Enhancing Data Management Efficiency in Precast Concrete Manufacturing Through a Custom Database Solution

Alaa Abu Nokta[1], Mohammad Darwish[1], and Mohamed Al-Hussein[1]

[1] Department of Civil and Environmental Engineering, University of Alberta, Edmonton, AB, Canada
abunokta@ualberta.ca, mdarwish@ualberta.ca, malhussein@ualberta.ca

Abstract

It is crucial in complex production environments, such as precast concrete manufacturing, to have efficient data management. Construction enterprises must navigate and organize vast amounts of data as part of their critical decision-making functions. The research described in this paper uses a case study to examine the implementation of a custom database solution for data management in a precast concrete manufacturing facility. The database is developed to address existing organizational issues and production inefficiencies stemming from the absence of a centralized data management system. By automating and organizing data retrieval, the database streamlines data flow and enhances the accessibility and integrity of critical information. Moreover, a dashboard is developed to display essential performance indicators, such as project tracking, estimates of future revenue, and production schedules. The system manages various types of data, from management to production information. The case study highlights the importance of integrated data management systems in improving productivity, quality control, and overall performance in the construction industry.

Keywords

Data Management, Precast Concrete, Modular Construction, Database

1 Introduction

The application of data-driven approaches in construction projects has increased significantly in recent years, reflecting a growing recognition of the crucial role these approaches can play in project lifecycle management [1]. This expansion of data-driven applications within the construction industry is primarily attributable to the emergence and maturation of knowledge-based management [2], which facilitates innovation, ensures effective quality control [3], and can be used to manage large, complex datasets in an efficient manner [4]. Construction projects typically operate in complex environments, necessitating precise coordination among stakeholders, materials, and production processes. Consequently, the use of integrated database systems has become increasingly critical as a means of handling the substantial volumes of data generated throughout a facility's lifecycle [5].

In today's construction industry, efficient management of data, which is extensive and sourced from multiple stages and stakeholders, remains a challenge [6]. Traditionally, data management and information exchange in construction have been performed manually [7], resulting in wasted time, increased costs, and frequent data loss and inconsistencies stemming from human error [8]. Therefore, there is a critical need to transition from manual methods to robust technologies that ensure consistency and quality, as well as automated database management solutions that minimize these risks and support precise, informed decision-making.

Precast concrete manufacturers face unique industry-specific challenges, such as the need for optimized resource allocation, streamlined production workflows, and enhanced project monitoring, and this further emphasizes the importance of database solutions explicitly tailored to the needs of this subsector [9]. Data-centric structures have been demonstrated to be particularly effective in safeguarding data quality, maintaining security, and ensuring that critical information is accurate and readily accessible [10]. Moreover, the diversity and complexity of the data sources associated with construction necessitate comprehensive, versatile databases populated with data from real-life projects [11].

The studies outlined above provide a foundation for understanding the benefits of database integration in construction project management. In this context, this paper presents a data management framework that provides a solution to the industry's need for historical data tracking and a centralized data system. The main objective and contribution of the paper is the development of a structured database tailored to enterprises producing ribbed-structure precast concrete panels. The developed database enhances data integrity,

ensures consistent quality control, and enables efficient data storage while supporting informed decision-making.

The database was developed using data collected through a case study conducted at a precast concrete manufacturing facility in Edmonton, Canada. The database encompasses records of various aspects of management, production, geometric information of the panels, installation, material tracking, project tracking, and quality control.

2 Background

2.1 Literature review

Knowledge management plays a crucial role in project-based industries such as construction. However, the distinctive characteristics of construction projects often pose challenges with respect to the effective capture and utilization of information [3]. Dawood and Marasini [9] emphasized the significance of tailored database solutions in addressing specific challenges faced by precast concrete manufacturers, highlighting advantages such as optimized resource allocation, streamlined production workflow, and improved project monitoring. Similarly, Mathew Zachariah et al. [10] underscored the capability of data-centric structures in preserving data quality and security, ensuring that critical information remains accurate and accessible.

