FDRE TECHNICAL AND VOCATIONAL TRAINING INSTITUTE (FDRE TVTI)
DEPARTMENT OF INFORMATION TECHNOLOGY



የኢፌዲሪ የቴክኒክና ሙያ ስልጠና ኢንስቲትዩት
FDRE TECHNICAL & VOCATIONAL TRAINING INSTITUTE

THESIS TITLE:
DESIGN AND ARCHITECTURAL ANALYSIS OF A SCALABLE CLOUD-BASED LEARNING MANAGEMENT SYSTEM FOR REMOTE AND BLENDED LEARNING IN ETHIOPIAN TECHNICAL AND VOCATIONAL TRAINING

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
OF
MASTER OF SCIENCE IN INFORMATION TECHNOLOGY

BY
SINTAYEHU FELEK
Student ID: TTMR/199/16

Principal Advisor: Birknesh W/Yohannes (PhD)

Addis Ababa, Ethiopia
June 9, 2026

FDRE TECHNICAL AND VOCATIONAL TRAINING INSTITUTE
COLLEGE OF GRADUATE STUDIES
DEPARTMENT OF INFORMATION TECHNOLOGY

DESIGN AND ARCHITECTURAL ANALYSIS OF A SCALABLE CLOUD-BASED LEARNING MANAGEMENT SYSTEM FOR REMOTE AND BLENDED LEARNING IN ETHIOPIAN TECHNICAL AND VOCATIONAL TRAINING

By: Sintayehu Feleke
ID No.: TTMR/199/16

A thesis submitted to the Department of Information Technology, College of Graduate Studies, FDRE Technical and Vocational Training Institute (FDRE TVTI), in partial fulfillment of the requirements for the degree of Master of Science in Information Technology.

Principal Advisor: Birknesh W/Yohannes

Addis Ababa, Ethiopia
June 9, 2026

DECLARATION

I, the undersigned, declare that this thesis, entitled ***Design and Architectural Analysis of a Scalable Cloud-Based Learning Management System for Remote and Blended Learning in Ethiopian Technical and Vocational Training,*** is my own original work, prepared under the supervision of my advisor. It has not been submitted for the award of any degree, diploma, or any other academic qualification in this or any other institution. All sources of materials used in this dissertation have been duly acknowledged.

Declared by:

Name: **Sintayehu Feleke Berga**

Signature: 

Department: **Information Technology, FDRE TVTI**

Date: **June 3, 2026**

This thesis has been submitted for examination with my approval as the candidate's advisor.

Principal Advisor: **Birknesh W/Yohannes (PhD)**

Signature: 

Date: **June 3, 2026**

APPROVAL PAGE

This is to certify that the thesis entitled ***Design and Architectural Analysis of a Scalable Cloud-Based Learning Management System for Remote and Blended Learning in Ethiopian Technical and Vocational Training*** submitted by ***Sintayehu Feleke Berga (ID No. TTMR/199/16)***, in partial fulfillment of the requirements for the degree of Master of Science in Information Technology, has been examined and approved by the Board of Examiners of the Department of Information Technology, FDRE Technical and Vocational Training Institute.

Examination Role	Name	Signature	Date
Principal Advisor	Birknesh W/Yohannes (PhD)		June 3, 2026
Internal Examiner	_____	_____	_____
External Examiner	_____	_____	_____
Department Head, IT	_____	_____	_____
Dean, College of Graduate Studies	_____	_____	_____

Place: Addis Ababa, Ethiopia

Date of Final Approval: _____

ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere gratitude to Almighty God for granting me the strength and patience to complete this dissertation.

I am deeply indebted to my Principal Advisor, ***Birknesh W/Yohanis (PhD)***, for the invaluable guidance, constructive criticism, and continuous encouragement throughout this study.

My sincere thanks go to the Department of Information Technology and the College of Graduate Studies of FDRE TVTI for providing the academic environment, laboratory facilities, and resources required to complete this research.

I am also grateful to Agena Polytechnic College (APTC) for granting permission to collect data and for the cooperation of its staff during the study.

Finally, I owe a deep debt of gratitude to my family, friends, and classmates for their unwavering support, patience, and encouragement throughout my postgraduate studies.

ABSTRACT

LMSs have been essential platforms for remote and blended learning. Many LMSs are designed for a highly stable and available internet connection, an adequate digital environment, and a content-based learning paradigm. But, many LMSs do not consider the broader digital ecosystem, infrastructural circumstances, heterogeneous digital device range, and competency learning model of Ethiopian TVT institutions. This study aimed to design and analyze a scalable cloud-based LMS architecture suitable for Ethiopian TVT institutions. The methodology of this study followed the Design Science Research approach. It followed several steps, including conducting a literature review, analysis of the existing situation, derivation of requirements, designing the architecture, and conducting an analytical evaluation. The study proposed a context-aware cloud-based LMS architecture reflecting infrastructural, operational, and educational challenges. The architecture incorporates cloud-native design, offline-first synchronization, asynchronous processes, bandwidth-adaptive content delivery, modular services, and competency-based assessment. Based on the proposed architecture, a high-level system model and prototype model were designed to reflect institutional processes, organizational structure, student progress and performance, competency-based assessment, and blended learning support. The architecture was evaluated through a traceability analysis, scenario-based analysis, architectural evaluation, and comparative analysis. The evaluation results showed that the proposed architecture is sufficiently technical and contextually appropriate to address scalability, resiliency, bandwidth, and competency-based learning challenges of the Ethiopian TVT institutions. Hence, this study contributed a context-aware architectural model for further LMS development, deployment, and digital transformation.

