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Website-Based laboratory management system of UNHAN RI Chemical Laboratory

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ABSTRACT

Effective laboratory management plays a crucial role in supporting academic and research activities in higher education; however, many university laboratories still rely on manual recording systems that lead to data inconsistencies, weak inventory control, and limited monitoring of material and equipment usage. These challenges are particularly critical in chemistry laboratories with high-intensity utilization and strict governance requirements, such as those in defense-oriented institutions. This study aims to develop and implement a web-based Laboratory Management System, namely LABUNICA, to improve the efficiency, accuracy, and accountability of laboratory operations in the Chemical Laboratory of Universitas Pertahanan Republik Indonesia. The system was developed using the Rapid Application Development (RAD) method, emphasizing iterative prototyping, direct user involvement, and continuous refinement based on operational feedback. System analysis and design were conducted through interviews, observations, and UML-based modeling, followed by front-end and back-end development and black-box testing. The results indicate that LABUNICA successfully streamlines laboratory workflows, reduces redundancy in usage recording, enhances real-time inventory monitoring, and supports role-based access control for users and administrators. The implementation of LABUNICA improves documentation accuracy, system usability, and operational transparency compared to previous manual practices. This study contributes to the laboratory information system literature by demonstrating the effectiveness of a user-centered, web-based management system tailored to the operational characteristics of a defense university chemistry laboratory, with practical implications for digital laboratory governance in higher education institutions.

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1. INTRODUCTION

Laboratory management is closely related to the implementation of academic and research activities in higher education institutions. Laboratory operations require accurate documentation, clear procedures, and continuous monitoring to ensure that materials and equipment are available, safe, and used appropriately. However, many academic laboratories still rely on manual recording systems

that are no longer suitable for current operational demands. Previous research by Marwah *et al*. (2020) shows that laboratories without digital management systems often experience weak inventory documentation, unclear records of equipment borrowing and returns, and limited access to information related to schedules and student final projects. These shortcomings gradually reduce the effectiveness of laboratory utilization and hinder academic productivity. As information technology continues to develop rapidly, manual systems struggle to provide the level of accuracy and transparency required in modern laboratory management (Akase & Kpera, 2024; Obeagu & Obeagu, 2024; Venkatesh et al., 2024).

Similar circumstances are evident in Chemical Laboratory of Universitas Pertahanan Republik Indonesia (UNHAN RI), which serves as an essential facility for both instructional and research activities for cadets and academic staff. The operation of this laboratory depends heavily on the availability of chemical materials and the readiness of laboratory instruments. At present, inventory records are still maintained manually as resulting in frequent inconsistencies between actual stock conditions and written documentation. Interviews with the client, two laboratory assistants, and direct field observations reveal that the existing recording system lacks structure and is difficult to monitor systematically. In addition, the laboratory is used simultaneously for practicum sessions and research activities, leading to a high intensity of material and equipment usage. With a limited number of laboratory personnel, manual documentation becomes an added workload that complicates supervision and reporting.

Manual recording practices have been shown to cause delays in report preparation, inaccuracies in chemical quantity records, and limited control over equipment usage (Nadira Atthima *et al*., 2024). Laboratory assistants often need to physically check material availability before updating records, which consumes time and increases the likelihood of human error. As a result, academic and research activities are sometimes disrupted due to the absence of up-to-date information on laboratory resources. Several previous studies demonstrate that these issues can be addressed through the implementation of Laboratory Information Systems (LIS) (Aziz et al., 2022; Farzandipour et al., 2019; Mumba et al., 2019; Oakley et al., 2025). Marianne *et al*. (2023) report that LIS adoption improves laboratory performance by streamlining workflows, automating data management processes, and optimizing the use of available resources.

The use of digital technology in laboratory management is also closely related to broader developments in educational governance and information systems. Prastyo, Suwahono, and Suryandari explain that manual laboratory management is highly susceptible to errors, slow data processing, and weak supervision, all of which negatively affect learning and practicum activities (Prastyo, B., Suwahono, S., & Suryandari, E. T 2020). By contrast, digital systems allow laboratory processes to be documented more systematically and monitored more reliably, thereby improving safety and accountability (Nurmadewi, 2024).This approach is consistent with national regulations governing educational facilities. Government Regulation of the Republic of Indonesia No. 13 of 2015 emphasizes that laboratories are an integral part of educational infrastructure and should be supported by information and communication technology to ensure effective learning processes (Indonesia, 2015).

