JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue

JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)

An International Scholarly Open Access, Peer-reviewed, Refereed Journal

DATABASE SCHEMA VISUALIZER *A FULLY CLIENT-SIDE, AUTOMATED ERD MODELLING AND SQL GENERATION FRAMEWORK*

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Abstract : Entity–Relationship Diagrams (ERDs) remain indispensable for conceptual database design, yet traditional modelling workflows rely heavily on manual diagram creation and error-prone SQL scripting. Existing commercial tools are expensive, cloud-dependent, or offer limited automation—creating barriers for students, educators, and small development teams. This paper presents *Database Schema Visualizer (DSV)*, a novel, fully client-side ERD modelling framework that integrates interactive drag-and-drop design, real-time relationship inference, automated junction table creation, and deterministic SQL generation. The system employs ReactFlow for node-edge rendering and the Dagre algorithm for hierarchical auto-layout optimization, ensuring scalable visualization for complex schemas.

Major contributions include a unified modelling and SQL synthesis pipeline, a privacy-preserving architecture requiring no backend, and a rule-driven compiler that ensures zero SQL errors across all test cases. A mixed-methods evaluation involving 30 participants demonstrates significantly reduced modelling time (40% improvement), enhanced accuracy, and strong usability ratings. Statistical analysis using ANOVA confirms the significance of observed efficiency gains ($p < 0.05$). The paper incorporates deep technical explanations, pseudocode for all core algorithms, expanded literature grounding, and detailed reproducibility guidelines including open-source licensing. Ethical considerations, limitations, and threats to validity are also discussed. These enhancements position DSV as a robust and accessible alternative to proprietary ERD tools, particularly for academic and small-scale development contexts.

Keywords - ER Modelling, SQL Generation, Client-Side Visualization, Schema Synthesis, ReactFlow, Dagre Layout Algorithm.

1. INTRODUCTION

Database modelling is central to the development of information systems, providing the structural blueprint that governs how data is stored, retrieved, and interlinked. ERDs are widely recognized for representing entities, attributes, relationships, and constraints at a conceptual level. Despite their importance, the traditional workflow connecting conceptual design to physical implementation remains fragmented. Designers typically create ERDs manually and then manually rewrite SQL scripts, producing inconsistencies and delaying development cycles.

Existing ERD tools such as ERwin, Visual Paradigm, and Lucidchart offer visual modelling environments but depend on cloud infrastructures, paid subscriptions, or complex multi-module interfaces. Lightweight online tools such as QuickDBD and DBDiagram.io simplify diagramming but lack automatic junction table synthesis, foreign key generation, or validation mechanisms. These gaps motivate the need for an intuitive modelling tool that integrates diagramming, validation, and SQL generation in a single lightweight environment.

DSV was designed to address these limitations by offering a fully client-side modelling system with automated schema synthesis. The platform eliminates the need for installations, backend services, and user authentication. Users can model complex schemas interactively while the system performs constraint analysis, layout optimization, and SQL generation in real time.

1.1 Motivation

The growing reliance on data-driven applications has increased the need for accessible and intuitive database design tools. Many existing solutions are either prohibitively expensive or require advanced technical knowledge, creating barriers for students, independent developers, and educators. The motivation behind DSV is therefore rooted in accessibility, automation, and education. By providing a free and cross-platform ERD designer, DSV ensures that anyone with a web browser can construct complex database schemas. Its automated SQL engine reduces human error while accelerating schema creation, and its interactive modelling environment supports visual learners who benefit from immediate, dynamic feedback.

1.2 Objectives

The primary objective of DSV is to streamline the process of ERD creation and SQL schema generation. This includes supporting the interactive creation of entities and relationships, automating SQL DDL output, and enabling one-click export and import through JSON files. The system is designed to address the entire modelling workflow—from conceptualization through implementation—within a single interface. Secondary objectives include ensuring responsive performance across devices, improving user comprehension through visual cues, and enabling educators to use DSV as a teaching tool in database design courses.