Keywords: *Learning Management System, Cloud Computing, Technical and Vocational Training, Competency-Based Learning, Remote Learning, Blended Learning, Offline-First Architecture, Educational Technology.*

Table of Contents

DECLARATION I
APPROVAL PAGE II
ACKNOWLEDGEMENTS III
ABSTRACT IV
LIST OF FIGURES VIII
LIST OF TABLES IX
LIST OF ABBREVIATIONS AND ACRONYMS X
CHAPTER ONE: INTRODUCTION 1
1.1. Background of The Research 1
1.2. Statement of the Problem 3
1.3. Research Questions 4
1.4. Objective of the Research 5
1.4.1. General Objective 5
1.4.2. Specific Objective 5
1.5. Significance of the Research 5
1.6. Contribution of the Study 6
1.7. Scope and Limitations 6
1.7.1. Scope of the Research 6
1.7.2. Limitations of the Research 7
1.8. Organization of the Paper 8
CHAPTER TWO: REVIEW OF RELATED LITERATURE 9
2.1. Theoretical and Technical Foundations of LMS Design 9
2.2. Technological Landscape and Context in Ethiopia 10
2.3. Empirical and Technical Literature on Cloud-Based LMS Systems 11
2.4. Conceptual Framework for LMS Design 14
CHAPTER THREE: RESEARCH METHODOLOGY 16
3.1. Research Design 16
3.2. Research Approach 16
3.3. Research Framework 17
3.4. Data Sources 18

3.5. System Analysis Method 19
3.6. Architectural Design Method 20
3.7. Validation Strategy 21
3.8. Ethical Considerations 22
CHAPTER FOUR: SYSTEM ANALYSIS, DESIGN, IMPLEMENTATION, AND RESULTS 24
4.1. Introduction 24
4.2. System Analysis 24
4.2.1. Contextual and Operational Constraints 24
4.2.2. Pedagogical and Functional Requirements 26
4.2.3. Derived System Requirements 27
4.2.4. Requirement to Architecture Mapping 31
4.3. Proposed Context-Aware Cloud-Based LMS Architecture 33
4.3.1. Architectural Overview 33
4.3.2. Client and Edge Layer 34
4.3.3. Application Layer (Microservices Architecture) 35
4.3.4. Data and Storage Layer 35
4.3.5. Cross-Cutting Concerns: Security and Observability 36
4.4. System Model and Prototype Description 37
4.4.1 Conceptual System Model 37
4.4.2. User Interaction and Functional Flow 39
4.4.3 Prototype Representation and TVT Workflow Integration 42
4.4.4. Functional Prototype Implementation and Demonstration 44
4.5. Design Validation and Architectural Justification 49
4.5.1. Scalability Validation 50
4.5.2. Availability and Resilience Validation 50
4.5.3. Bandwidth Efficiency Validation 51
4.5.4. Pedagogical Alignment Validation 51
4.5.5. Validation Summary 52
4.6. Limitations of the Proposed Architecture 53
CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS 55
5.1. Conclusion 55

5.2. Achievement of Research Objectives 56
5.3. Contributions of the Study 57
5.4. Recommendations 58
5.5. Future Research Directions 58
References 60

LIST OF FIGURES

Figure 2.1: Conceptual Framework of Research Proposed 15
Figure 3.1: Research Framework 18
Figure 4.1: Contextual and Operational Constraints Affecting Cloud-Based LMS Architecture in Ethiopian TVT Institutions 26
Figure 4.2: Transformation from Contextual Constraints to Architectural Design Decisions 32
Figure 4.3: Proposed cloud-based LMS architecture 34
Figure 4.4: Conceptual System Model of the Proposed LMS 38
Figure 4.5: Functional Flow of Users' Online and Offline Interaction in the Proposed LMS 40
Figure 4.6: Functional workflow of the proposed LMS 41
Figure 4.7: Offline Synchronization and Background Processing Flow 42
Figure 4.8: Prototype Service and User Interaction Overview 43
Figure 4.9: Administrative Workspace 45
Figure 4.10: Instructor Workspace 46
Figure 4.11: Student Learning Workspace 47
Figure 4.12: Competency and Grade Reporting 48
Figure 4.13: Offline Synchronization Monitoring 48

LIST OF TABLES

Table 2.1: Comparative analysis of related LMS studies 12
Table 4.1: Functional Requirements 28
Table 4.2: Non-Functional Requirements 30
Table 4.3: Mapping of Constraints, Requirements, and Architectural Responses 31
Table 4.4: Summary of Design Validation and Architectural Justification 52

LIST OF ABBREVIATIONS AND ACRONYMS

LMS	Learning Management System
TVT	Technical and Vocational Training
ICT	Information and Communication Technologies
CDN	Content Delivery Network
FR	Functional Requirement
NFR	Non-Functional Requirement
UI	User Interface
UX	User Experience
API	Application Programming Interface

CHAPTER ONE: INTRODUCTION

1.1. Background of The Research

Education has changed as a result of using digital technology in ways that have changed the way we develop, deliver, and manage teaching and learning activities. The emergence of Learning Management Systems (LMSs) as primary platforms where teachers can develop their teaching resources, administer assessments (tests), communicate with learners, and track how learners are progressing toward their learning goals in both traditional (face-to-face) and distance education environments (Dhawan, 2020; Manninen, 2014). These systems are increasingly adopted to support blended and online learning models, particularly in higher education institutions.

Globally, there has been a surge in e-Learning and LMS usage over the last few years due to advancements in Information and Communication Technologies (ICTs) as well as the demand for flexible learning modalities. According to studies, LMSs have improved access to educational resources and enhanced continuity of instruction when properly aligned with institutional and learner requirements (Al-Fraihat, 2020; García-peñalvo, 2011). However, there are additional contextual factors that greatly affect LMS effectiveness, such as infrastructure availability, digital literacy, and institutional readiness to implement LMSs.