Proper management of educational facilities has a direct impact on the quality of educational services provided by an institution. Purwandani and Sutarsih argue that well-managed facilities contribute to a comfortable and supportive learning environment, which in turn enhances educational outcomes. In the chemical laboratories, where materials and instruments require strict supervision, management systems must be detailed, reliable, and easy to monitor (Purwandani & Sutarsih, 2019). Laboratory management systems also reflect the principles applied in e-Government initiatives within public institutions and educational organizations. Darmawan Napipulu *et al*. (2020) describe how web-based systems such as E-Lapor improve transparency, coordination, and accountability in public services through structured reporting and monitoring mechanisms.

Further support for the use of structured digital platforms can be found in the work of analyzing web-based community complaint systems developed using UML approaches (Hafidz & Yahya, 2025; Oguntosin et al., 2021)(Mahbub *et al*., 2020). Their study demonstrates that clearly defined workflows covering reporting, verification, and information updates and lead to more organized and transparent system operations. Similar workflow structures are required in laboratory environments, particularly for inventory tracking, usage logging, and condition monitoring of equipment. Based on these considerations, this study focuses on the development of a website-based Laboratory Management System for the Chemical Laboratory of Universitas Pertahanan

Republik Indonesia, known as LABUNICA. The system is designed to document, control, and track the use of laboratory materials and equipment in a structured and accountable manner. Through the implementation of LABUNICA, laboratory management is expected to become more efficient, compliant with educational standards, and better able to support academic and research activities within the Chemistry Study Program of UNHAN RI.

Despite the extensive body of research on Laboratory Information Systems (LIS), most existing studies primarily focus on clinical laboratories, general academic laboratories, or industrial settings, with limited attention given to chemistry laboratories within defense-oriented higher education institutions. Previous LIS implementations often emphasize basic inventory management or scheduling functions, without addressing the specific operational characteristics of chemical laboratories that operate under strict safety regulations, dual-use materials, and high-intensity utilization for both education and research. Moreover, few studies explicitly incorporate user-based system development approaches that involve laboratory assistants and academic users throughout the design process, particularly using rapid development models that allow iterative refinement based on real operational needs. This study addresses these gaps by developing LABUNICA, a web-based Laboratory Management System tailored to the Chemical Laboratory of Universitas Pertahanan Republik Indonesia, integrating material inventory control, equipment usage tracking, and activity documentation within a single platform. The novelty of this research lies in its contextual application to a defense university chemistry laboratory, the integration of operationally relevant features aligned with laboratory governance standards, and the adoption of a user-centered Rapid Application Development (RAD) approach to ensure system usability, accountability, and practical relevance in supporting academic and research activities.

2. RESEARCH METHOD

This study adopts the Rapid Application Development (RAD) method as the main approach for developing the LABUNICA laboratory management system (Anaking et al., 2023; Setyatama & Andrianto, 2018; Singgalen, 2024). RAD was selected because it is well suited for system development projects with a clearly defined scope and a need for relatively short development cycles. The LABUNICA system focuses on specific functions such as inventory recording, equipment monitoring, and usage logging, which aligns with the strengths of RAD. This method emphasizes iterative development, allowing the system to evolve gradually through continuous interaction with users. The RAD approach applied in this study is centered on three main activities such as prototype development, direct user validation, and repeated improvement based on actual feedback. An initial prototype of the LABUNICA system was developed to represent the core functions required by laboratory staff. This prototype was then evaluated directly by users, including laboratory assistants, to assess its usability and functional suitability. Feedback obtained during this stage was used to refine both system features and interface design. This iterative cycle was repeated until the system met operational requirements and user expectations. Figure 1. shows stage of the Rapid Application Development (RAD) method applied in the development of the LABUNICA laboratory management system.

