

Smart Quality Monitoring for Transmission Line Construction

¹Niraj Dutta, ^{2*}Ram Chandra Tiwari

¹Dept. of Civil Engineering, Hillside College of Engineering, Kathmandu, Purbanchal University, Nepal

²Dept. of Civil Engineering, I.O.E., Pulchowk Campus, Tribhuvan University, Nepal

*Corresponding Author: rct2075ce_rctiwari@pcampus.edu.np

Abstract

High voltage transmission lines play a critical role in Nepal's power sector, necessitating stringent quality supervision for construction and erection. Unfortunately, supervision and documentation of quality supervision are mostly done on paper which causes delay, inefficiency in tracing quality inspection reports, and increased errors in recording and supervising work. In this research, a web based quality supervision system for constructing transmission lines in Nepal has been developed and tested. The system consists of activities, quality inspection reports, progress, and photographs of work carried out in a web based system. Input of structured information, workflows, and automatic reporting were included in the system design. A sample transmission line project of 220 kV has been used to demonstrate the application of the system while an expert-based survey was carried out to verify the necessity of having such a system. The system successfully collected the input of construction and inspection reports, improved the traceability of quality reports, and reduced the effort and time needed to supervise and record the work done.

Keywords: High-Voltage Transmission Lines, Quality Supervision, Construction Management, Web-Based Application, Digital Inspection System, Infrastructure Quality Control.

I. INTRODUCTION

There has been an ever-growing demand for electricity due to rapid increase in population, urbanization, and industrialization in Nepal. With an intention to meet growing electricity demand and harness hydropower resources available in abundance, major investment has been done for installation of high voltage transmission systems including 132kV, 220kV, and 400kV systems [8]. Transmission lines are important elements of the national grid that ensure efficient evacuation of electric power from generation stations to end-user load points. Construction of such systems necessitates adherence to international and national standards, such as IEC 60826 [7], ACI 318-19 [2], and IS 456 [3].

Construction of transmission line includes linear infrastructure development along with installation of towers at regular intervals. Foundation development and erection of tower structures form important stages in construction process. Quality of work carried out during these processes is very important as this will impact structural

stability and performance of system. Tower foundation and erection works require strict quality control measures as recommended by various industry manuals like PGCIL (2015).

Management of quality has always followed certain framework in construction projects. One such framework is PMBOK [9]. However, most of the developing nations, including Nepal, lack structured supervisory methods in construction projects. These projects are managed using manual procedures and paper documents such as site diary, inspection report, testing report, and progress report.

Several studies carried out recently suggest benefits of use of advanced technology like web-based and mobile systems in construction project management [4-6, 10]. Cheung et al. [4] and Abu Laiba [1] conclude that web-based management systems facilitate effective management of construction projects with respect to quality control and documentation. Further, Garcia et al. [5] and Zhang et al. [10] confirm that use of advanced technologies and mobile systems help in monitoring and controlling quality in construction projects.

II. LITERATURE REVIEW

Construction of a transmission line entails a specialized type of construction activity with respect to linear stretches, scattered job locations, and conducting the works in difficult terrains like mountains and valleys. For Nepal, all these factors pose serious challenges regarding supervision and control of the constructions. Earlier research works have proven the positive impacts of web-based construction management systems in coordinating construction activities, improving information flows, and documentation quality [4], [1].

Transmission lines include foundation works, tower erection, and conductor stringing with respect to which foundation works and tower erection are vital aspects. Foundation works entail excavation, stub setting, PCC, reinforcements, concrete casting, curing, and backfilling. The quality control of concrete is based on certain standards like ACI 318-19 and IS 456 with regard to mix design, casting, curing, and strength testing [2], [3]. Quality data recording in digital format facilitates better verification and conformity with construction procedures [6].

Web-based systems incorporate progress monitoring, quality inspection, and document management in a unified way. Studies reveal that such an arrangement facilitates information sharing and coordination among project participants in real time [4]. Similarly, use of databases in construction processes has facilitated better management in terms of consistency and accessibility [1]. The application of mobile computing in construction can facilitate real-time site data capture, photographic documentation, and reports generation [5]. Moreover, implementation of integrated web-based information systems in construction greatly enhances the efficiency of quality management [10].