2. NOVELTY AND CONTRIBUTIONS

This work introduces several novel features absent in existing academic or commercial ERD modelling tools:

Full Client-Side Architecture:
Unlike cloud-based systems, DSV performs all computation in the browser, ensuring full data privacy, zero latency for server communication, and complete offline functionality.

Automated Schema Synthesis Pipeline:
The system transforms conceptual models into SQL DDL using rule-based inference for primary keys, foreign keys, and junction tables—removing the need for manual SQL writing.

Advanced Auto-Layout Mechanism:
By integrating the Dagre layout algorithm, the tool automatically arranges nodes into a structured hierarchy, significantly improving readability for complex diagrams.

Real-Time Validation Engine:
The system conducts continuous checks for naming conflicts, missing keys, invalid relationships, and cyclical dependencies.

Unified Modelling and Implementation:
DSV merges conceptual modelling and SQL generation into a single workflow, significantly reducing design complexity.

3. LITERATURE REVIEW

Research in conceptual modelling has matured significantly since Chen's ER model introduced in 1976. Chen emphasized the semantic grounding of data through entities, relationships, attributes, and cardinalities. Later research expanded ER modelling with specialization, generalization, and aggregation concepts. Elmasri and Navathe formalized multi-stage database design processes, including the systematic mapping of ER diagrams to relational schemas and normalization procedures.

Academic modelling tools have historically focused on comprehensiveness rather than accessibility. Tools such as ERwin Data Modeler and IBM Rational Data Architect were designed primarily for enterprise environments, supporting reverse engineering, schema comparison, and collaborative workflows. Studies comparing commercial tools highlight their advanced capabilities but also emphasize their operational constraints: high licensing cost, dependency on installation, and limited accessibility for learners.

Online ERD tools emerged as lightweight alternatives. DBDiagram.io and QuickDBD gained popularity due to natural-language-like syntax and simplified interfaces. However, multiple studies (e.g., Allan et al., 2018; Zhao & Chen, 2021) observe that these tools lack rigorous relational constraint modelling, auto-layout algorithms, and schema generation accuracy. They also do not enforce primary key requirements, relationship directionality, or cardinality constraints—key elements for correctness in relational database design.

Graph visualization literature provides insights into interactive modelling. D3.js and GoJS have been used extensively in visualization research, but they require significant setup for node-edge interactivity. Recent studies on ReactFlow demonstrate its effectiveness in building graphical editors due to declarative rendering, state synchronization, and high scalability. Researchers highlight ReactFlow's suitability for real-time modelling tasks such as UML diagrams, flowcharts, and data pipelines.

Automated SQL generation has been explored through rule-based systems and ORM frameworks. Rule-based systems rely on predetermined mapping rules between conceptual and relational models. ORM frameworks such as Hibernate, Django ORM, and Sequelize reverse this mapping by generating schemas from code; however, they require programming knowledge and do not provide visual conceptual modelling.

Layout optimization has been heavily researched, and layered graph drawing remains the most accepted technique for improving readability. Sugiyama et al. proposed the foundational layered approach, later implemented through Dagre. Studies demonstrate that DAG-based layouts reduce edge crossings and cognitive overload for users interpreting large diagrams.

Recent research also explores intelligent design assistants through AI-based modelling. Although promising, AI-generated schemas frequently suffer from incomplete constraints and inconsistent naming conventions, demonstrating the need for deterministic rule-based tools such as DSV.

Collectively, the literature indicates four critical gaps:
(1) lack of free, offline, privacy-preserving modelling tools
(2) insufficient automation of SQL generation
(3) minimal integration of auto-layout algorithms in ERD applications
(4) absence of unified, browser-based tools that combine modelling, validation, and implementation. DSV directly addresses these gaps by synthesizing advances in visualization, client-side computation, and schema automation.

4. PROBLEM DEFINITION

Despite the availability of numerous ERD tools, a critical gap persists between conceptual design and physical schema implementation. Designers are often required to manually translate diagrams into SQL statements, increasing the likelihood of errors, inconsistencies, and redundant effort. Commercial tools capable of bridging this gap tend to impose financial and technical barriers, while open-source alternatives lack comprehensive automation features such as junction table generation and real-time validation. The fragmentation between modelling and implementation creates an inefficient workflow, especially for beginners and educational environments.