LMS adoption is not without challenges in the context of TVT due to the nature of its pedagogical approach. Competency-based learning is at the heart of a TVT education; therefore, an LMS must facilitate practical skill acquisition, ongoing evaluation of performance, and the ability to demonstrate measurable levels of competency through evidence of skills achieved, not just theory (Abebe, 2023). In order to achieve this, LMSs will need to have modular course design, opportunities for a variety of assessments, and functionality to record and monitor skill development and progression over time.

The Ethiopian government considers digital transformation in education as critical to achieving strategic goals, particularly for universities and Technical Vocational Institutions (TVT) (MOE, 2021; MoSHE, 2020). Digital learning platforms, including Learning Management Systems (LMS), are recognized as important tools in expanding educational access and improving the quality of instruction while also enhancing employment opportunities through skill enhancement

and workforce development. Although digital transformation has been identified as a priority at the national level in policy documents and through a variety of national initiatives, the current level of digital infrastructure within Ethiopian TVT institutions varies greatly. There are substantial differences among TVT institutions concerning internet connectivity, computer/device availability, and the overall capacity to use information and communication technology (ICog, 2023; Camara Education, 2023).

It is well documented that there are ongoing challenges related to how well LMS platforms are being used within both the Ethiopian educational environment and a more general context throughout Africa (Unwin et al., 2010; Ferede et al., 2022). that are preventing effective use of these tools. Some of these challenges include: limited access to bandwidth, unreliable internet connections, lack of adequate technical support for users, and poor digital readiness of users. Many learners also access the learning materials via low-quality mobile devices, which also limits their capacity to engage with learning materials that require a lot of resources (Isaacs, 2012).

Most LMS platforms are a viable option for the improvement of how TVT develops in Ethiopia, however, many of these LMS have a design flaw (to put it kindly) when it comes to their suitability to TVT institutions in Ethiopia, who have limited access to IT infrastructure, a lack of reliability in terms of internet connectivity, and a general lack of support from existing LMS for competency-based assessment (one of the most important foundations to the success of Community Development through TVT education) (Abebe, 2023). As a result of these extensive definitions of infrastructure, as defined here, current LMS platforms also tend to have a limited capacity to accommodate the features necessary for competency-based learning methodologies (learning methodologies based on competency-based assessments), which adds a décor to the LMS architecture of TVT institutions within the context of the Ethiopian educational framework. As this thesis discusses the need to consider the change in architecture of the existing LMS platforms and the requirement for scalability, offline access to resources for learning, adaptively delivering content to learners, and competency-based learning methodologies, it will also evaluate the impact of developing a context-aware, cloud-based LMS from previous studies on cloud-based LMS.

1.2. Statement of the Problem

There are many existing national advancement efforts globally to promote the use of Learning Management Systems (LMS) for digital education in Ethiopia. TVT (Technical and Vocational Training) institutions are experiencing ongoing challenges with inadequate infrastructure and technology needed to effectively utilize LMS. Most LMS platforms were designed for organizations where consistent internet access and access to relatively standardized high-quality equipment are present; however, these conditions do not apply to Ethiopian TVT institutions, where low internet access, insufficient bandwidth access, and minimal access to multiple unrelated hardware resources are the norm (MOE, 2021; ICog, 2023).

Numerous empirical resources state that inconsistency of internet access, high costs to use data, and frequently inconsistent access to reliable network resources create significant barriers to both learners and instructors using LMS platforms effectively. Consequently, learners have difficulties accessing course material, submitting coursework, and receiving timely feedback, thus negatively impacting the continuity and quality of the teaching and learning experience.

A significant challenge is the mismatch between the functionalities available in existing LMSs and the competencies-based pedagogical approach of TVT education. With an emphasis on ongoing evaluation, acquiring practical skills, and confirming competence, TVT programmes do not find LMSs that have been created predominantly for content delivery and summative evaluation very helpful for following a learner's development of skills and demonstrating that he or she has attained competence (Abebe, 2023).

This is supported by literature establishing that system usability, functioning, and adaptability are critical factors within the e-learning adoption literature for determining the success of an LMS (Al-Fraihat, 2020; Bassam & Alshorman, 2018). Although these factors are present in all resource-constrained circumstances, the absence of an LMS architecture suited to the constraints of infrastructure creates additional challenges for learners and instructors alike; the lack of scalability of systems and lack of support for low-bandwidth functioning further contribute to these challenges.

In spite of cloud-based technology's ability to solve issues of scalability, accessibility, and system resiliency, research only touches the surface when it comes to LMS architecture for TVT institutions in Ethiopia. Most studies pay more attention to factors associated with adoption than they do to the actual design of a context-aware LMS architecture (Dhawan, 2020; Yirga Adamu, 2024) or user attitudes toward the use of LMS and instructional outcomes.

The main problem this research solves is that there is no cloud-scalable, offline learning, competency-based educational process LMS architecture for Ethiopia's TVT institutions. Solving this issue from an architectural design perspective will enable the development of a scalable, resilient, and inclusive digital learning system that reflects the realities of the TVT sector in Ethiopia.

Plus, the majority of the existing LMSs are not designed for the TVT (Technical and Vocational Training) environment, where competency-based practical assessment, continuous assessment, modular progression, and hands-on training are critical components of the learning process. Most existing LMSs are built around the ideology of course content delivery, assignment submission, and online test taking. Hence, these LMSs do not provide adequate support for blended learning environments and low-bandwidth scenarios within the TVT learning environment. A cloud-based, scalable LMS design that is aware of the TVT competency-based working environments and supports an offline, cloud-based learning infrastructure is a critical need.