With regard to Nepal, several transmission line projects including the 220kV corridor and 400kV corridor have been undertaken in difficult terrains by the Nepal Electricity Authority [8]. Nevertheless, supervisory activities still depend heavily on documentation by hand. Quality management principles, like those contained in PMBOK, highlight the importance of systematic procedures in quality management and documentation [9]. Yet, web-enabled supervisory systems are still lacking in transmission line projects. For this reason, it is obvious that an integrated web-based system designed specifically for transmission line construction is highly desirable.

III. METHODOLOGY

The overall methodological framework are shown in Fig. 1 and 2 respectively. This study employed design and development research to develop and validate a web-based software application to be used for the supervision of the quality of construction of high-voltage transmission lines. System analysis, design, implementation, and validation are among the steps involved in the process so that the software can serve its purpose.

In developing the system, requirement analysis, design, modeling of database, coding, and testing were done. Requirement analyses were done based on construction activities, construction specifications, and information from experts. A client/server technology with three-tier architecture composed of presentation layer, application layer, and data layer was applied in the design of the system. The database is modeled based on the different stages of construction which include digging, stubbing, preparation of PCC, rebar work, concreting, backfilling, and erection of towers, as well as quality data such as cube test.

The process also takes into account the actual flow of work related to transmission line construction projects and facilitates stage-by-stage data input by means of standardized inputs and validations in order to make sure that accuracy and traceability are achieved. The quality control system directly ties test results to specific tower locations and construction stage phases.

Simulation was done academically, through which a sample of transmission line construction project of 220 kilovolt line was considered and validated. Progress reports and quality control summaries were generated in accordance with the input data. Logical, functional, and output validity testing was done accordingly.

Furthermore, a questionnaire was given to engineers and project personnel through an expert survey to evaluate how efficient, traceable, accessible, and transparent the proposed solution is compared to traditional paper-based systems.

Thus, this methodology guarantees that the proposed solution is valid, logical, and functional within its application scope in Nepal.