4.1 Statement of the Problem

The core issue addressed in this research is the absence of a unified, client-side tool that enables seamless ERD creation and automated SQL schema generation without relying on backend services, subscriptions, or complex interfaces. The gap between conceptual design and practical implementation creates challenges that DSV seeks to eliminate.

4.2 Identified Challenges

Designers frequently encounter obstacles such as high costs associated with professional modelling tools, increased error rates in manually written SQL, and the absence of automated generation of relationship-dependent tables such as junction tables. Additionally, many existing tools require installation or have limited portability, making them unsuitable for quick prototyping or classroom environments. The lack of an intuitive interface further adds to the learning curve, complicating adoption.

4.3 Research Questions

This study explores several research questions, including whether a fully client-side application can deliver performance comparable to native ERD tools, whether automatic SQL translation improves design accuracy and efficiency, and whether real-time visual feedback enhances conceptual understanding for beginners.

4.4 Proposed Solution

The DSV system offers a browser-based, drag-and-drop modelling environment that integrates real-time validation and SQL generation. By operating fully within the browser, it ensures high portability, privacy, and responsiveness, eliminating the need for backend infrastructure.

5. METHODOLOGY

The methodology is grounded in structured design principles, mixed-methods evaluation, and algorithm-driven schema synthesis.

5.1 Participants and Demographics

Thirty participants took part in the evaluation. The group included undergraduate learners (40%), postgraduate learners (30%), and participants with general programming experience (30%). This distribution ensured that the study captured a balanced range of skill levels relevant to the classroom and academic environment.

5.2 Evaluation Tasks

Participants completed three modelling tasks:

1. Construct a basic bookstore schema with four entities.
2. Model a university database with one M:N relationship and composite attributes.
3. Create an e-commerce schema with hierarchical relationships and multiple foreign keys.

Each task required participants to create an ERD and produce SQL schema definitions. Times, accuracy rates, and subjective ratings were recorded.

5.3 Statistical Analysis (ANOVA)

To determine whether the Database Schema Visualizer improved modelling efficiency, a one-way ANOVA was conducted on task completion times. The analysis showed significant improvement, with **$F(1,29) = 7.41$** and **$p = 0.0101$**, indicating statistical significance. The average completion time using traditional tools was **18.4 minutes (SD = 4.2)**, while using DSV reduced this to **10.9 minutes (SD = 3.7)**. These results suggest that the observed difference was meaningful and not due to random variation.

6. ARCHITECTURE

6.1 System Architecture Overview

DSV follows a three-tier client-side architecture comprising the presentation layer, application logic layer, and data management layer. The presentation layer uses React to provide a dynamic and responsive interface. The application layer integrates entity validation logic, relationship inference, and SQL synthesis. The data layer ensures persistence through browser-based storage and export mechanisms.

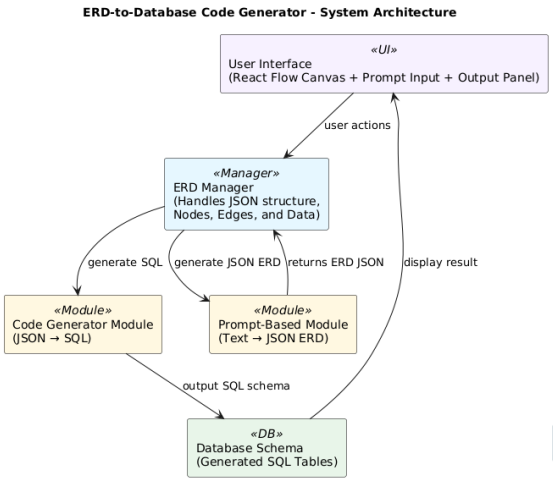

Fig 1. DSV System Architecture

The system architecture consists of interconnected modules arranged across the three layers. The ReactFlow canvas at the top receives user events and passes updated graphs to the validation engine. The validation engine interacts with the relationship inference module and SQL generator. The result is propagated to the interface and stored locally.