1.3. Research Questions

The following research questions guide this study:

1. What limitations exist in conventional LMS architectures when applied to remote, blended, and competency-based learning in Ethiopian TVT institutions?
2. What architectural components and design patterns are required to support competency-based and blended learning within a cloud-based LMS for Ethiopian TVT institutions?
3. How does the proposed architecture address scalability, resilience, bandwidth efficiency, and operational requirements in the Ethiopian TVT context?

1.4. Objective of the Research

1.4.1. General Objective

The main objective of this study is to design and evaluate an architectural analysis of a scalable cloud-based Learning Management System tailored to the operational and pedagogical requirements of Ethiopian TVT institutions.

1.4.2. Specific Objective

The specific objectives of the study are to:

- To analyze the infrastructural, operational, and pedagogical requirements of Ethiopian TVT institutions relevant to cloud-based LMS design.
- To design a scalable cloud-based LMS architecture that supports competency-based, remote, and blended learning in low-bandwidth environments.
- To develop a conceptual system model illustrating the components, data flow, and interactions of the proposed architecture.
- To implement a functional prototype demonstrating core LMS workflows, competency-based assessment support, and academic management features.
- To evaluate architectural analysis of the proposed system in terms of scalability, resilience, bandwidth efficiency, and suitability for Ethiopian TVT institutions.

1.5. Significance of the Research

Both the theoretical and practical domains of educational technology and systems design are enhanced by this research. The study enhances existing literature about Learning Management Systems (LMS) and cloud-based educational platforms by providing a context-aware architectural model for use in resource-constrained regions. In contrast to previous studies that have mainly focused on system adoption, user experience, or instructional outcomes, this research provides the most detail available concerning structural and architectural factors of LMS designs under low bandwidth conditions, intermittent connectivity, and competency-based education. Also, the study illustrates how the Design and Development Research (DSR) can be used to model and validate

educational system architectures without completing full-scale implementations, thus adding to methodological discussions within the field.

The proposed architecture can serve as a practical reference for Ethiopian Technical and Vocational Education Training (TVT) institutions, system developers, and policymakers with regard to their digital education initiatives. The design provides a model that demonstrates how learning management systems (LMS) should be designed in order to enable the delivery of scalable, offline, adaptive, and competency-based assessments for learners in the Ethiopian context. This study supports more informed decision-making by explicitly defining both infrastructure limitations and the diversity of user conditions so that institutions can better select, customize, or develop LMS platforms. Additionally, the architectural principles provided in this research may also be applied to other developing regions that are similarly constrained by technology and education, providing an opportunity for scalable and inclusive digital learning solutions to be established in regions outside the immediate study area.

1.6. Contribution of the Study

The overall contribution of this study is the design of a context-aware cloud-based LMS architecture for Technical and Vocational Training (TVT) colleges in Ethiopia. Unlike existing LMS systems in one or two domains, i.e., supporting content, assignment submission, and online quizzes/exams, the proposed architecture supports the academic hierarchy of TVT programs, a competency-based assessment workflow, offline or blended learning, and cloud-based, scalable components. Plus, the study has developed a working LMS model prototype demonstrating the support of departments, programs, levels, courses, trainers' assignments, competency assessment, grade calculation, and generation of students' transcripts. Hence, the contribution of the study is not the innovation of a cloud LMS but the integration of cloud-native LMS architecture with the workflow of Ethiopian TVT colleges and the requirements of competency-based training.

1.7. Scope and Limitations

1.7.1. Scope of the Research

The main focus of this study is designing and evaluating an architectural analysis of a scalable cloud-based Learning Management System (LMS) for Ethiopian Technical and Vocational

Training (TVT) Colleges. The study focuses on the architecture, components, and interactions, including services and data flow, as well as non-functional requirements for remote and blended learning in low-resource educational institutional settings.

The presented architecture is scalable, highly available, resilient, bandwidth-efficient, offline-first, asynchronous, and supportive of competency-based learning in a cloud-native LMS. The study also considers the academic structure and practices of the TVT colleges in Ethiopia in a department-program level structure, a competency-based assessment process, the assignment of trainers, student management, and continuous assessment.

The architecture model includes LMS administrators, who configure and manage the learning system; instructors, who deliver course content and assess competencies; and trainees, who access learning content, complete assessments, and track their progress through the LMS.

While the research prototype encompasses primary processes and functionalities within the LMS domain (e.g., academic structures, competency grading, student enrollment, transcript reports, and blended learning), the study did not involve a full deployment, integration, and sustained operations phase for multiple TVT institutions.

The study also considered common issues in the case of Ethiopian TVT surroundings such as limited access to the internet, low bandwidth, intermittent network access, and different user device in the design architecture.

1.7.2. Limitations of the Research

The study is primarily on the design and architecture of a scalable cloud-based LMS for Ethiopian Technical and Vocational Training (TVT) institutions. The development of a prototype LMS demonstrated core system workflows, but did not include deployment within one or more institutions to test production scale usage.

While the prototype implementation demonstrated functionalities such as academic hierarchy management, competency-based assessment workflow, trainer and trainee interactions, grade computation, and transcript generation, other advanced features such as evidence management,

large-scale distributed deployment, and integration with external systems were not addressed fully within the scope of this research.

Also, the architectural analysis was conducted through requirement analysis, contextual reasoning, workflow modeling, and prototype-based validation rather than through long-term empirical performance testing involving multiple institutions and users. Thus, large-scale usability studies, institutional adoption trends, and long-term performance remain to be determined.

