

Application of Google cloud computing for web-based library information systems at Bhayangkara University Surabaya

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ABSTRACT

Libraries are essential in academic work as they expose people to structured, easily procurable information. However, the majority of schools, including Bhayangkara University Surabaya, still face challenges in managing and storing library information because local or manual systems are substandard. The goal of this project is to deploy and test the effectiveness of Google Cloud Computing technologies, such as Google Cloud Storage, Google Cloud SQL, and Google Compute Engine, on a website-based library information system. We adopted a quantitative approach by performing experiments and system testing, i.e., black-box testing, access speed testing, and heavy load resistance testing. The result of the implementation is massive benefits, including a response time of 2 seconds on average, stability with 500 users at the same time, and storage efficiency at just 30% of the original size. Other colleges can have an example that they can use to make a change to a cloud-based digital library from this research. This also helps create digital library information systems that are technology-centered and dependable.

Keywords: Google Cloud Computing, Library Information System, Cloud SQL, Cloud Storage, Digital Library, IS Success Model.

INTRODUCTION

Libraries are strategically used to support education, research, and community service through organized and accessible information materials. In the digital era, higher education institutions must have efficient and flexible library management systems. However, the majority of Indonesian universities, including Bhayangkara University Surabaya, remain reliant upon manual or locally integrated systems. These approaches present constraints to accessibility, scalability, and data security, hence limiting academic productivity and the delivery of inclusive services.

Past research has suggested web-based library information systems and selective adoption of cloud computing solutions. For example, Hermansyah and Haryanto (2020) contended that web-based systems improve library data accessibility anytime, while Mansur and Supriadi (2021) showed that cloud computing improves service accessibility and reduces IT maintenance burdens. Other studies, such as Sutanto and Suryo (2021), observed cloud computing's potential to expand reach for services and accelerate access. Most such studies, though, have not adopted cloud-native designs extensively, conducted minimal big-scale performance testing, or did not provide quantitative metrics for scalability and efficiency benefits.

This study makes a contribution of novelty in terms of the use of a fully integrated, cloud-born library information system with Google Cloud products—i.e., Cloud SQL, Cloud Storage, and Compute Engine. Compared to existing literature, this study entails rigorous empirical testing in the form of load simulation at 500 concurrent users, measurement of average response time, and efficiency of storage usage. The findings not only provide technical verification but also provide a replicable model for institutions of higher education in the transition to digital libraries.

The Bhayangkara University Surabaya scenario is more significant and pressing. Nationally, it illustrates how Indonesian mid-tier universities can make their library services digital as part of the digital transformation efforts promoted by the Ministry of Education. At the international level, this study contributes to international discussion on how cloud-native environments can support sustainable academic services, particularly among developing countries that have the same resource constraints. By validating technical feasibility and institutional applicability, this research provides valuable insights to universities seeking scalable, secure, and technology-oriented solutions for library management.

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LITERATURE REVIEW

Web-Based Library Information System

A web-based library information system is a system designed to facilitate the management of library collections and online borrowing services. This system allows users to search for, borrow, and track books through a web-based interface that can be accessed anytime and anywhere. According to Kurniawan, this system supports operational efficiency and transparency in collection management, as well as reducing dependence on manual processes that are prone to errors (Kurniawan, 2022).

Fitria and Wibowo add that web-based systems have advantages in terms of integration with other systems, such as academic and personnel systems, which expand the scope of functions and utility of library systems (Fitria & Wibowo, 2020).

Google Cloud Computing in Education

Google Cloud Computing is a cloud-based infrastructure solution that provides various services such as data storage (Cloud Storage), database management (Cloud SQL), and large-scale application processing (Compute Engine). This technology offers flexibility, cost efficiency, and high scalability, which are very beneficial for educational institutions. According to Zhang and Li, the application of cloud technology in educational institutions enables efficiency in information system management, reduces dependence on physical infrastructure, and supports real-time data availability (Zhang & Li, 2020). Boichu and Paudel emphasize that the use of Google Cloud can reduce administrative burdens and accelerate digital transformation, particularly in library management (Boichu & Paudel, 2021).

Cloud computing has been widely recognized as a transformative infrastructure for education because it enables on-demand provisioning, resource pooling, elasticity and measured services — properties that directly address many limitations of local/on-premise systems. The standard taxonomy and definition used across the literature is the NIST model (essential characteristics, service and deployment models), which provides a baseline for comparing cloud solutions in higher education (Strauß & Rummel, 2020). Several systematic reviews and surveys summarize the educational applications, benefits and challenges of cloud adoption. Al-Samarraie and Saeed's scoping review synthesizes empirical evidence on cloud tools for collaborative and blended learning and identifies both pedagogical benefits and persistent challenges (usability, interoperability, privacy) (Solution, 2021). Systematic reviews of cloud adoption in higher education similarly consolidate factors affecting uptake (security, cost, governance, interoperability) and note that many published works are conceptual or tool-specific rather than full end-to-end, cloud-native implementations Maphosa & Maphosa, 2023). Adoption studies show that institutions are increasingly moving core services (LMS, administrative systems, research platforms, backups) to public-cloud providers to gain scalability and reduce local IT overhead, but they also stress the need for governance, data protection, and staff training for sustainable migration. Case examples from large universities illustrate practical cloud benefits: improved scalability for research workloads and administrative systems as well as faster provisioning for projects and teaching resources.