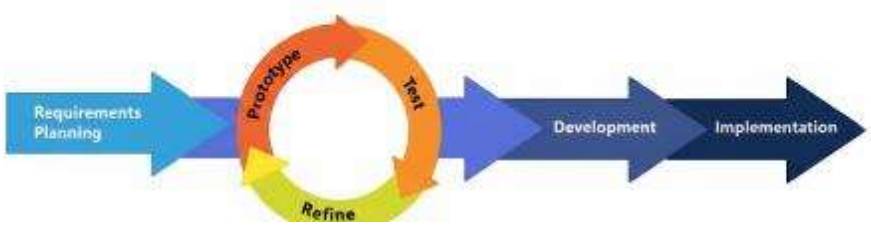


Figure 1. RAD Method Applied in the Development of the LABUNICA Laboratory Management System

The implementation of RAD in this study was carried out through several structured stages. The first stage involved system analysis and design, during which system requirements were identified through interviews and discussions with users. The second stage focused on prototype development, where an initial version of the system was built and evaluated based on user feedback.

The third stage consisted of full system development and testing, ensuring that all functions operated as intended through regular functional testing. Then, the system was implemented in the laboratory environment, accompanied by user training. The final stage involved documentation and maintenance, including system monitoring and updates to ensure stable and continuous operation.

3. RESULTS AND DISCUSSIONS

The analysis and system design stage began with problem identification and data collection conducted through direct interaction with the client. The development team held two formal meetings with the client to understand the operational issues faced by the laboratory and the expectations for the proposed system. These meetings focused on identifying the main challenges of manual laboratory management and exploring potential solutions that could be implemented through a web-based system. Discussions also covered the scope of system features, user roles, and access levels required to support daily laboratory activities. The outcomes of these meetings were documented in the Interview Reports I and II, as well as in the Project Charter and Software Requirements Specification (SRS). The data collection activities were carried out on 27 February 2025 and 7 March 2025, providing a structured foundation for the subsequent design phase.

Based on the results of interviews and direct observations, the business process model of the LABUNICA system was developed by simplifying existing manual workflows. Previously, the recording of laboratory equipment and material usage required multiple steps and separate documentation, which increased the risk of errors and data inconsistencies. Through analysis, the development team designed a more streamlined process that integrates users and administrators into a single workflow. Each instance of equipment or material usage is recorded directly into a daily logbook without requiring additional manual input. This approach reduces redundancy and ensures that usage data are captured in real time. The redesigned business processes are represented through use case diagrams within the system design shown in Figure 2.

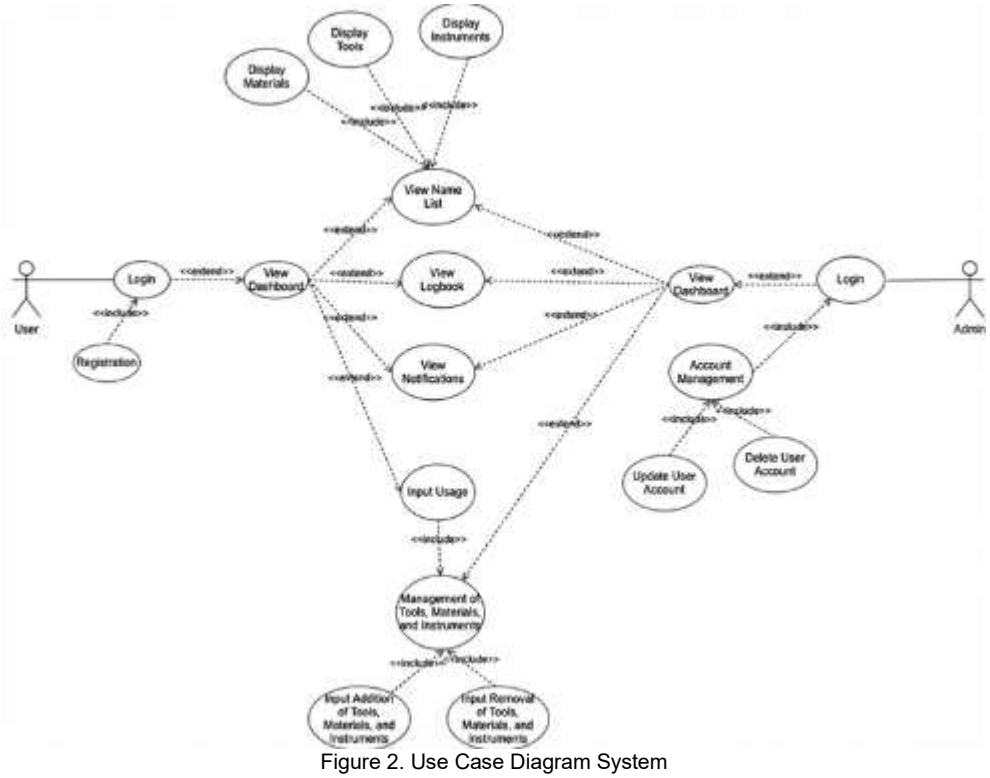
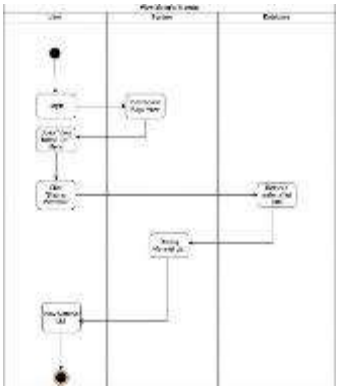