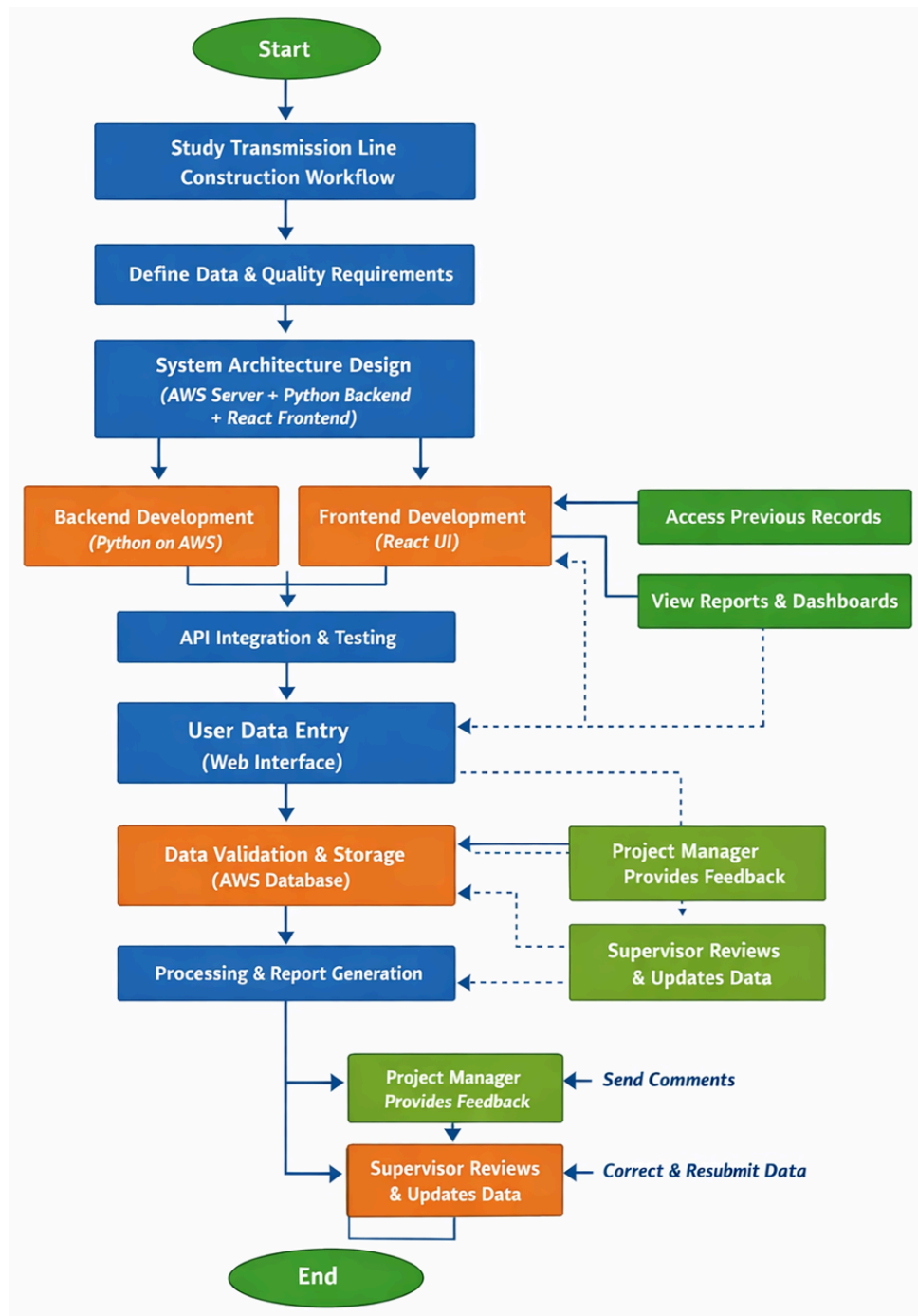
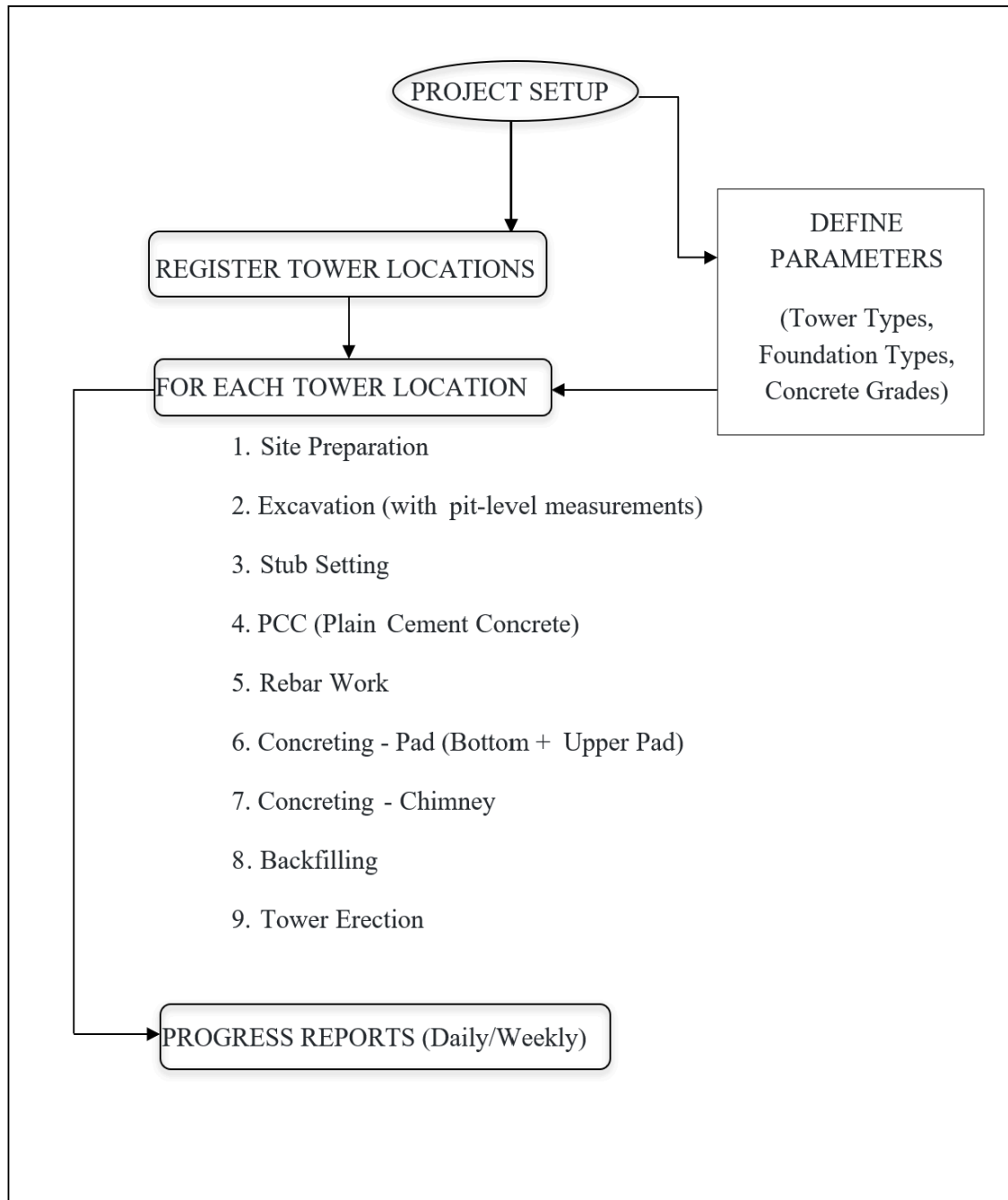