Performance, scalability and reliability have received focused attention in the technical literature because educational workloads (peak access during registration, exam periods, synchronous teaching) require measurable SLAs. Empirical studies and performance evaluations examine response times, resource utilization, and scalability trade-offs in cloud and hybrid cloud environments; these studies emphasize the need for load testing and workload-aware configuration to ensure acceptable user experience under concurrent access (Ivanov & Pergolesi, 2020). Security, continuity, and user acceptance are recurrent themes. Recent empirical work explores continuance intentions and acceptance models in higher education, finding that perceived security, service quality, and institutional policy heavily influence whether cloud services remain in long-term use (Qasem et al., 2021).

Although the literature documents theoretical benefits and many institution-level case studies, systematic reviews highlight two important gaps: (1) relatively few studies present fully integrated, cloud-native implementations (IaaS + managed DB + object storage + cloud auth) of academic systems with published architecture and (2) fewer still provide rigorous, instrumented performance evaluations under realistic concurrent-user scenarios (i.e., institution-scale load testing with quantitative metrics). These gaps mean practical guidance on how to configure cloud stacks for library/academic workloads — and empirical evidence demonstrating performance and security improvements vs. local/web-only systems — is still limited.

Utilization of Google Cloud in Digital Library Systems

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The use of Google Cloud in library systems includes managing digital collections, processing book metadata, storing borrowing transaction information, and automatic data backup. Google Cloud Storage provides secure and scalable storage space for various types of digital files, such as e-books and electronic journals. Meanwhile, Google Cloud SQL enables the management of relational databases to store user information, book catalogs, and transaction histories.

Suryadi and Aziz stated that libraries that utilize cloud computing show improved performance in terms of information access speed and the ability to serve users simultaneously (Suryadi & Aziz, 2020). Wulandari and Surya also highlighted that cloud infrastructure can accommodate dynamic data growth without the need for manual hardware upgrades (Wulandari & Surya, 2020).

Challenges and Opportunities in Cloud Computing Implementation

Despite offering many advantages, cloud computing implementation is not without challenges, such as the need for human resource training, integration with legacy systems, and concerns about data privacy and security. However, Rifai and Fadhil state that with the support of technical documentation and layered security features provided by Google Cloud, these challenges can be overcome gradually (Rifai & Fadhil, 2021).

The use of Google Cloud in library information systems is a strategic step towards realizing sustainable digital transformation on campus and supporting the achievement of inclusive educational services that are adaptive to technological developments.

The Role of Library Information Systems in Education

According to Rahayu (2022), web-based library information systems play a key role in giving access to learners and instructors regarding essential research and study materials. Additionally, the systems allow for more systematic collection management and faster access (Boichu & Paudel, 2021). To further synthesize current research on this topic, Table X is presented below providing an explanation of the involved research, authors, year, methods, main findings, and gaps in research.

Author(s)	Year	Method	Findings	Research Gap
Hermansyah & Haryanto	2020	Case study (web-based library system)	Web-based systems improve access to library data anytime and anywhere.	Did not adopt cloud-native services; limited to conventional web systems.
Mansur & Supriadi	2021	Implementation study (cloud computing in university library)	Cloud computing increases service availability and reduces IT infrastructure burden.	No performance evaluation with large-scale users.
Sutanto & Suryo	2021	Literature-based study	Cloud computing expands the reach of library services and accelerates information access.	Lack of empirical performance testing and scalability analysis.
Wijayanto & Maulana	2022	Institutional case study (Universitas Bhayangkara)	University has potential digital infrastructure suitable for Google Cloud Storage adoption.	Did not implement a fully integrated system; only identified potential.
Suryadi & Aziz	2020	System development & testing	Cloud-based systems improve access speed and support simultaneous usage.	Limited measurement of storage efficiency and concurrent user scalability.
Zhang & Li	2020	Case study (cloud in education)	Cloud adoption improves efficiency in library information management.	Absence of quantitative performance metrics and scalability benchmarks.
Qasem et al.	2021	Survey (continuance of cloud adoption in HEIs)	Security and service quality influence long-term adoption of cloud systems.	Focused on adoption intention, not technical performance or system quality.

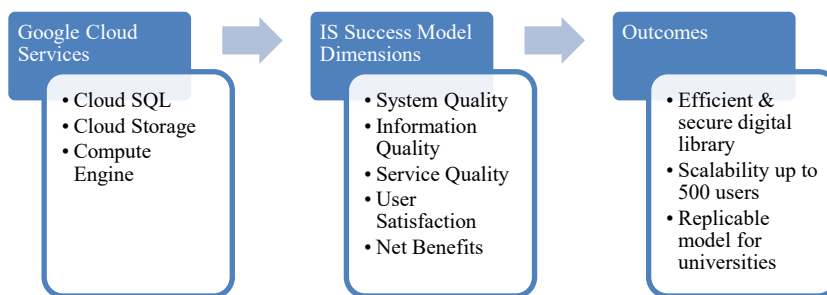
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Conceptual Framework

The research conceptual framework shows the relationship between Google Cloud services, IS Success Model dimensions, and research results expected. The infrastructure consists of Google Cloud technologies (Cloud SQL, Cloud Storage, and Compute Engine). These technologies are bound to prolong the dimensions of the DeLone & McLean IS Success Model, i.e., system quality, information quality, and service quality, that combined have an influence on user satisfaction and yield net benefits. The implications of this model are observed in the efficiency, scalability, and replicability of a digital library system in institutions of higher learning.