Figure 2. Use Case Diagram System

The activity diagrams then shown in Figure 3, which cover both general user activities and administrative operations within the system. User-oriented activities include viewing laboratory materials, equipment, and instruments, recording usage, accessing logbook records, and receiving system notifications. Administrative activities extend to user management functions, such as updating and deleting user accounts, as well as managing laboratory inventory through the addition

and removal of materials, equipment, and instruments. Authentication processes, including user registration and login, are also represented to illustrate access control mechanisms.



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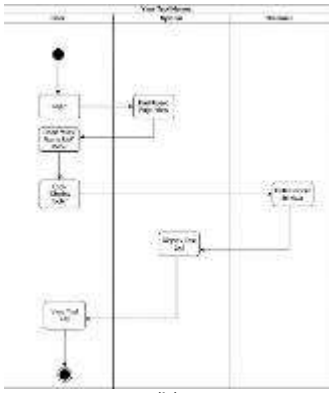

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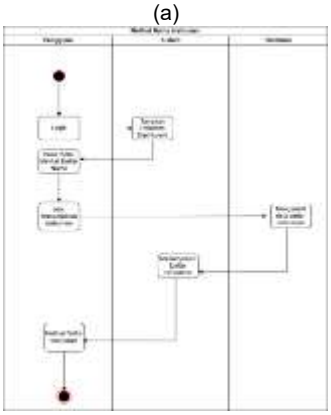

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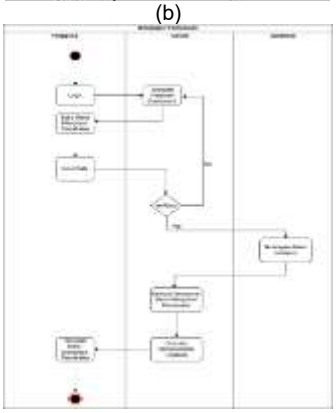

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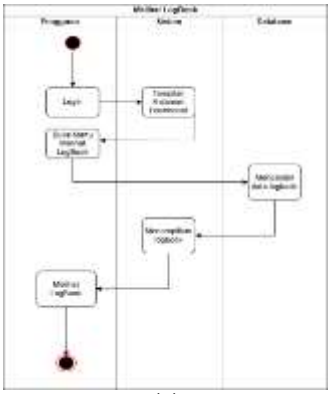

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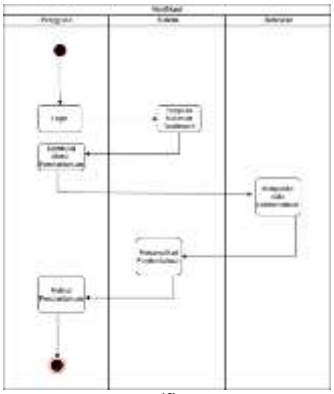