The identification of requirements was also guided by a review of literature, policy documents, a general understanding of institutional work processes, and the actual procedures of TVT assessment. These factors were the context for the study but not an extensive field study across all TVT institutions in Ethiopia.

But, the mentioned shortcomings notwithstanding, the study delivered a context-aware architecture and a functional prototype that showed the feasibility of integrating competency-based TVT workflow, blended learning, and scalable cloud-based architecture for the Ethiopian TVT context.

1.8. Organization of the Paper

This research has been organized into five chapters. The first chapter presents the introduction part, which reflects background, statement of the problem, research question, objective of the study, significance of the study, scope of the study, and organization of the paper. The second chapter deals with a review of related literature. The third chapter deals with research methodology, including research design, target population, and method of data collection. The fourth chapter deals with data analysis, presentation, and ethical considerations. The fifth chapter deals with drawing conclusions and recommendations.

CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1. Theoretical and Technical Foundations of LMS Design

LMSs opt to move away from only being repositories of materials and evolve to be larger, more complex, distributed systems capable of delivering both synchronous and asynchronous learning, analytics, and individualized training services. Historically, early LMSs such as Moodle and Blackboard had essentially delivered the content (mostly) to learners; however, LMSs today are typically developed as service-oriented architectures that employ APIs for integration purposes, and use adaptive learning technologies themselves, which are based on theories of learning stemming from both **constructivist** and **connectivist** (Vygotsky, 1978; Siemens et al., 2019).
The movement to a cloud-based architecture has made it possible for LMSs to automatically scale based on demand, have multi-tenant deployment options, provide automatic software updates, and reduce the amount of money institutions spend on managing their own server infrastructure (García-peñalvo, 2011). The utilization of cloud-native architectures commonly incorporates distributed storage, container orchestration technologies, microservices, and containerization in order to afford high levels of reliability and availability; these design principles are particularly advantageous when local resources are either inadequate or inconsistent.

The principles (Manninen, 2014) & technical requirements for blended learning support systems should include online/offline caching features and asynchronous connectivity in cases where there isn't reliable broadband. Therefore, LMS research will increasingly use software architecture, constraints of the networks on which they operate, human-computer interaction, and cloud scalability as theoretical bases, along with traditional pedagogical teaching methods.

The literature suggests that LMS platforms have evolved into cloud-native and service-oriented architectures; however, the majority of the designs in the literature assume consistent infrastructure (i.e., consistent connectivity) with all users having the same device. This limits the applicability of these designs in resource-constrained environments and needs to be reinterpreted based on the low bandwidth, intermittent connectivity, and diversity of user capabilities in Ethiopia's TVT institutions.

While cloud-native and service-oriented LMS designs are widely found in literature, the designs are, for the most part, tailored for stable infrastructure and internet connection, and relatively

homogeneous user devices. In contrast, the design considerations for Ethiopian TVT institutions include intermittent connectivity, limited bandwidth, heterogeneous user devices, and competency-based practical training. Hence, the novelty of this study is not the cloud-native LMS technologies themselves but the contextualization and integration of the architectural designs into a scalable LMS for remote, blended, and competency-based learning in Ethiopian TVT institutions.

2.2. Technological Landscape and Context in Ethiopia

It is important to consider that there are significant infrastructure challenges faced by the TVT institutions in Ethiopia, and as such, any LMS designs will need to consider constraints such as insufficient broadband penetration, poor internet connectivity, power outages, and a lack of suitable digital devices. Though the aim for digital transformation has been established by way of a national priority as part of the Digital Ethiopia 2025 initiative (Ministry of Innovation and Technology, 2020), persistent challenges with broadband access, power stability and availability of appropriate devices provide an environment (Unwin et al., 2010; Isaacs, 2012) that will likely lead to LMS platforms relying on stable connections and high-bandwidth connectivity to have a low probability of being successful in TVT institutions.

Organizations such as the Ministry of Education and Camara Education have improved device distribution initiatives through their provision of computers to rural schools (Camara Education, 2023), but the challenges of digital readiness persist, and many teachers continue to use traditional teaching methodologies (Ferede et al., 2022). As well, common LMS solutions (e.g., Moodle, Canvas, and Google Classroom) typically do not support low-bandwidth or intermittent connectivity environments or the competency-based modular approach to assessment required in Ethiopian TVT systems (Abebe et al., 2023).

The reviewed evidence demonstrates that there are many factors impacting the success of LMS implementation in Ethiopian TVT institutions, particularly the limitations of the infrastructure utilized to access the LMS, more specifically, the lack of a stable connection to the internet, the limited availability of devices, and uneven levels of digital readiness. While many current LMS platforms are designed for much better access than what the current infrastructure can provide,

there are inherent gaps between the capabilities of LMS systems and the conditions under which organizations can successfully implement them.

2.3. Empirical and Technical Literature on Cloud-Based LMS Systems

The technical efficiency, scalability, and adaptability of the architecture of LMSs deployed in the cloud are increasingly becoming important in LMS research, especially in resource-limited environments. The current research literature indicates that cloud-based LMSs must employ cloud native architectures to achieve elasticity, high availability, and resiliency in educational settings that use unstable connection methods or have limited hardware capacity. Specifically, (García-peñalvo, 2011) demonstrates that cloud-based LMSs deliver these benefits over locally installed LMSs because they automatically provision resources and allow educational institutions to support multiple concurrent users without maintaining expensive infrastructure. This provides a direct solution to the infrastructure limitations often found in developing countries.