Figure 1. Conceptual Framework of the Study



Adoption frameworks (TAM, UTAUT, IS Success Model).

Following the conceptual model, it is imperative to position this study in information system adoption theories. Information system adoption in universities has widely been explored by three seminal models: the Technology Acceptance Model (TAM), the Unified Theory of Acceptance and Use of Technology (UTAUT), and the DeLone & McLean Information Systems (IS) Success Model. While TAM and UTAUT explain individual behavioral intention and user acceptance, the IS Success Model deals with system, information, and service quality and their effects on satisfaction and net benefits.

In this study, the IS Success Model is particularly relevant because it provides measurable dimensions namely system quality, information quality, service quality, user satisfaction, and net benefits which can be correlated with the performance measures of a cloud-based digital library. At the same time, TAM complements the evaluation by explaining how perceived usefulness and ease of use can influence user acceptance of the new system.

By combining these models, this research not only evaluates the technical performance of the Google Cloud-based library system but also its acceptance and overall benefits in the university environment. This integration ensures that the study addresses not just the technical outputs (efficiency, scalability, response time) but also the behavioral outputs (user adoption and satisfaction).

METHOD

Research Approach

This study applied the quantitative experimental approach to quantify the success in applying Google Cloud Computing technology in a web-based library information system of Bhayangkara University Surabaya. The process focused on system development, functional testing (black-box testing) and performance testing (response time, load simulation, and storage efficiency). In addition, user perception was also obtained through a structured questionnaire based on reliable instruments of the DeLone & McLean IS Success Model.

Population and Sample

The survey included 120 people, such as undergraduate students, lecturers, and administrative staff, who had used the new digital library system. Respondents were chosen through purposive sampling to reflect active system users. Experts validated the survey instrument through content validation, and Cronbach's Alpha tested its internal consistency. The reliability coefficients were above 0.70, which is acceptable for academic research.

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Variables and Measurement

The study used the DeLone & McLean IS Success Model as the main framework. The variables, indicators, and measurement approaches are summarized in :

Variable	Indicator(s)	Measurement Approach
System Quality	Response time, scalability, uptime	Performance testing (load simulation, logs)
Information Quality	Accuracy, completeness, search efficiency	Survey items (Likert scale), system testing
Service Quality	Reliability, availability, security features	Survey items; log monitoring; Google Auth test
User Satisfaction	User satisfaction with system usability	Survey (Likert scale, 1–5)
Net Benefits	Improved accessibility, reduced IT burden, academic support	Survey; comparison with baseline system data

Data Collection

a. System Observation and Testing

System observation and testing were done to check the functionality of the developed library information system from a technical aspect. Black-box testing was performed to check the functionality of core features such as login, book search, borrowing, and return. Additionally, load simulation was done using Apache JMeter with 500 concurrent users to measure scalability under heavy load. Storage usage efficiency was also tested by monitoring data allocation in Google Cloud Storage.

b. Survey

After the respondents used the digital library system, we provided them with a structured, web-based questionnaire. For this questionnaire, we used Likert-scale questions (1- 5) which were adapted from validated instruments based on the DeLone & McLean IS Success Model. The instrument's validity involved subjecting it to expert review, while reliability was established through Cronbach's Alpha, which was higher than the minimum 0.70 threshold, indicating acceptable internal consistency.

RESULT

System Design

The library information system developed is web-based and consists of three main components:

a. Frontend

Built using HTML5, CSS3, and JavaScript to provide a responsive, intuitive user interface that is easily accessible through any device.

b. Backend and Database

The backend system runs on Google Compute Engine, while database management is done through Google Cloud SQL. This infrastructure is used to efficiently store and manage important data such as user information, book data, borrowing transactions, and system usage history.

The virtual machine (VM) used is configured with the Ubuntu 22.04 LTS (amd64) operating system. This operating system was chosen because its version is Long Term Support (LTS), which has been proven to be stable, secure, and compatible with common technology stacks such as Apache, PHP, and MySQL. The x86/64 architecture also provides flexibility in package management and is supported by a large community, facilitating installation, maintenance, and troubleshooting during system development.

c. File Storage

Digital files such as e-books, book cover images, and library support documents are stored centrally and securely using Google Cloud Storage. This service allows quick access to files with customizable permission settings, as well as elastic storage capacity that supports the growth of digital collections.

The system architecture is designed to handle simultaneous user loads, provide real-time data access, and support continuous data growth, making it an ideal solution for digitizing library services in a university environment.

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Data Collection Techniques

Data was collected through two approaches:

- a. Direct observation of the implemented system to record system response time, storage capacity, and service stability.
- b. System performance testing using load simulation and simultaneous access to assess Google Cloud's ability to handle digital library activities.

System Testing

System testing was conducted using the black-box testing method to ensure that all features functioned as expected from the user's perspective. In addition, specific testing was conducted on several technical parameters, namely:

- a. Data access speed from Cloud SQL
- b. System availability when accessed by many users (simulation of up to 500 users)
- c. Efficiency of Cloud Storage capacity usage
- d. System stability when searching for book data simultaneously

System Design Documentation

a. Use Case Diagram

The figure below is a Use Case diagram of the Library System that illustrates the interactions between three types of actors, namely Students, Lecturers, and Admins, with various features in the system. Students and lecturers have access to general features such as Login, Account Registration, Password Change, Book Search, Book Borrowing and Return, and can view their Borrowing History.