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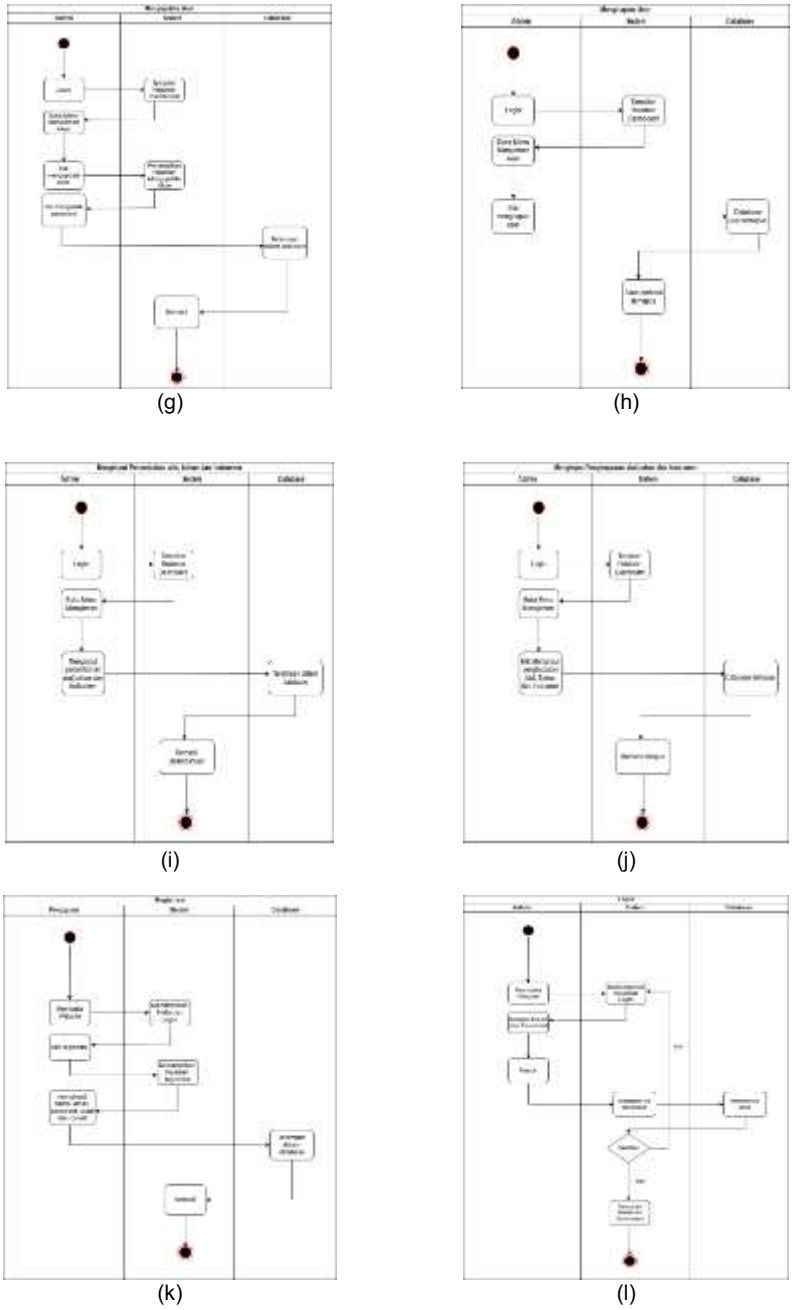


Figure 3. Activity Diagram: (a) viewing laboratory materials, (b) viewing laboratory equipment, (c) viewing laboratory instruments, (d) recording material and equipment usage, (e) accessing the laboratory logbook, (f) viewing system notifications, (g) updating user data, (h) deleting user accounts, (i) adding laboratory materials, equipment, and instruments, (j) removing laboratory materials, equipment, and instruments, (k) user registration, and (l) user login.

The class diagram was developed to represent the structural design of the LABUNICA system and to describe how system data are organized shown in Figure 4. By modeling the data structure in this way, the class diagram provides a clear overview of how information related to users, laboratory materials, equipment, instruments, and usage records is stored and managed.