Fig. 1: System Architecture

**METHODOLOGY:** Flow Chart for Data Model

IV. RESULTS AND DISCUSSION

This research describes the results of the development of a web-based quality supervision system for high-voltage transmission line civil works, tested using a simulated 220 kV project in the Kathmandu Valley.

A questionnaire survey carried out among 24 experts revealed their favorable attitude towards digital supervision technology. Respondents were in favor of reduction in reporting time (88.24%), higher efficiency of data input (88.24%), improvement in

real-time access (88.24%) and reduced probability of data loss (76.47%). Majority of experts (76.47%) strongly recommend implementation of the system under discussion, which speaks of its widespread applicability and superiority to conventional methods of transmission line supervision.

As per the simulated project, all stages of construction have been successfully documented by the system, namely excavation, stub setting, pouring PCC, reinforcement work, concreting process, backfilling and tower installation. Quality control measures were also documented, including results of cube test, and linked to corresponding towers. Moreover, photographic materials were used to verify the quality of work performed.

In functional testing the accuracy of system calculations has been validated. In particular, the volume of excavated earthwork and results of concrete cube test have been shown to correspond to manual calculations. Also, progress reports generated by the system allowed saving considerable amount of time and effort compared to manual reporting process.

Thus, the presented results reveal significant advantages of the system in terms of efficiency, clarity and decision making support in construction supervision. Still, further validation needs to be conducted using real field conditions.

A. Questionnaire Survey

The questionnaire survey results among 24 respondents (listed below) are presented in tables, of which the results of the 1st, 5th, 10th, 15th, 20th, and 24th questions are included here.