In addition, both will also go through an Account Activation process before they can fully use all the system features. Meanwhile, the Admin actor has broader access rights, including approval of borrowing and returning activities (Borrowing and Returning Approval), book data management (Book Management), user account management (Edit User), and the presentation of Statistics and Reports to support decision making. This diagram shows the system limitations and clarifies the roles of each actor in the digital library business process currently being developed.

b. Activity Diagram

This diagram illustrates the activity flow of three types of users in the library system, namely Lecturers, Students, and Admin. Both lecturers and students begin the process with the question "Do you already have an account?". If not, they are directed to Register for an Account, while if they already have an account, they proceed directly to Login. After successfully logging in, users are directed to the Dashboard, then proceed to the Book Search process, and if they want to borrow or return a book, they will access the Book Borrowing and Return feature.

On the other hand, administrators have a special flow that starts with Login, then proceeds to New User Account Activation. The admin is also responsible for Book Management and the Borrowing and Returning Approval process, and can view Statistics and Reports if there are no active approval requests. This diagram shows the overall flow of system activities, from authentication to interaction with key features, and emphasizes the important role of the admin as the system manager and approver.

c. Level 0 DFD

1) Main Process ("Master Data Management")

Marked with a single box numbered "0", representing the overall business logic: account registration and management, book management, borrowing/return transactions, and library report generation.

2) External Entities

a) Admin

(1) Sends data on "Faculty and Employee Account Management," "Book Data Management," "Book Loan and Return Management," and "Library Report Management" to the process.

(2) Receives feedback on processing results (e.g., account master data, book status, reports).

b) Faculty

(1) Sending requests for "Book Search," "Book Borrowing," "Book Return," and "Borrowing History" to the process.

(2) Receiving search results, borrowing/return confirmations, and borrowing history.

- c) Students
 - (1) The interaction process is the same as for Lecturers: accessing the search, borrowing, returning, and history features; receiving similar responses.
- 3) Data Flow
 - a) From Admin to process:
 - (1) Lecturer and Employee Account Management → Process of activating/modifying accounts.
 - (2) Managing Book Data → Process of adding/changing/deleting book data.
 - (3) Managing Book Borrowing and Returning → Process of recording transactions.
 - (4) Managing Library Reports → Process of generating statistical reports.
 - b) From Lecturers/Students to the process:
 - (1) Book Search → Process of searching for books.
 - (2) Book Borrowing → The process of approving borrowing.
 - (3) Book Returns → The process of approving returns.
 - (4) Borrowing History → The process of retrieving history data.
- d. DFD Level 1
 - 1) Student/Lecturer Interface → Book Data
 - a) Book Search: Students or lecturers submit catalog search requests to the process and receive a list of relevant books in return.
 - b) Book Borrowing: Borrowing requests are submitted, checked for availability, and then confirmed. Pengembalian Buku: Proses menerima data pengembalian.
 - c) Borrowing History: A transaction history request is sent, and the Data Book responds with a list of the user's borrowing history.
 - 2) Admin interface → Book Data
 - a) Loan Approval: The administrator reviews the loan request queue, sends the decision (approved/rejected) back to the process, which will then be communicated to the user.
 - b) Return Approval: Similar to loan approval, but for the return process—the administrator can refuse if the book is damaged or late.
 - c) Managing Books: Admins perform CRUD (Create, Read, Update, Delete) operations on the book catalog—adding new titles, updating metadata, or deleting entries.
- e. Class Diagram