Multiple research studies show that using a cloud-based LMS will lead to a more responsive system with lower latency if the LMS is optimized for use on distributed cloud infrastructure. (Fabito et al., 2021) report that when asynchronous delivery models were paired with lightweight/mobile-first interfaces, then students' access to materials would be improved even when there were bandwidth limitations and students had access to the internet "intermittently." The study emphasizes the benefits of designing LMSs with an emphasis on compressed content delivery, caching methods, and limited server-side rendering, which are critical for the TVT environment in Ethiopia due to the lack of reliable internet access in some parts of the country.

According to (Unwin et al., 2010), in the African context, a majority of LMS implementations are unsuccessful due to the reliance on high-bandwidth architectures and an underlying expectation that all students will have access to the same device. Their analysis indicates that those systems that do not account for adaptive bandwidth management, offline functionality, or modular content delivery will have great difficulty becoming adopted in low-resource environments, which illustrates a significant technical disparity between existing LMS systems and the contextual infrastructure and pedagogical limitations of institutions like Ethiopian TVT colleges.

Further, local research supports that Ethiopian institutions need LMS architectures that integrate multilingual capabilities, simple interface requirements, mobile-first prioritization, and

customizable competency-based training workflow capabilities. Research conducted by Abebe et al.(2023) shows that most LMS platforms in use at TVT colleges are not pedagogically aligned and fail to be technically flexible and have missing core modules such as practical task tracking, a modular assessment engine, and TVT-specific reporting. The study has revealed significant evidence for LMS systems with flexible backend architectures, extensible APIs, and modular/microservice-based components that allow institutions to add and modify capabilities to an LMS without the need to re-engineer the entire LMS platform.

Research on educational systems that are dependent on the cloud has been trending toward the importance of containerization and distributed hosting as a foundational design principle of scalable learning systems. According to many development research methods (Richey, 2007), have been advocating for iterative prototyping methods that include validating technical performance (load/stress/response time) into system design cycles of cloud-based learning management systems (LMS). This is directly related to current approaches to developing cloud-based LMSs using tools like Docker, Kubernetes, and CI/CD pipelines to provide reliable, scalable, and rapid deployment solutions.

The research reviewed shows that when designing learning management systems for low-throughput, technical performance, scalability, a flexible architecture, and the ability to be adapted locally are all critical to the future of these systems. While examples exist from more developed countries for systems hosted on 'clouds', the technical systems supporting multiple users at once—TVT institutions in Ethiopia are still lacking their version of contextually relevant local LMS architecture. This study attempts to document the missing link in the development of a scalable learning management system that will be able to support low-bandwidth access to real-world evidence of value-added TVT processes and, ultimately, support the expansion of TVT institutions.

Table 2.1: Comparative analysis of related LMS studies

Study	Context	Contribution	Limitation / Gap
(García-peñalvo, 2011)	Developed countries	Demonstrates scalability & cost benefits of cloud LMS	Not suitable for low-bandwidth or low-device environments

(Fabito et al., 2021)	Developing (Philippines)	Shows mobile-friendly & asynchronous cloud LMS use	Not designed for TVT or practical skill assessments
(Abebe et al., 2023)	Ethiopia TVT	Identifies LMS–pedagogy misalignment	Offers no technical model or architecture
Olanrewaju et al. (2022)	West African polytechnics	Provides low-bandwidth adaptive cloud LMS	Not aligned with the Ethiopian competency-based TVT
(MOE, 2020) (MoSHE, 2020)	Ethiopia	Recognizes infrastructure barriers	Offers policy direction but no technical LMS solution

This comparative study shows that even though cloud-based LMS solutions are flexible and scalable; it does not solve all issues related to low-bandwidth environments, intermittent connectivity, and competency-based requirements of assessment (i.e., assessment based on competency). The focus of the studies conducted in an Ethiopian context is primarily on the adoption of these systems and their pedagogical alignment, but they do not propose specific architectural solutions to address the issues of the Ethiopian TVT system. Therefore, there is a significant gap in the existing literature regarding the design of context-aware, cloud-based LMS architectures specifically designed for the Ethiopian TVT system.

Previous research on Learning Management Systems (LMS) has mostly concentrated on the adoption and usability of the system as well as how effective instruction is within the system; however, very little emphasis has been placed on the architectural design aspects of LMS platforms for resource-constrained environments. Although cloud-based LMS solutions have been researched, they do not typically contemplate an unstable infrastructure and do not consider any solutions for the offline-first functionality necessary for these LMS to be used in support of competency-based education models typically associated with Technical and Vocational and Training (TVT) systems. There is a significant lack of available data on the design and analysis of scalable, contextualized, cloud-based LMS architectures that incorporate low-bandwidth optimization, offline functionality, and support for competency-based education in the context of

Ethiopian TVT materials. The purpose of this research is to address this gap by proposing a context-aware cloud-based LMS architecture specifically tailored for Ethiopian TVT institutions and demonstrating its applicability through architectural analysis, competency-based workflow modeling, and functional prototype implementation aligned with real TVT operational practices.

2.4. Conceptual Framework for LMS Design

There is an underlying conceptual framework for this study that includes three interrelated areas:

1. the development of cloud infrastructure and scalability;
2. the design of LMS system architecture and models; and
3. adapting the LMS to the context of TVT institutions in Ethiopia.

This framework has been created to fill a research gap regarding the lack of contextually appropriate LMS architectures that are able to meet two kinds of LMS requirements (technical and pedagogical), especially in resource-scarce countries and institutions.