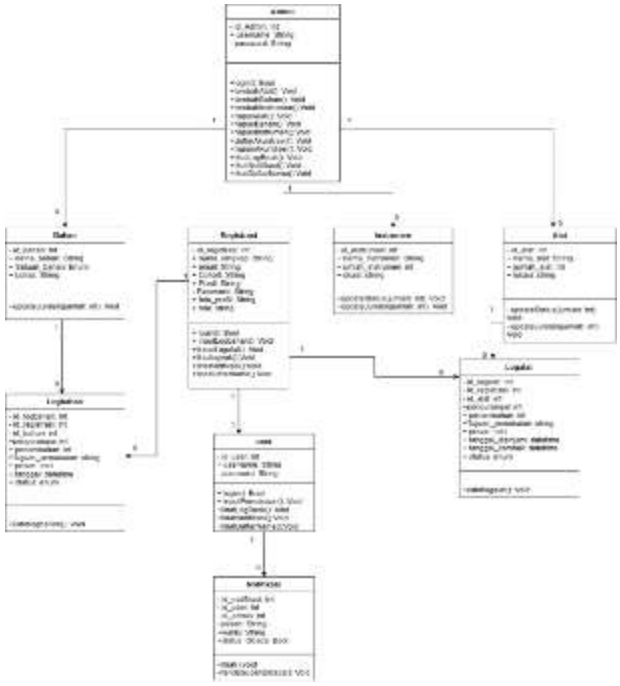


Figure 4. Class Diagram System

In addition to the documentation of concepts and system requirements, several supporting project management documents were completed during this stage. Schedule and Project Control documents were used by the project manager to monitor task progress and ensure that development activities followed the planned timeline. The Project Charter outlined the project objectives, scope, performance indicators, estimated duration, and potential risks associated with system development. A Work Breakdown Structure (WBS) was also prepared to divide project tasks into detailed and manageable components. This structure helped clarify team responsibilities and supported more organized planning and execution.

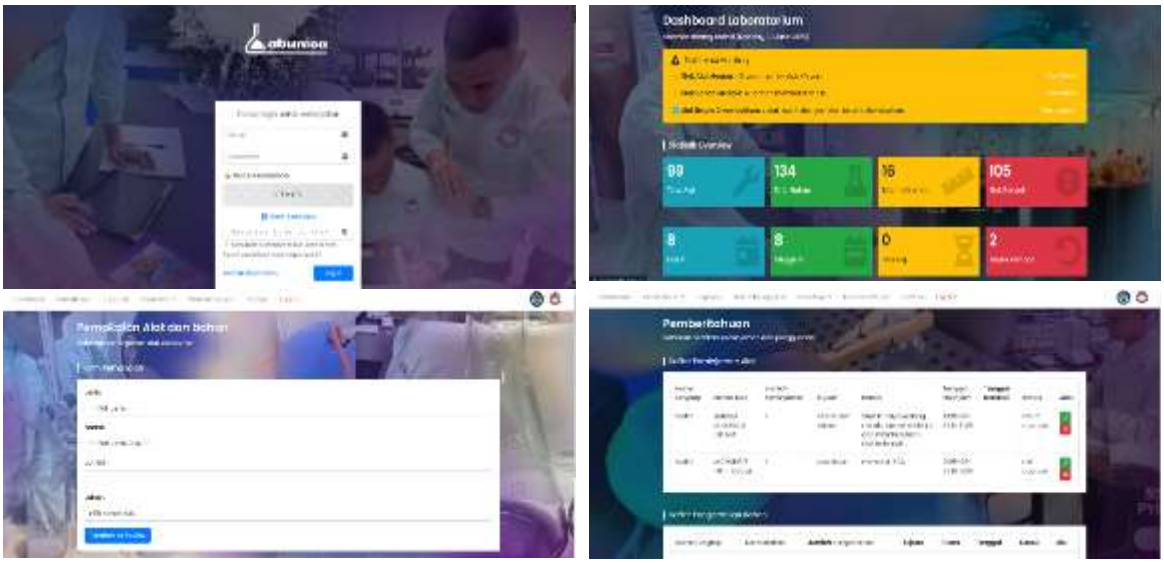
The application design stage focuses on developing a user interface that effectively supports interaction between users and the LABUNICA system. The user interface serves as a medium that connects users with system functionality, to perform tasks efficiently and comfortably. A well-designed interface helps users understand system workflows and reduces the learning curve during system adoption. According to Khusnul Alifah (2023), user interface design contributes to usability, comfort, and user satisfaction, which are essential for maximizing system operation. In the laboratory management, interface clarity is particularly important to avoid errors in data entry and interpretation. Therefore, the interface design of LABUNICA emphasizes clarity, consistency, and ease of use.The LABUNICA user interface was designed by the UI/UX team using the Figma platform, allowing collaborative design and early visualization of system features. The design includes interfaces for login and registration, inventory management of laboratory materials and equipment, usage reporting, and monitoring activities.