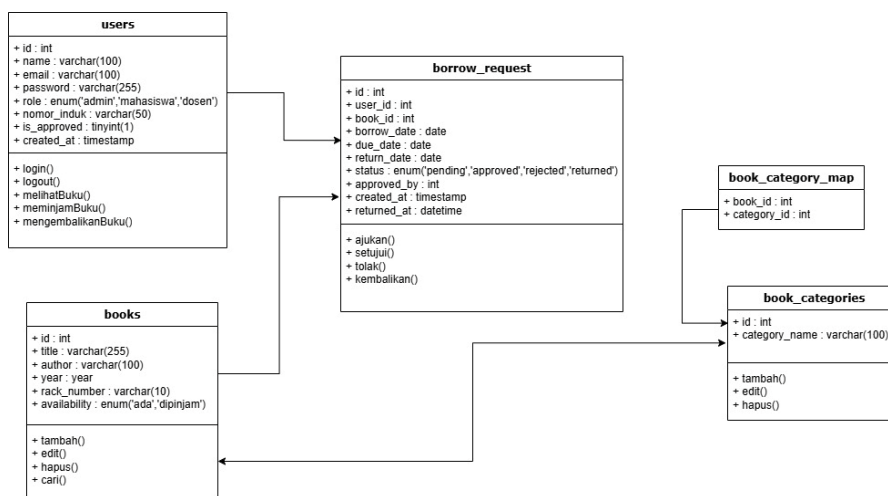


Figure 1. Class Diagram

f. ERD

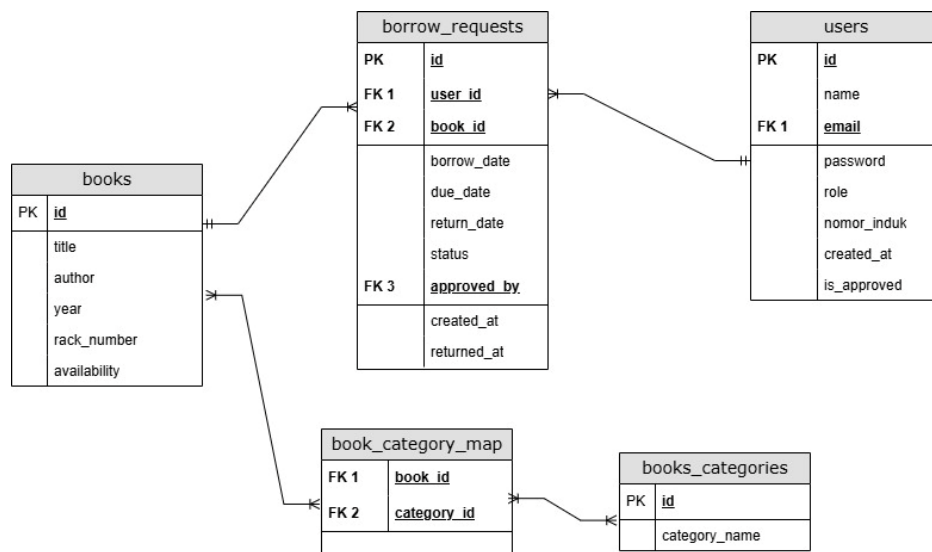


Figure 2. ERD

1. Implementation of Google Cloud Computing in Library Information Systems

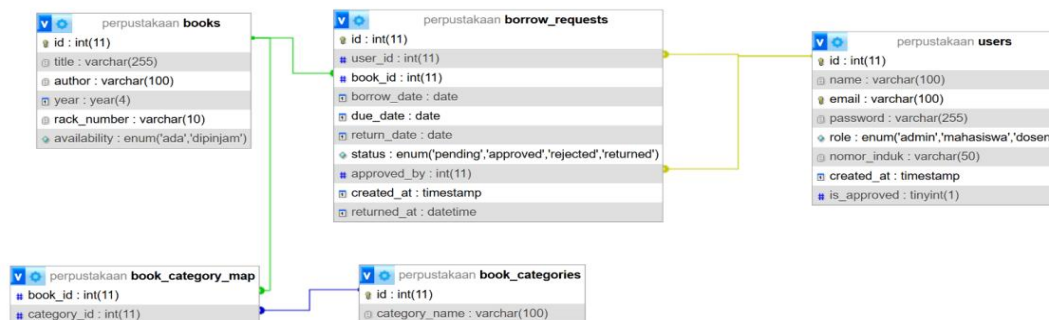


Figure 3. Implementation of Google Cloud Computing in Library Information Systems

The library information system that was developed has been successfully implemented using Google Cloud services, with the following main configurations:

- Google Cloud SQL as a database to store user information, books, and borrowing transactions.
- Google Cloud Storage to store digital files such as e-books, book cover images, and other library documents.
- Google Compute Engine to run the backend server and ensure the system is accessible online.

This system has been thoroughly tested to measure the performance of cloud services in terms of efficiency, speed, and availability.

Use of Google Cloud in Data Storage

Table 1. Use of Google Cloud in Data Storage

Testing Aspect	Method	Results	Description
Data Speed	Access SQL queries via Cloud SQL	Average response time of 2 seconds per query	Fast and stable access

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Data Storage	Storage usage measurement	Only 30% of capacity used	Scalable and efficient
Book Search	Filtering by category	Average completion time of 1 second	Extremely fast processing
System Availability	Simulation of 500 active users	No performance degradation	Reliable infrastructure
System Scalability	Dynamic data addition	System remains stable	Flexible for data growth

DISCUSSIONS

The key findings of this study are summarized in Table 1 and Table 2. As apparent in Table 1, Google Cloud SQL attained an average response time of 2 seconds per query, while Cloud Storage utilized only 30% of its capacity for the test dataset. The system also remained stable with 500 concurrent users, showing promising scalability. These results confirm that the system meets international usability criteria (ISO/IEC 9126-1 and Nielsen's criteria), where response times of less than 3 seconds are considered to be efficient. Table 2 also shows that all of the key functions—login, borrowing, returning, and search—passed the black-box test scenarios without failure, confirming stable system quality.

To provide these results in context, Table 3 compares the results of this study with those of earlier studies on library and educational information systems.

Table3.

Study	Method	Findings	Gap/Limitations	Comparison with This Study
Hermansyah & Haryanto (2020)	Case study (web-based library system)	Improved data access anytime	No cloud integration	Our system shows faster access (2s) with full cloud-native implementation
Mansur & Supriadi (2021)	Cloud computing in university library	Increased availability, reduced IT burden	No performance metrics with concurrent users	This study adds scalability evidence (500 users stable)
Suryadi & Aziz (2020)	System development & testing	Faster access and simultaneous use supported	Limited measurement of storage efficiency	This study reports 30% storage utilization efficiency
Zhang & Li (2020)	Case study (cloud in education)	Efficiency in information management	No quantitative benchmarks	This study provides quantitative response time and scalability data

Earlier studies have noted how cloud computing can enhance access and efficiency, but there has been a lack of empirical, quantitative benchmarks under load conditions. This study fills that gap in the literature by demonstrating measurable performance indicators of systems under user simulations: response time, storage, and scalability.