The first of three dimensions of the conceptual framework to be explored is cloud infrastructure and scalability, which includes the technological foundation of LMS operations. The elements of cloud infrastructure that support the functioning of LMS operations are: distributed computing resources, load balancing mechanisms, elastic scaling, and dependable data storage. Cloud-based infrastructure enables the allocation of resources to be completed as requested or needed by an institution, and it reduces the demand on local hardware, particularly in those environments that are affected by unreliable power and/or inadequate institutional infrastructure (García-peñalvo, 2011).

Dimension two concerns with how the LMS is built internally and how it works functionally; therefore, there are many different elements to its design such as; having modular components, a service-oriented architecture, API communications, systems that provide for asynchronous processing as well as offline-first synchronization, and using mechanisms that assess based on competency so that the LMS aligns with how TVT education is implemented (pedagogically). Principles related to the architectural design of the LMS include flexibility, interoperability, and scalability.

Ethiopian TVT's third dimension, contextual adaptation, guarantees that the proposed design of the system will work within the constraints of the local operating environment. For example, it provides optimized design for low bandwidths, accommodates the use of multiple different client devices, has multiple languages built into the system, and uses very simple forms of interaction with users with low ICT capacities (Abebe, 2023). The third dimension is the bridge between the generic design of an LMS and the specific design required by Ethiopian TVT institutions.

These three dimensions provide an integrated framework that will assist in the design and analysis of the proposed LMS architecture. The framework's combination of cloud scalability, modular design, and contextual adaptations will provide a structured basis from which to build a scalable, resilient, and contextually aware LMS model for remote and blended learning in Ethiopian TVT institutions.

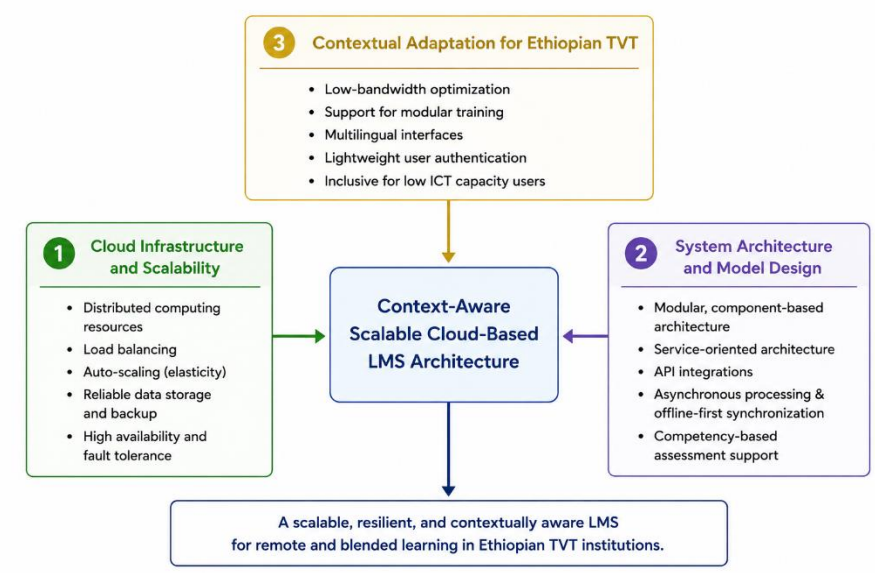


Figure 2.1: Conceptual Framework of Research Proposed

CHAPTER THREE: RESEARCH METHODOLOGY

3.1. Research Design

In order to solve a technological and architectural issue in the field of educational information systems, this research takes a design-oriented research method. The research focuses on the methodical design and analysis of a cloud-based Learning Management System (LMS) architecture appropriate for Ethiopian TVT institutions rather than on empirical assessment of user perceptions or system uptake.

Design-oriented research is appropriate when the primary goal is to develop and justify an artefact such as a model, framework, or system architecture that addresses a clearly defined problem (Richey, 2007). In this study, the artefact is an architectural model of a cloud-based LMS optimized for low-bandwidth environments, offline learning, and competency-based education.

The research design aligns with Design and Development Research, which focuses on the creation and refinement of design solutions through analytical and theoretical validation rather than full-scale implementation or experimental testing (Richey, 2007).

3.2. Research Approach

This study employs the use of a design science research model to evaluate or develop original technology artifacts intended to address existing problems. This is different from exploratory research that is generally focused on identifying problems, as this research is grounded in the previously documented experiences of the limitations of existing learning management systems in resource-limited environments, specifically those encountered during the delivery of technical vocational education and training (TVT) in Ethiopia. Researchers have previously identified insufficient bandwidth, unreliable connectivity, insufficient infrastructure, and LMSs that do not align with competence-based education as issues with existing LMSs. As such, this study's objective will not be to duplicate the identification of the above-mentioned problems, but rather to provide a means of creating and assessing a suitable technical architecture to address them.

Following the principles of Design Science Research (Hevner et al., 2004), the study proceeds through the following stages:

1. Defining design objectives based on identified challenges,
2. Developing a conceptual and architectural model of a cloud-based LMS, and
3. Validating the proposed architecture using both analytical and design-based validation methods.

This ensures that the findings from this research project serve both to advance theoretical knowledge and to develop a practical (also applicable) architectural model for Ethiopian vocational education training (TVT).

3.3. Research Framework

(Richey, 2007) describes how Design & Development Research principles provide the research method base/framework for this study. The Research uses a Design Science Research (DSR) approach, focusing on creating and analytically assessing a technology artifact instead of discovering empirical research problems.

The literature notes that there are pedagogical and technical problems related to the adoption of LMS in Ethiopian TVT institutions; therefore, this research did not repeat the problem identification and analysis phase. Instead, the research study begins with identifying design objectives from the identified problems (low bandwidth, intermittent connectivity, and the need for competency-based assessment support).