Q1. Professional role of respondents (Site Engineer / Project Manager / QC Engineer / Design Engineer)

Q2. Years of experience in transmission line projects

Q3. Digital systems reduce time required for reporting

Q4. Mobile/web data entry is faster than paper-based records

Q5. Automatic report generation improves monitoring efficiency

Q6. Manual records are vulnerable to loss in remote areas

Q7. Centralized database reduces risk of data loss

Q8. Cloud storage improves long-term record preservation

Q9. Paper records are difficult to manage in remote tower sites

Q10. Mobile data entry is convenient in rugged terrain

Q11. Offline data entry with synchronization improves usability

Q12. Digital linkage of cube tests improves traceability

Q13. Electronic cube test storage is more reliable

Q14. Automatic pass/fail improves quality assurance

Q15. Real-time access improves stakeholder communication

Q16. Dashboards improve transparency of progress and quality

Q17. Web-based access reduces need for site presence

- Q18. Photo + GPS improves reliability of supervision records
 Q19. Visual records support audits and dispute resolution
 Q20. Stage-wise photo attachment is better than manual archiving
 Q21. Web-based supervision is better than paper-based method
 Q22. Digital supervision improves quality management in transmission line projects
 Q23. System supports better technical decision-making
 Q24. Overall recommendation for implementation of digital supervision system

TABLE I: Q1. Your Professional Role.

Response	Frequency	Percentage (%)
Site Engineer	8	47.06
Project Manager / Consultant	4	23.53
Quality Control Engineer	3	17.65
Design Engineer	2	11.76

Inference: Majority of respondents were professionals involved in TL Sector.

TABLE II: Q5. Automatic report generation improves overall project monitoring efficiency.

Response	Frequency	Percentage (%)
4	14	82.35
3	3	17.65

Inference: Majority of respondents were in favour of digital tools for automated report generation.

TABLE III: Q10. Mobile-based data entry is more convenient for engineers working in rugged terrain.

Response	Frequency	Percentage (%)
4	11	64.71
3	4	23.53
2	2	11.76

Inference: The distribution of responses indicates a strong professional inclination toward the adoption of digital tools for construction supervision indicating that Mobile-based data entry is more convenient for engineers working in rugged terrain.

TABLE IV: Q15. Digital systems allow real-time access to construction data by all concerned stakeholders.

Response	Frequency	Percentage (%)
4	15	88.24
3	2	11.76

Inference: The distribution of responses indicates a strong professional inclination toward the adoption of digital tools for construction supervision indicating that digital systems allow real-time access to construction data by all concerned stakeholders.

TABLE V: Q20. Stage-wise photo attachment is more systematic than manual photo archiving.

Response	Frequency	Percentage (%)
4	15	88.24
2	1	5.88
3	1	5.88

Inference: The distribution of responses indicates a strong professional inclination toward the adoption of digital tools for construction supervision indicating that Stage-wise photo attachment is more systematic than manual photo archiving.

TABLE VI: Q24. Overall Recommendation for Digital Supervision System

Recommendation	Frequency	Percentage (%)
Highly Recommended for Immediate Implementation	13	76.47
Recommended with Minor Improvements	4	23.53

B. Overall Assessment

The overall assessment shows that most of the experts either highly recommend or recommend, with minor improvements, the implementation of the proposed digital supervision system. The absence of negative recommendations indicates strong confidence in the applicability of the system for improving efficiency, transparency, and reliability of supervision and quality management in high voltage transmission line construction projects. Fig. 3 shows the Pie-Chart showing overall recommendation of digital supervision over traditional supervision

Q24. Overall Recommendation for Digital Supervision System
17 responses

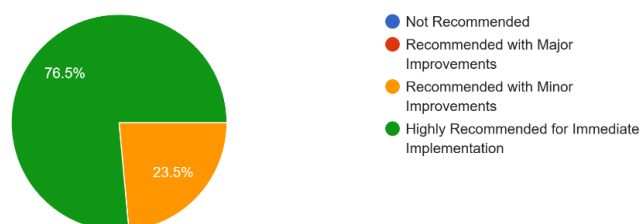


Fig. 3: Pie-Chart showing overall recommendation of digital supervision over traditional supervision.

V. CONCLUSIONS, SUGGESTIONS AND RECOMMENDATIONS

The present research involved development and validation of a web-based application that is aimed at facilitating quality supervision for civil works during high-voltage transmission line constructions in Nepal. Development of a digital tool facilitating record management and monitoring of construction processes was viewed as the main goal of this project.