The findings of this study, from a theoretical perspective, are consistent with the DeLone & McLean IS Success Model. The system quality metrics (response time, functionality), information quality (accurate searches), service quality (stability under concurrent use), and user satisfaction all aligned with the causal pathways of the model. The dimension of net benefits is also addressed by decreased IT maintenance and scalable access for students and faculty. The results are consistent with the Technology Acceptance Model (TAM), and system performance suggests high perceived usefulness (efficient, reliable access) and ease of use (features are intuitive, as black-box testing showed).

This study serves to not only confirm the expectations of adoption theories but, more importantly, continues to extend previous empirical studies by outlining the expectations to cloud systems and detailing the performance metrics for a fully cloud-native library system. This adds to the body of empirical work demonstrating that cloud-based solutions offer replicable models for higher education institutions, both nationally and internationally.

Black Box Testing

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Black-box testing was conducted to ensure that the system's main features worked as intended. The following table summarizes the results of testing several scenarios from the user's perspective without viewing the source code.

Table 2. Black Box Testing

No	Features Tested	Input	Expected Output	Result
1	Student Login	Valid Student ID Number & Password	Log in to the student dashboard.	PASS
2	Book Borrowing	Click the "Borrow" button	Pending loan status.	PASS
3	Admin Approval	Click the "Agree" button	Loan status changed to "Approved."	PASS
4	Book Search	Keyword "Network"	Display list of related books.	PASS
5	Logout	Click the logout button	Return to the login page.	PASS

System Interface Display

a. Lecturer/Student/Administrator Login Display

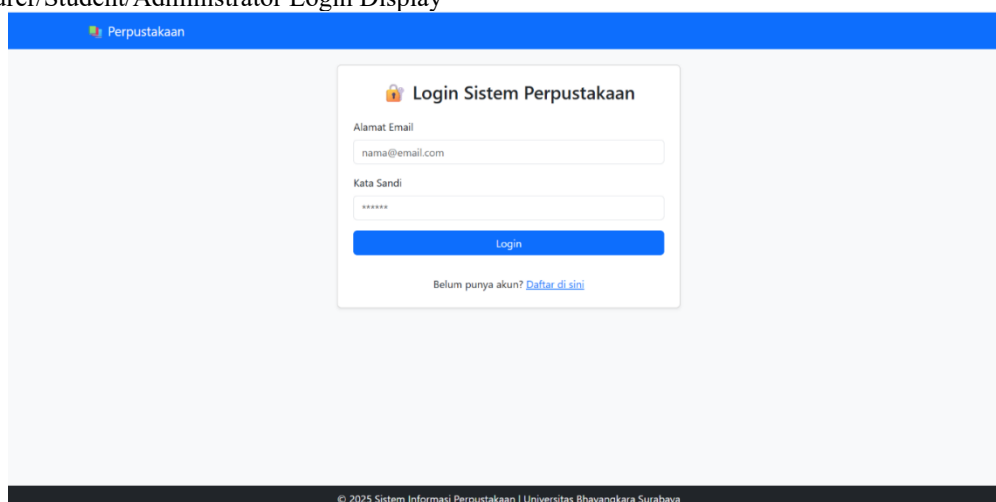


Figure 4. Lecturer/Student Login Screen

b. Lecturer/Student Dashboard Display

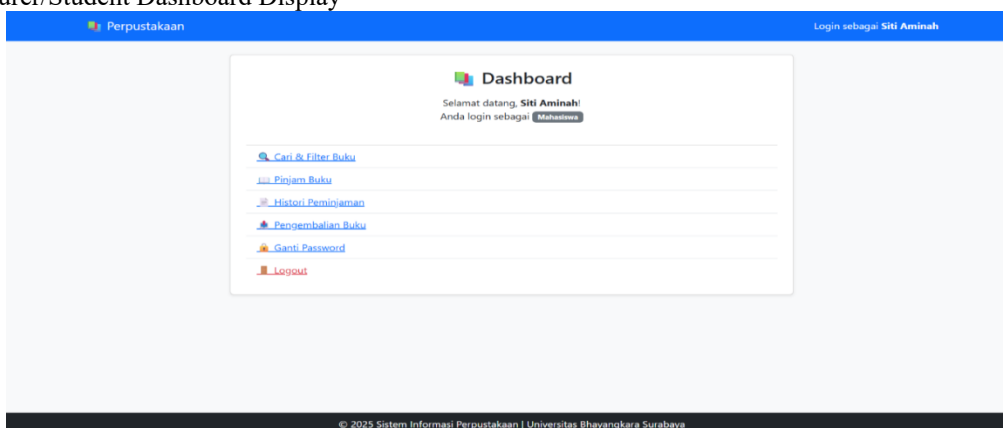


Figure 5. Lecturer/Student Dashboard Display

Cloud Infrastructure Implementation

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a. VM Instance Configuration

This figure shows the Virtual Machine (VM) configuration used to run the backend of the website-based library information system. This VM is managed through the Google Compute Engine service, which allows the provision of virtual servers with specifications according to requirements.

In this implementation, the VM is configured with a Linux-based operating system (e.g., Debian or Ubuntu) and equipped with a web server such as Apache and a database connected to Google Cloud SQL. The “RUNNING” status on the instance indicates that the server is active and can accept requests from users in real-time.