Christensen et al. [11] noted that the diversity of data significantly influences a database's overall quality. Supporting this perspective, Batselier and Vanhoucke [12] emphasized that comprehensive and versatile databases incorporating data from real-life projects are essential for integrated project management. Such databases facilitate real-time project tracking and reporting, thus enabling informed decision-making and proactive problem-solving [13, 14].

Recent studies have highlighted the value of dashboards in visually representing real-time data. Nimbarte et al. [15] emphasized the critical role dashboards play in improving user engagement and clarity in decision-making. They noted that dashboards effectively enhance communication among team members and offer a centralized platform for monitoring project progress, financial metrics, and key performance indicators (KPIs).

The Entity Relationship (ER) diagram has also been widely recognized as an essential component of database design. ER diagrams graphically illustrate relationships among entities such as people, objects, locations, or events, providing the foundational structure for relational databases [16]. ER diagrams are especially useful for clearly depicting data structures and relationships [17].

In summary, the literature underscores the utility of customized database solutions in addressing the specific challenges associated with precast concrete manufacturing, emphasizes the role of knowledge management in enhancing data quality and security, and highlights the advantages of dashboards and ER diagrams in improving data visualization and system design. Collectively, these insights establish the foundation for the structured database solution presented herein.

2.2 Case company's concrete panel system

The case company produces a wide range of precast concrete products and custom-built solutions for the residential and commercial markets. Its unique reinforced ribbed concrete panel system features vertical and horizontal ribs. The panel's structure includes layers of plywood, rebar, Styrofoam, wire mesh, and concrete. The panels are designed to provide structural and thermal strength, enhance durability, and reduce concrete usage. Figure 1 shows the layers of the panel's ribbed structure.

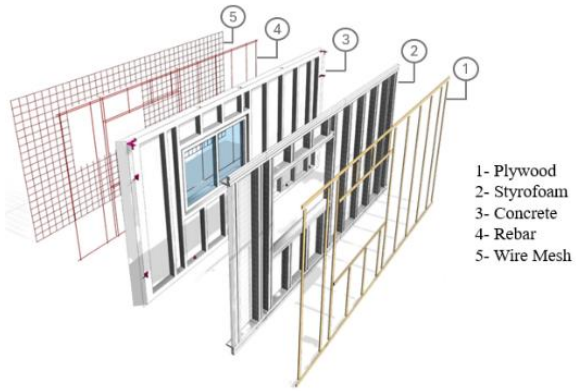

Figure 1: Breakdown of the case company's concrete panel system

2.3 Case company's project lifecycle

The case company's projects typically follow the lifecycle shown in Figure 2. The cycle begins with consultative meetings between management and the client to clarify the project's scope of work and to specify design criteria. The project management team then issues a quote to the client. If the client accepts the quote, a contract is negotiated and executed, and the project proceeds to the engineering stage. At this point, the

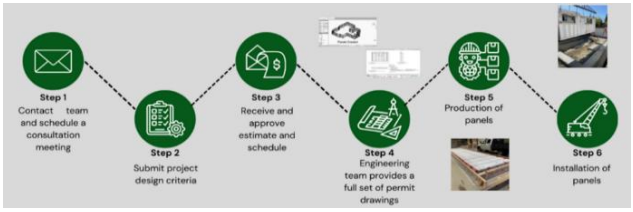

Figure 2: Project lifecycle

permit and production drawings are issued for production. The project then advances to production, at which stage precast panels are formed and poured. The project then proceeds to the final stage, installation.

2.4 Problem statement

Variations in product specifications, as well as the different attributes linked with each project, underscore the need for a system that combines work orders and organizes data flow within the enterprise while also serving as a resource for data reference. Such a system must support the following functions:

- Store client information (e.g., contact information).
- Input new project information into the system as projects are received from clients.
- Update the status of projects during each phase of their lifecycle.
- Generate production orders once a project is approved.
- Store panel information and bills of materials.
- Track concrete orders and the compressive strength testing results for the concrete panels manufactured.
- Store material and supplier information to support procurement and issue purchase orders.
- Provide reports to track sales and provide overall performance insights.