Simulation of the construction process carried out in the Kathmandu Valley 220 kV Transmission Line Project helped to validate functionality of the developed solution. The presented system effectively depicted the process of tower foundation and erection, including construction activities related to excavation, stub setting, PCC, reinforcement, concreting, backfilling, and tower erection. The developed quality control mechanism made it possible to link results of cube tests and conformity of materials used at certain stages of construction.

Validation of functionality of the proposed solution included verification of the accuracy of calculations, logic of activities, and generation of progress and quality reports. The research revealed that digital solutions offer substantial advantages compared to the traditional methods of supervising construction works. In particular, digital tools enable better organization and reporting of construction processes.

Thus, development of a web-based application for quality supervision in transmission lines helps to facilitate organization and management of construction projects.

The following suggestions are proposed:

- i. It is recommended that the system be deployed and tested in real-life transmission line projects through actual use by multiple users simultaneously.
- ii. Offline data collection using mobile devices, followed by synchronization offline at later times, should also be integrated into the system for application in remote locations.
- iii. Other modules like safety inspection, environmental monitoring, equipment management, and weather data should also be integrated into the system to provide a more holistic solution.
- iv. Engineers and supervisors should be trained in how to utilize the system effectively.
- v. Further research should consider integrating this system with GIS and Building Information Modeling (BIM).
- vi. Comparative analysis should be done to measure the benefits of implementing this system against traditional approaches in actual projects.

ACKNOWLEDGMENTS

We would like to convey our thanks for their valuable cooperation to Mr. Janardhan Nepal (chairman), Dr. Samit Thapa (principal), and Pramod K. Karmacharya (coordinator), Master of Science in Construction Management, and Prabhu Ram Pokharel (HOD), Hillside College

of Engineering, Purbanchal University for their guidance, encouragement, and support during the course of this project work.

AUTHOR CONTRIBUTIONS

N. Dutta developed and tested the web-based application and carried out the data collection. R. C. Tiwari supervised the entire study and helped with system design and data analysis.

DATA AVAILABILITY

The data presented in this study was obtained during the process of developing the system and simulated project cases, along with the expert questionnaire survey. Simulated project data and system output data have been provided in the manuscript and supplementary materials. More data may be requested from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

- [1] A. Abu Laiba, "Web-based construction project management systems for quality and progress control," *J. Constr. Eng. Manage.*, vol. 134, no. 9, pp. 677–685, 2008, doi: 10.1061/(ASCE)0733-9364(2008)134:9(677).
- [2] American Concrete Institute, *Building Code Requirements for Structural Concrete (ACI 318-19)*. Farmington Hills, MI, USA: ACI, 2019.
- [3] Bureau of Indian Standards, *IS 456: Plain and Reinforced Concrete – Code of Practice*. New Delhi, India: BIS, 2000.
- [4] S. O. Cheung, H. C. H. Suen, and K. K. W. Cheung, "PPMS: A web-based construction project management system," *Autom. Constr.*, vol. 13, no. 3, pp. 361–376, 2004, doi: 10.1016/j.autcon.2003.12.003.
- [5] J. Garcia, L. Chao, and H. Kim, "Mobile computing for construction site data management and quality control," *J. Inf. Technol. Constr.*, vol. 19, pp. 107–123, 2014.
- [6] F. A. Ghansah, J. Ren, and N. Julka, "Digital quality management systems for concrete works: Traceability and compliance improvement," *Constr. Innov.*, vol. 24, no. 1, pp. 55–72, 2024.
- [7] International Electrotechnical Commission, *IEC 60826: Design Criteria of Overhead Transmission Lines*. Geneva, Switzerland: IEC, 2017.
- [8] Nepal Electricity Authority, *Annual Report 2023/24*. Kathmandu, Nepal: NEA, 2024.
- [9] Project Management Institute, *A Guide to the Project Management Body of Knowledge (PMBOK® Guide)*, 7th ed. Newtown Square, PA, USA: PMI, 2021.
- [10] J. Zhang, H. Li, and M. Skitmore, "Integrating web-based information systems for construction quality management," *Autom. Constr.*, vol. 68, pp. 64–75, 2016, doi: 10.1016/j.autcon.2016.04.006.