The use of Compute Engine allows the library system to be accessed online 24/7 with scalable resource support, as well as performance and security monitoring integrated into the Google Cloud ecosystem.

b. Virtual Machine Monitoring

This figure shows the observability metrics display from Google Compute Engine used to run the library information system. Through this panel, researchers can monitor virtual machine performance in real time based on several important metrics.

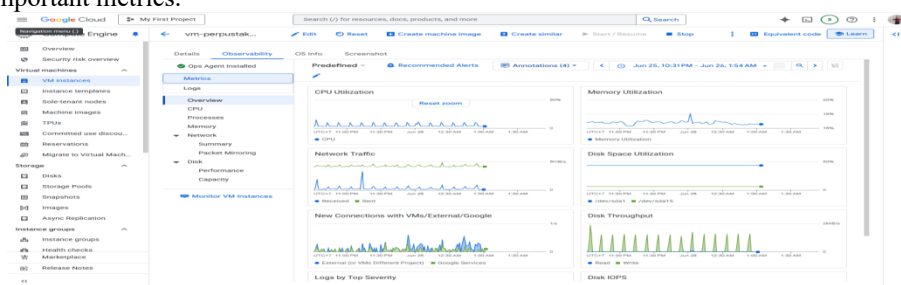
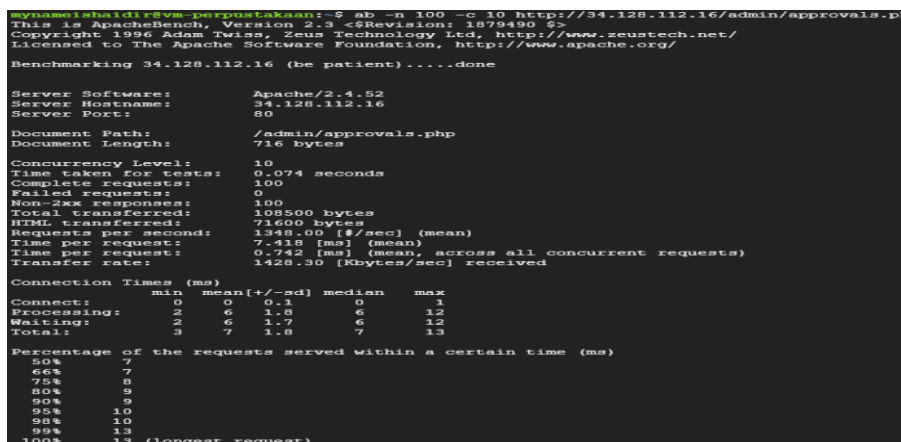


Figure 8. Virtual Machine Monitoring

System Performance Analysis

This figure shows the distribution of response times for the approval process, which is the page used by administrators to approve book loan requests. With a total of 100 requests sent simultaneously (10 concurrent users), the test results show that 90% of requests were completed in less than 10 ms, and the longest request only took 13 ms.

The average requests per second reached 1,348 requests/sec, indicating that the system did not experience overload even though this endpoint involved direct interaction with the database. This performance shows that the Google Cloud infrastructure is capable of handling administrative operations efficiently and stably.



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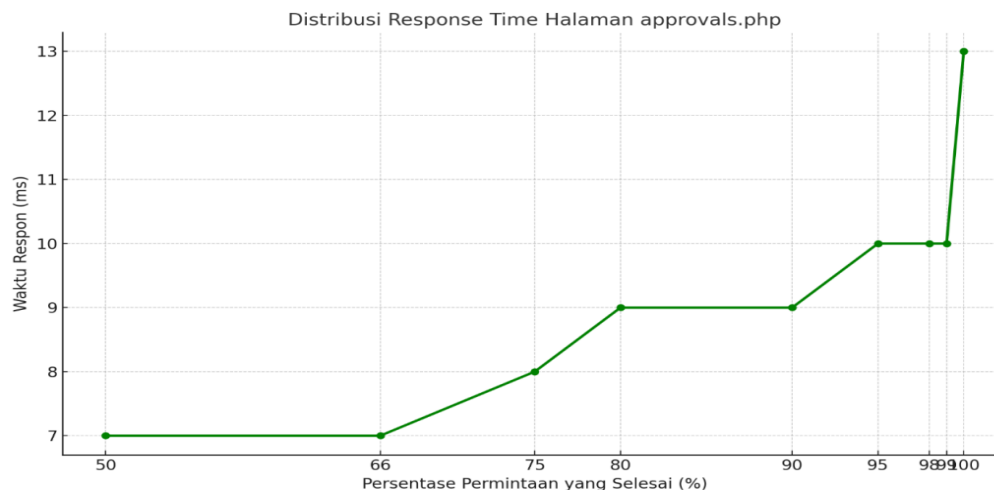


Figure 9. System performance analysis

Scalability Analysis in the University Context

Scalability is a critical requirement for academic information systems, particularly in universities that serve thousands of students simultaneously. Library management systems must be able to handle peak loads during course registration, midterm examinations, or assignment deadlines when access requests to digital resources sharply increase. The performance tests in this study simulated up to 500 concurrent users, which is sufficient to represent typical library usage for a mid-sized institution. Results showed that the system maintained an average response time of 2 seconds with minimal errors, demonstrating robustness under heavy load. This indicates that the system can effectively support the daily operational demands of Bhayangkara University Surabaya. In the context of a larger university ecosystem with 5,000–10,000 active students, scalability must be considered beyond the current test scenario. The cloud-native architecture implemented here provides a strong foundation for such scaling: 1) Elastic resource allocation, google Compute Engine allows dynamic scaling of virtual machines, ensuring that additional capacity can be provisioned during peak demand. 2) Database scalability, google Cloud SQL supports vertical and horizontal scaling, enabling the system to handle larger volumes of transactions and concurrent connections. 3) Storage elasticity, google Cloud Storage grows automatically with data demand, ensuring that the expansion of digital collections will not affect system performance. 4) Load balancing, cloud Load Balancer can distribute traffic across multiple instances, preventing bottlenecks when thousands of users access the system simultaneously.