3 Methodology

The primary objective of the research presented in this paper was to create a comprehensive database solution that addresses the need to have a system that protects data integrity, tracks performance, forecasts production schedules, and generates reports as needed. MS Access was used to structure the database due to its user-friendly interface, cost-effectiveness, and ability to create tables, queries, forms, and reports. Another reason for choosing MS Access is that the case company is relatively small, such that having a single employee manage the database is sufficient. Its cost-effectiveness makes it an ideal fit for the case company's needs, offering robust functionality without the need for extensive IT resources. Moreover, given that there are plans to link the database to a simulation model that will be created using the Simphony.NET in the future, the interoperability between MS Access and the Simphony.NET simulation environment is another notable advantage.

Tables were built to contain critical information related to clients and projects, and they were connected using the appropriate relationship types. Additionally, the database was designed to facilitate tracking of project status and to generate reports of relevant project information. Each table is crucial in organizing and managing specific aspects of projects, clients, and resources. A structured database design ensures data integrity, efficient data retrieval, and comprehensive reporting for various stakeholders within the organization. In order to appropriately structure the database, the case company's workflow was studied. The flowchart shown in Figure 3 was built to represent the company's production process.

The process begins with gathering information about the project as the basis for establishing a scope of work. The project management team prepares a quote and issues it to the client. Upon the client's approval, the project will proceed to the engineering phase, which involves preparation of production drawings of the panels and a bill of materials. Purchase orders are issued based on materials' suppliers and prices, the bill of materials, and the project information. Following this phase, concrete is ordered. Following forming and pouring in the off-site production facility, quality control testing is conducted, marking the completion of the production phase. The final stage is the installation of precast components at the site.

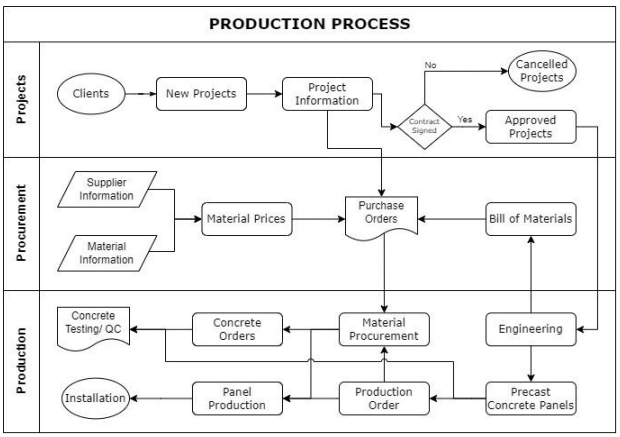

Figure 3: Production flowchart

4 Database development

4.1 Entity-Relationship diagram

An ER diagram was created to support the development of a database skeleton, complete with relationships between the various entities across different tables. The ER diagram served as a crucial blueprint for creating the database, visually representing the database's structure and the relationships among various entities. This diagram not only aided in understanding the intricacies of the data model, but also formed the foundation for effective database design. The ER diagram guided the decision-making process by outlining entities, relationships, and attributes, ensuring a coherent and organized database. Figures 4 and 5 illustrate the different entities, their attributes, and the relationships among them.

