim, K. S., & Low, S. (2023). Clinical Outcomes and Cost Analysis of PreserFlo versus Trabeculectomy for Glaucoma Management in the United Kingdom. *Ophthalmology Glaucoma*, 6(4), 342–357. <https://doi.org/10.1016/j.ogla.2022.11.006>
- Varriale, V., Cammarano, A., Michelino, F., & Caputo, M. (2023). Integrating blockchain, RFID and IoT within a cheese supply chain: A cost analysis. *Journal of Industrial Information Integration*, 34. <https://doi.org/10.1016/j.jii.2023.100486>
- Zhang, J., Cheng, J. C. P., Chen, W., & Chen, K. (2022). Digital Twins for Construction Sites: Concepts, LoD Definition, and Applications. *Journal of Management in Engineering*, 38(2). [https://doi.org/10.1061/\(asce\)me.1943-5479.0000948](https://doi.org/10.1061/(asce)me.1943-5479.0000948)