Development activities were divided into front-end and back-end processes to ensure clear separation between user interface logic and data processing. The front-end development focuses on presenting system features in accordance with the approved interface design, while ensuring that user interactions are responsive and consistent. Each module was implemented based on predefined requirements and validated through internal testing. Front-end development for LABUNICA includes modules designed for two main user roles: general users and laboratory administrators. For administrators, modules were developed to support login, profile management, user management, inventory management, notification handling, and logbook monitoring. These modules allow administrators to control system access, manage laboratory resources, and oversee usage activities. For general users, modules include registration, login, profile management, material and equipment usage submission, logbook access, and notification viewing. Each module was designed to reflect role-based access control, ensuring that users can only access features relevant to their

responsibilities. All front-end modules were completed and verified according to the development checklist.

Back-end development focused on database modeling, data migration, and controller configuration to support system operations. Models, controllers, routes, and views were developed for each module to ensure smooth communication between the application interface and the database. This includes modules for authentication, user management, inventory management, usage logging, notifications, and email services. The back-end structure was designed to maintain data consistency and support real-time updates. By implementing a modular backend architecture, system functionality can be expanded without disrupting existing components. The completed LABUNICA application provides functional interfaces for both general users and laboratory administrators. General users are able to log in, view laboratory materials, equipment, and instruments, submit usage requests, access logbook records, and receive notifications. Administrators can manage users, control inventory additions and reductions, monitor usage logs, and respond to system notifications. These features collectively support daily laboratory operations in a more organized and traceable manner. The application output reflects the system requirements defined during the analysis phase. As a result, LABUNICA is able to support laboratory management activities more effectively than previous manual practices.

To support system adoption and long-term use, a user guidebook was prepared as part of the program documentation. This guidebook serves as a reference for laboratory staff, cadets, lecturers, and other stakeholders in operating the LABUNICA system. It provides step-by-step instructions for using system features and managing laboratory data. The guidebook also helps ensure that system usage follows established procedures and safety standards.The Implementation of the LABUNICA application shown in Figure 5.



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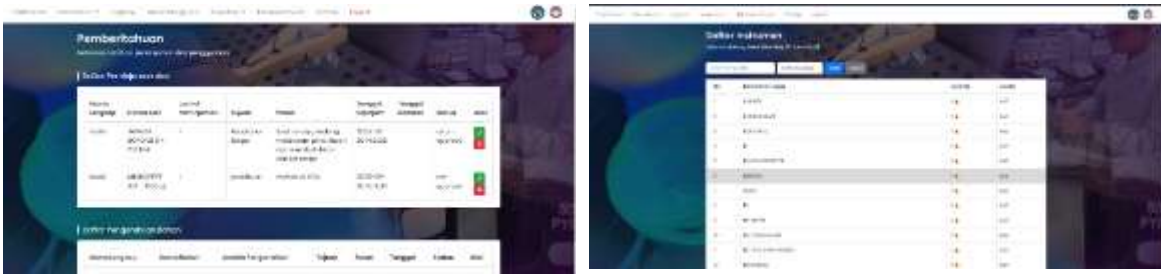

(b)

Figure 5. Labunica App: (a) user, (b) admin

The testing phase was conducted to evaluate the performance and reliability of the LABUNICA system before full deployment. Black box testing was applied to examine the functionality and interface behavior of each module without analyzing the internal program structure. A total of fourteen test scenarios were executed to cover fourteen system modules, representing both front-end and back-end components for the two primary user roles, namely administrators and general users. The testing process revealed several functional issues and minor inconsistencies, which were systematically corrected through iterative refinement. As a result, the testing outcomes contributed to improved system stability, usability, and overall reliability in supporting laboratory management activities.

Following successful testing, the system proceeded to installation, training, documentation, and maintenance stages as part of the final implementation process. The installation phase ensured that the software environment was properly configured so the system could operate effectively on user devices. Training sessions were conducted through both direct meetings and online guidance, supported by the LABUNICA user manual to facilitate user understanding and adoption. Comprehensive documentation was compiled, including project specifications, administrative records, and project management documents, to ensure technical completeness and administrative accountability. Maintenance activities were carried out to address potential errors identified during usage and to sustain optimal system performance. Collectively, these stages ensured that LABUNICA was not only technically functional but also operationally ready to support structured, efficient, and sustainable laboratory management within the Chemical Laboratory of Universitas Pertahanan RI.