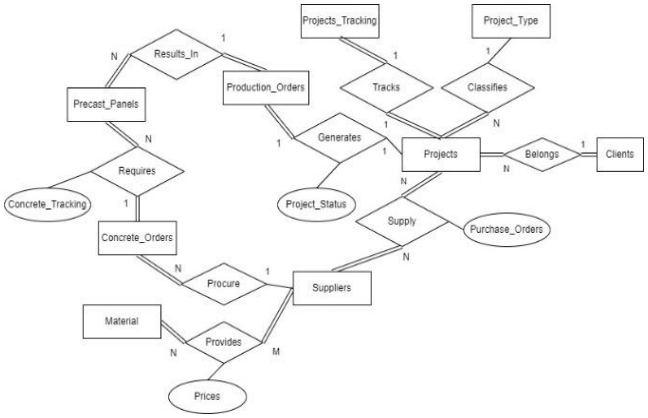

Figure 4: ER Diagram

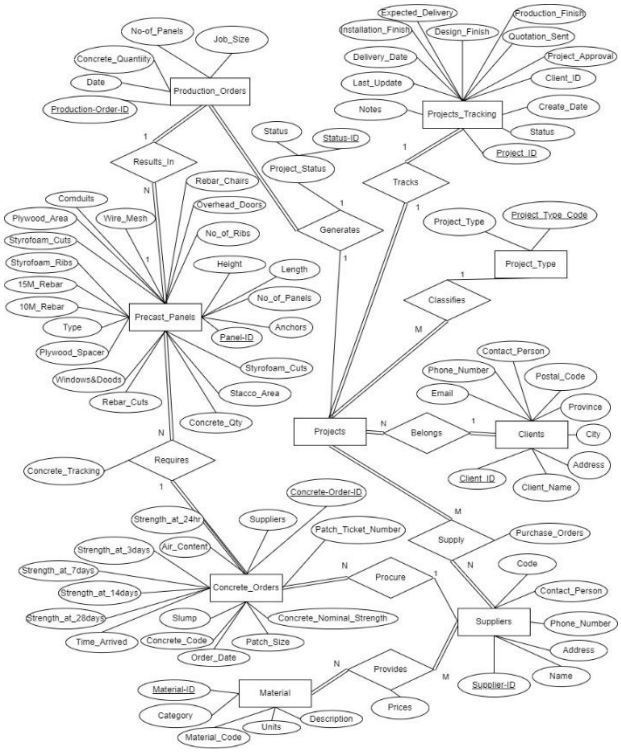

Figure 5: High-level ER Diagram

4.2 Database tables

The database tables (designed in MS Access) and their assigned attributes closely follow the proposed ER diagram. What follows is a summary of the tables and their use:

- *Clients*: This table is crucial for maintaining client information, including contact details. It provides centralized client data storage, facilitating access for various departments.
- *Project_type*: This table defines various project types, serving as a point of reference for categorizing and searching projects. It also ensures consistency in project-type definitions across the database.
- *Projects_info*: This table stores detailed project information, including cost estimates and scopes of work. It centralizes project-specific details for efficient project management and facilitates easy tracking and reporting on project-related metrics.
- *Project_tracking*: This table provides a comprehensive overview of project progress by tracking project status and key dates. It enables real-time monitoring of project timelines and milestones and facilitates communication among team members by documenting important project events.
- *Production_orders*: This table manages production orders and tracks concrete quantities. It organizes orders and links them to projects, streamlining the production process. Additionally, it provides insights into resource allocation and project-specific production requirements.
- *Precast_panels*: This table details the design specifications of precast panels. It offers a comprehensive view of panel characteristics, aids in quality control, and supports the accurate estimation of material and resource requirements.
- *Concrete_orders*: This table manages concrete orders, recording details such as supplier information and concrete specifications (e.g., strength). It tracks concrete usage across projects for resource planning purposes and facilitates quality control by recording concrete strength at various stages.
- *Panels_concrete_tracking*: This table tracks concrete usage for precast panels. It provides a detailed account of concrete application on panels and aids in troubleshooting and quality assurance for panel-related concrete work.
- *Project_status*: This table defines various project statuses, standardizes project status definitions for consistent reporting, and enhances communication by providing a common language for tracking project progress.
- *Materials*: This table centralizes information about materials used in projects. It tracks material details to support efficient inventory management and facilitate project cost analysis and budgeting.
- *Suppliers*: This table stores details about suppliers, including contact information and rates. It enables quick access to supplier information for procurement activities and supports the establishment of relationships via purchase orders and prices.
- *Prices*: This table records prices of materials from

different suppliers. It facilitates cost estimation and budgeting for projects and streamlines the process of selecting suppliers based on pricing information.