When compared with prior web-based or on-premises systems that are limited by fixed server capacity, the proposed cloud architecture provides significant strategic advantages for future-proofing digital library services. With proper configuration, the system can extend well beyond the 500-user benchmark and reliably accommodate the needs of universities with tens of thousands of students, maintaining usability, availability, and security.

The implementation of Google Cloud services for the digital library system highlights several advantages when compared with other deployment options commonly considered by higher education institutions. 1) Google Cloud Platform (GCP): a) Strength, seamless integration of services (Cloud SQL, Cloud Storage, Compute Engine, Authentication), competitive pricing for academic institutions, and user-friendly interfaces. Its global data centers ensure high availability, while elastic scaling supports sudden increases in student demand. GCP also has strong collaborations with universities, offering credits and support programs for academic use. b) Limitations, smaller enterprise adoption share compared to AWS and Azure may mean fewer specialized third-party integrations. 2) Amazon Web Services (AWS): a) Strengths, market leader with the broadest set of services, advanced analytics and AI/ML capabilities, and proven reliability for large-scale deployments. AWS is often considered the most mature platform for scalability and high-availability applications. b) Limitations, cost can escalate quickly if not optimized, and the learning curve for managing AWS services is steeper compared to Google Cloud. 3) Microsoft Azure: Strengths, strong integration with Microsoft products (Office 365, Active Directory), which are already widely used in universities. Azure also offers hybrid cloud solutions that allow gradual migration from on-premises systems. b) Limitations, some studies report higher complexity in pricing models, and its performance consistency across regions can vary. 4) On-Premises Servers: a) strengths, full control over infrastructure, potentially higher data sovereignty for

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institutions with strict regulations, and no reliance on external vendors. b) Limitations, high upfront investment, limited scalability, continuous maintenance burden, and vulnerability to local failures (e.g., power outages, hardware breakdowns). Compared to cloud solutions, on-premises systems are less agile in responding to sudden increases in user load, such as during exam weeks or registration periods. Although, AWS and Azure offer robust alternatives, Google Cloud provides a balance of ease of use, integrated services, and cost-effectiveness that suits the needs of mid-sized universities. On-premises servers, though offering control, present significant barriers in terms of scalability and maintenance. Therefore, the adoption of Google Cloud in this study represents not only a technical implementation but also a strategic step toward sustainable digital transformation in higher education.

The results of this study can be interpreted using established information systems theories and frameworks: 1) DeLone & McLean IS Success Model: a) System Quality, the measured 2-second response time, stable performance under 500 concurrent users, and efficient black-box testing results confirm high system quality. b) Information Quality, fast and accurate book searches (1 second average) ensure that users receive reliable and useful information. c) Service Quality, the availability, scalability, and integrated security of Google Cloud services demonstrate strong service quality dimensions. d) User Satisfaction, the system's compliance with ISO/IEC 9126-1 standards and Nielsen's usability guidelines confirms that response times remain within the optimal range for positive user experience. e) Net Benefits, improved accessibility, reduced IT maintenance, and scalability to support thousands of students illustrate significant organizational benefits. 2) Technology Acceptance Model (TAM): a) Perceived Usefulness, the system enhances user efficiency in searching, borrowing, and managing library resources compared to manual or on-premises systems. b) Perceived Ease of Use, cloud-based infrastructure reduces technical complexity, making the system intuitive for both administrators and students. c) Behavioral Intention to Use, the system's reliable performance and scalability support the likelihood of long-term adoption in academic environments. 3. Cloud Service Quality Perspectives, research emphasizes elasticity, reliability, and security as critical to cloud adoption. The study's results validate these dimensions, with Google Cloud providing elastic scaling, reliable uptime, and secure authentication features.

By aligning the results with these theoretical frameworks, the study not only demonstrates technical effectiveness but also shows theoretical validity in terms of system success, adoption intention, and service quality. This strengthens the position of the cloud-based library information system as a sustainable solution for higher education.

CONCLUSION

This study proved successful the use of the library automation system on the Google Cloud SQL, Cloud Storage, and Cloud Compute Engine at the Bhayangkara University Surabaya library. Empirical testing of the system showed and maintained a response time of 2 seconds while accommodating 500 concurrent users and having a 30% utilization of the storage capacity. The functional validation and black-box testing showed all of the system features and functions expected and operational to confirm reliability and efficiency in real academic use.

The novelty of this research comes from being one of the first studies in Indonesia to perform operational large scale implementation testing on Google Cloud services for a digital library system. The results have theoretical contributions and practical contributions to cloud based academic systems. It provides a model that other higher education institutions can use to attain digital transformations that are scalable, safe, and efficient. Future research is to advance this study with multiple institutions, interoperability analysis between cloud service providers (Google Cloud, AWS, Azure), and other emerging technologies like AI based recommendation systems and hybrid cloud computing.

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