Discussion

The results of this study are consistent with previous research that highlights the effectiveness of Laboratory Information Systems (LIS) in improving documentation accuracy, workflow efficiency, and resource control within laboratory environments. Similar to the findings of Aziz et al. (2022), Farzandipour et al. (2019), and Mumba et al. (2019), the implementation of LABUNICA demonstrates that digitizing inventory management and usage logging significantly reduces data inconsistencies commonly associated with manual recording systems. The integration of real-time usage logs and centralized inventory data in LABUNICA addresses the same fundamental challenges reported in earlier LIS studies, namely delays in reporting, limited transparency, and difficulties in monitoring laboratory resources. Compared to most previous LIS implementations that focus on clinical or general academic laboratories, this study extends existing knowledge by applying a web-based management system to a chemistry laboratory within a defense-oriented higher education institution. Unlike studies by Oakley et al. (2025) and Marianne et al. (2023), which emphasize efficiency gains and workflow automation in standard laboratory settings, LABUNICA is designed to accommodate the operational characteristics of a defense university laboratory, including high-frequency usage, shared utilization for practicum and research activities, and stricter accountability requirements for material and equipment control. This contextual adaptation represents a meaningful distinction from prior work that often assumes homogeneous laboratory environments. From a system development perspective, the findings align with research by Hafidz and Yahya (2025), Oguntosin et al. (2021), and Mahbub et al. (2020), which demonstrate that clearly defined workflows modeled through UML diagrams contribute to system clarity and operational transparency. The use of use case, activity, and class diagrams in LABUNICA supports structured interaction between users and administrators, reinforcing earlier conclusions that visual

modeling improves system reliability and maintainability. Nevertheless, this study differs by explicitly simplifying manual workflows into a single integrated daily logbook process, reducing redundancy more aggressively than reported in previous LIS designs. In terms of development methodology, the application of a user-centered and iterative development approach through direct client involvement reflects recommendations from prior system development studies but is rarely documented in detail in LIS-focused research. While many earlier studies describe system features and technical outcomes, this research emphasizes the role of structured interviews, formal documentation (SRS, Project Charter, WBS), and continuous feedback in shaping system functionality. This approach strengthens the practical relevance of LABUNICA and supports Nurmadewi's (2024) assertion that digital laboratory systems must be closely aligned with user behavior to improve safety and accountability. The comparison with previous studies indicates that LABUNICA not only confirms the general benefits of LIS adoption reported in the literature but also contributes new empirical evidence from a defense university chemistry laboratory context. The integration of role-based access control, real-time logging, and streamlined workflows demonstrates that LIS can be effectively adapted to laboratories with complex operational demands. These findings suggest that future LIS research should move beyond generic implementations and increasingly consider institutional context, laboratory specialization, and participatory development approaches as critical success factors.

4. CONCLUSION

This study successfully demonstrates that the development and implementation of the LABUNICA web-based Laboratory Management System effectively address the operational challenges of manual laboratory management in the Chemical Laboratory of Universitas Pertahanan Republik Indonesia. By applying a user-centered Rapid Application Development (RAD) approach, LABUNICA is able to integrate inventory control, equipment usage tracking, and activity documentation into a single, structured, and accountable platform. The results indicate that the system improves data accuracy, enhances transparency, reduces administrative workload, and supports real-time monitoring of laboratory resources. Furthermore, the contextual adaptation of LABUNICA to a defense-oriented chemistry laboratory highlights its capacity to accommodate high-intensity usage, dual academic–research functions, and stricter governance requirements, thereby contributing empirical evidence that extends existing LIS literature beyond conventional laboratory settings. Future research is encouraged to expand the scope of LABUNICA by incorporating advanced features such as predictive inventory analytics, integration with institutional academic information systems, and enhanced safety monitoring modules for hazardous materials. Longitudinal evaluation involving quantitative performance metrics and user satisfaction analysis would also strengthen evidence of system impact on laboratory efficiency and academic productivity. From an institutional perspective, the adoption of LABUNICA can be considered a strategic model for digital laboratory governance in higher education, particularly within specialized or defense-related institutions. Policymakers and university administrators are advised to support similar digital transformation initiatives to promote standardized, transparent, and sustainable laboratory management practices aligned with national education and information technology policies.

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