- *Purchase_orders*: This table manages purchase orders, including details such as quantity, price, and delivery information. It tracks procurement activities, ensuring timely and accurate order fulfillment. Additionally, the table provides transparency in financial transactions related to project expenses.

4.3 Entity relationships

The relationships between tables in the database help to connect the data and facilitate a cohesive project and client management system. The Clients table is a foundational element, establishing connections with multiple other tables. The Projects_info table is linked to the Clients table through the "Client_Code," connecting each project to a specific client. The Project_type table provides a reference point for categorizing projects, which in turn determines the "project_type_code" in the Projects_info table.

The Project_tracking table is connected to the Projects_info table through the "Project-ID," enabling seamless tracking of project statuses and key dates. The Production_orders table is linked to both the Projects_info and Clients tables, providing a bridge between production activities and the specific projects and clients they pertain to. The Precast_panels table also establishes connections with the Production_orders and Projects_info tables, ensuring that details about precast panels are associated with the corresponding projects and production orders.

The Concrete_orders and Panels_concrete_tracking tables connect to the Projects_info and Production_orders tables, recording information about concrete supply and usage in relation to specific projects and production orders. Additionally, the Prices and Purchase_orders tables are linked to the Suppliers table, forming relationships that aid in tracking material costs, procurement details, and supplier information. These interconnected relationships create a comprehensive network, allowing for efficient information retrieval, accurate project progress tracking, and seamless coordination among the various elements of the company's operations.

4.4 Database dashboard

A dashboard for this database was developed to showcase the results by enhancing the user experience and providing valuable insights into the company's projects and financial status. The dashboard consists of twelve forms for entering information into the database and twelve reports for information retrieval.

Figure 6 provides an overview of the developed dashboard.

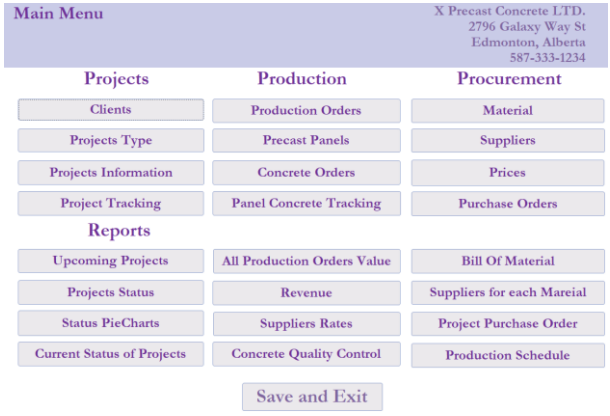

Figure 6: Developed dashboard

Below is a brief description of the reports generated by the developed dashboard:

- *Upcoming Projects*: Displays a list of approved future projects, providing details such as the project's name, client, and expected completion date.
- *Project Status*: Utilizes a bar chart and table to categorize projects based on their status (e.g., in progress, completed, or pending approval).
- *Status Pie Chart*: Incorporates a pie chart reflecting the distribution of projects across different statuses, providing both the project count and their cumulative value.
- *Current Status of Projects*: Allows users to input a specific project status, generating a report that details the projects in that particular status, including all relevant information.
- *Production Value*: Presents a comprehensive report listing the details of projects progressing to production orders, along with their associated values.
- *Revenue Report*: Generates a report showcasing completed projects and their values, enabling quick assessment of the revenue generated.
- *Suppliers Rates*: Includes a table summarizing the prices of materials from different suppliers, facilitating comparisons and procurement decisions.
- *Concrete Quality Control*: A detailed report linking concrete orders to the panels they were used for, including testing results for quality control purposes.
- *Bill of Materials*: Offers a breakdown of materials required for each project by panel, with a summary of total materials for efficient project planning and resource allocation.
- *Suppliers for Each Material*: Enables users to input a material type, generating a list of suppliers to aid in procurement decisions.