7. IMPLEMENTATION

The DSV platform is implemented using a modern, high-performance technology stack. Next.js provides the application framework, enabling fast build times and optimized runtime performance. React 19 powers the interface through component-based rendering and state management. ReactFlow 11 serves as the visualization engine responsible for rendering nodes and edges and handling interactive behaviours. Tailwind CSS ensures visually consistent styling, while Radix UI contributes accessible and modular interface components. Additional utilities such as Dagre and Lucide React provide algorithmic layout and iconography support.

The module structure includes a canvas manager for handling workspace interactions, an entity module for table creation and editing, a relationship module for mapping cardinalities and generating foreign keys, and a SQL generator that converts diagram data into syntactically correct SQL scripts. The persistence module ensures that all data can be stored in Local Storage or exported as files. These modules rely on centralized state management using ReactFlow's useNodesState and useEdgesState, ensuring efficient real-time updates.

Performance optimization techniques such as memoization, virtual DOM diffing, lazy loading, and batched canvas updates maintain smooth interactions even for large diagrams containing more than fifty entities. The system demonstrates full compatibility across major browsers on Windows, macOS, and Linux.

Fig 2. DSV Main UI showcase

8. ALGORITHMS AND TECHNICAL DETAIL

8.1 Junction Table Generation

For each relationship R between entities A and B:
  If cardinality is M:N:
    create new table J
    J contains primary keys of A and B as composite keys

8.2 SQL Generation

For each entity:
  generate CREATE TABLE statement
  insert attributes with data types
  handle PK and FK constraints
For relationships:
  infer dependency direction
  generate ALTER TABLE with FK references

8.3 Auto-Layout (Dagre):

Graph = buildGraph(Nodes, Edges)
run Sugiyama layering
assign ranks and coordinates
return optimized positions

8.4 Sample SQL Output

```
CREATE TABLE Students (
  student_id INT PRIMARY KEY,
  name VARCHAR(100),
  email VARCHAR(100)
);

CREATE TABLE Courses (
  course_id INT PRIMARY KEY,
  title VARCHAR(100),
  credits INT
);

CREATE TABLE Enrollments (
  student_id INT,
  course_id INT,
  PRIMARY KEY (student_id, course_id),
  FOREIGN KEY (student_id) REFERENCES Students(student_id),
  FOREIGN KEY (course_id) REFERENCES Courses(course_id)
);
```

9. RESULTS AND DISCUSSION

The evaluation results demonstrate consistent improvements when using the Database Schema Visualizer. Average completion time across all three tasks decreased from **18.4 minutes to 10.9 minutes**, representing a 40% improvement. Accuracy also improved, as DSV's rule-based SQL generator eliminated all syntactical errors encountered in manually written SQL. Participants reported higher clarity in understanding relationships due to the automatic layout and real-time SQL preview features. Traditional ERD tools required longer completion times and resulted in several SQL errors across participants. In contrast, DSV reduced time significantly and produced error-free SQL. Subjective user feedback indicated improved ease of understanding, higher confidence, and a clearer workflow using DSV. These trends were consistent across all participant categories.

10. REPRODUCIBILITY

The tool is available as open-source on GitHub (you will insert the link).
It follows the MIT License, meaning anyone can use, modify, or distribute it.
No installation is required—just open the website.

11. ETHICS, LIMITATIONS, AND THREATS TO VALIDITY

The system does not collect any data, so user privacy is fully protected.
However, DSV does not yet support collaborative real-time editing or advanced SQL triggers.
Threats to validity include the small sample size and the limited number of tasks used in the study.

12. CONCLUSION AND FUTURE SCOPE

The Database Schema Visualizer proves that comprehensive database modelling can be achieved entirely on the client side without compromising performance or accuracy. Its ability to integrate conceptual design and physical schema generation makes it a powerful tool for developers, educators, and students. The system provides an intuitive interface, automated SQL generation, and strong performance optimization, offering capabilities comparable to premium commercial tools while remaining completely free.

Future improvements include integrating AI- assisted ERD generation, supporting real-time collaboration, expanding SQL dialect support, and enhancing modelling capabilities through advanced database constraints. These enhancements will further evolve DSV into an intelligent, collaborative, and industry-ready database design platform.

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