- *Project Purchase Order*: Lists all purchase orders related to the queried project, aiding in tracking of procurement activities.
- *Production Schedule*: Displays projects scheduled for production within a given date range, aiding in resource planning and scheduling.

The developed reports and dashboard provide a user-friendly interface for efficient project and client management, informed decision-making, and comprehensive data analysis.

5 Results

The developed database was implemented at the case company and was found to greatly improve project performance by streamlining processes such as purchase order management, reducing material waste, and providing more accurate production forecasts. Tailored reports, such as the "Upcoming Projects" and "Project Status" reports, were found to offer valuable insights into project progress and financial implications. The database, integrated with a dynamic dashboard, enabled real-time monitoring of KPIs and visual representations (e.g., "Status PieChart") that aided in identifying trends and bottlenecks in the project lifecycle. Figures 7, 8, 9, and 10 display some of the key outputs from the generated reports, including the exported concrete quantity report, project status percentage and value charts, and summary of upcoming projects.

It should be noted that the database is specifically designed to handle the unique requirements of precast concrete panel production. The database was found to improve communication and is now in use by the case company as an essential decision support tool. The developed database with user-friendly dashboard offers several benefits:

- Efficient monitoring: Tracks project status and performance metrics to support timely interventions.
- Enhanced productivity: Provides quick access to information for streamlined decision-making.
- Strategic planning: Offers a clear view of KPIs, helping management to identify areas for improvement.

While the use of a database for information storage and retrieval in construction management is not novel, the database developed in this study is structured to accommodate the unique design specifications and geometric information associated with ribbed precast concrete components. This approach ensures optimal performance and addresses the distinct needs of this construction subsector. Future work will involve creating a simulation model representing the case company's production process and integrating it with the developed database for estimation purposes.

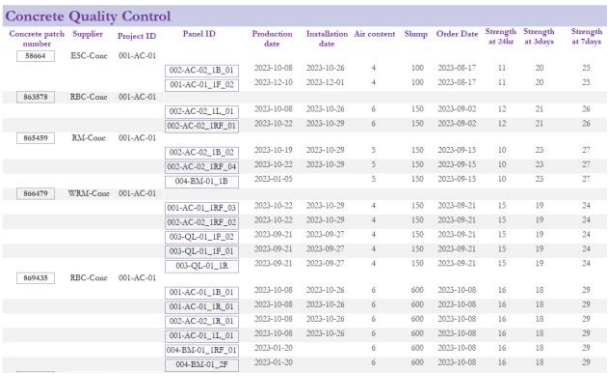

Figure 7: Concrete quality control report

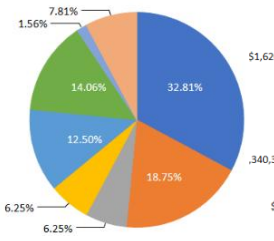

Figure 8: Percentage-based project status chart

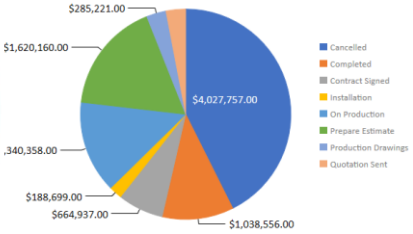

Figure 9: Financial value-based project status chart

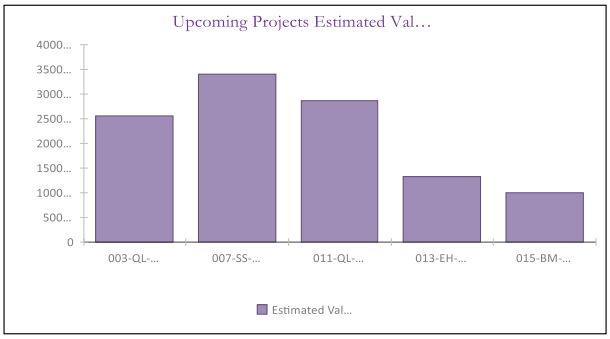

Figure 10: Chart representing the value of upcoming projects alongside their expected revenues

References

[1] Y. Huang, Q. Shi, J. Zuo, F. Pena-Mora, and J. Chen. Research status and challenges of data-driven construction project management in the big data context. *Advances in Civil Engineering*, 2021:674980, 2021.

[2] B. Ozorhon, C. G. Karatas, and S. A Demirkesen. web-based database system for managing construction project knowledge. *Procedia - Social and Behavioral Sciences*, 119:377–386, 2014.

[3] G. Eken, G. Bilgin, I. Dikmen, and M. T. Birgonul. A lessons learned database structure for construction companies. *Procedia Engineering*, 123:135–144, 2015.

[4] B. Thalheim. Component construction of database schemes. In *Lecture Notes in Computer Science: Proceedings of the International Conference on Conceptual Modeling*, 2503:20–34, 2002.

[5] L. Li, S. Msaadi, H. Manier, and M.-A. Manier. The creation of the hydrogen supply chain decision database. *Energies*, 16(24):8081, 2023.

[6] M. Bilal, O. L. Oyedele, J. Qadir, K. Munir, O. S. Ajayi, O. O. Akinade, and M. Pasha. Big data in the construction industry: A review of present status, opportunities, and future trends. *Advanced Engineering Informatics*, 30(3):500–521, 2016.

[7] M. Kantardzic. *Data Mining: Concepts, Models, Methods, and Algorithms*. Canada: John Wiley and Sons, Inc., 2011.

[8] H. T. T. Le, V. Likhitruangsilp, and N. Yabuki. A BIM-integrated relational database management system for evaluating building life-cycle costs. *Engineering Journal*, 24(2):75–86, 2020.

[9] N. Dawood and R. Marasini. An integrated database for real-time management of stockyard "stockman": A case study in precast concrete products industry. In *Proceedings of the CIB-W78 International Conference*, 2001.

[10] G. C. Mathew Zachariah, S. Santhosh, S. Anandhrosh, S. Thomas, and C. Mathew. Database and modern database technology. *International Research Journal on Advanced Engineering and Management*, 2(12):3680–3686, 2024.

[11] D. Christensen, R. C. Antolini, and J. W. McKinney. A review of estimate at completion (EAC) research. *Cost Analysis and Management*, 12(1):41–62, 1995.

[12] J. Batselier and M. Vanhoucke. Construction and evaluation framework for a real-life project database. *International Journal of Project Management*, 33(3):697–710, 2015.

[13] M. Martínez-Rojas, N. Marín, and M. A. Vila. The role of information technologies to address data handling in construction project management. Journal of Computing in Civil Engineering, 30(4): 04015064, 2015.

[14] W. Yandong and G. Jianya. A construction schema for provincial spatial database of China. Geo-spatial Information Science, 12(1):25–32, 2009.

[15] A. D. Nimbarte, N. Smith, and B. Gopalakrishnan. Human factors evaluation of energy visualization dashboards. Ergonomics in Design, 32(1):39–47, 2021.

[16] S. Hettiarachchi, C. Sugandhika, A. Kathriarachchi, S. Ahangama, and G. T. Weerasuriya. A scenario-based ER diagram and query generation engine. In *Proceedings of the 4th International Conference on Information Technology Research*, Moratuwa, Sri Lanka, 2019.

[17] C. Ordonez, S. Tahsin Al-Amin, and L. Bellatreche. An ER-flow diagram for big data. In *Proceedings of the IEEE International Conference on Big Data*, pp. 5795–5797, Atlanta, GA, USA, 2020.