The research process is divided into four key phases. The first phase defines the design requirements and scope using existing knowledge as the basis. The second phase is developing a modular cloud-based architecture of the LMS that meets the design requirements. The third phase includes a complete system model of the LMS & prototype representations of the system components, data flows, and service interactions. The fourth phase of the research involves the validation of the architecture and is fundamental to the research. Validation is done through analysis of architectural justification, scenario analysis, scalability, resilience, and bandwidth efficiency to check whether the proposed system is conceptually sound as well as technically feasible in the Ethiopian TVT context. The study addresses architectural viability and design rationale rather than full implementation in accordance with the principles of Design Science Research.

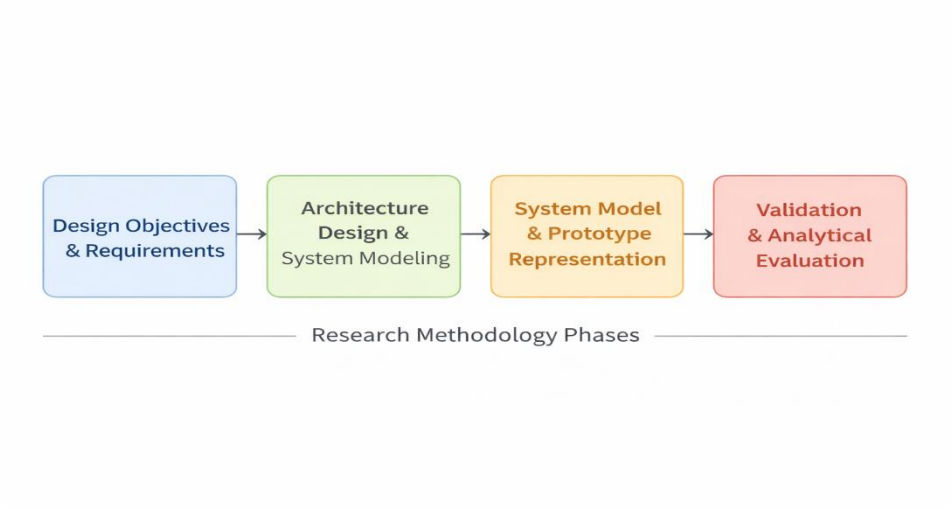


Figure 3.1: Research Framework

3.4. Data Sources

The study relied on secondary and contextual sources in justifying the design structure of the proposed LMS. Reports, articles, conference papers, policy papers, and existing works on cloud-based and e-learning education platforms and LMS architecture served as secondary sources. An understanding of how Ethiopian TVT institutions operate, how competency-based assessments are practiced, and institutional challenges guided the study in identifying requirements and in architectural design.

The study looks at both global and local sources. Global literature contains foundational knowledge of cloud computing architectures, the design of LMS, and the performance of e-learning systems, including research on the success and uptake of LMS (Al-Fraihat, 2020; Bassam & Alshorman, 2018); and additionally, more extensive studies on digital education in developing countries (Unwin et al., 2010; Isaacs, 2012).

Additionally, context-specific sources were used to gain a better understanding of the operational conditions of Ethiopian TVT institutions. Some context-specific sources are several national policy documents, such as Digital Ethiopia 2025, and reports by the Ministry of Education (MOE, 2021) and the Ministry of Science and Higher Education (MoSHE, 2020), which describe the various challenges that exist in the field of infrastructure, education, and learning.

Plus, the architecture was designed based on an understanding of the workflow of TVT institutions and competency-based training practices in the Ethiopian TVT institutions, particularly pertaining to course structuring, practical assessments, trainer roles, student evaluation, and challenges of blended learning. Assessment documents, competency evaluation checklists, and practices in TVT institutions were used to contextualize the proposed architecture and to ensure it complemented existing educational workflows.

The study did not employ large-scale empirical methods such as surveys or controlled experiments, as the primary focus of the research is on architectural design, system modeling, and prototype-oriented validation rather than statistical analysis of user behavior. However, contextual operational understanding and institutional workflow practices were considered during requirement identification and architectural decision-making.

3.5. System Analysis Method

This research's system analysis looks at how to make sure all of the Learning Management System's (LMS) functional and non-functional requirements can unite into one system through the systematic classification and definition of functional and non-functional system requirements. Requirement identification was informed through literature analysis, review of policy and institutional documents, contextual understanding of Ethiopian TVT operational workflows, and practical competency-based assessment procedures commonly used within TVT institutions.

Through analysis of current educational services utilizing Learning Management Systems (LMS) with regard to the various problems experienced by LMS users, particularly low bandwidth, a lack of consistency in their access to the Internet, heterogeneous devices/users, and developing competency-based education in current TVT environments, the researcher used these four categories of challenges to define requirements for each of the LMS's functions. The four categories of LMS function requirements include: functional LMS requirements like content distribution, user assessments, and user interaction; and non-functional LMS requirements like scalability, availability, performance efficiency, and offline usage availability.

In order to connect the identified challenges to the system capabilities identified, a requirement mapping approach was utilized. Connections were made between connectivity limitations to both

Offline First Design and Synchronization mechanisms, as well as between the pedagogical requirements of Competency-Based Education (CBE) to both modular assessment components and skills tracking tools. By mapping these challenges to corresponding system capabilities, the system design directly meets the technical limitations (or constraints) and the educational objectives of CBE.

Plus, practical institutional structures such as department-program-level organization, trainer assignment procedures, continuous assessment practices, and competency evaluation workflows observed within TVT environments were considered during requirement mapping and architectural decision-making.

The result of undertaking this process is a set of structured design requirements that guide making architectural decisions as described in the following chapter. This systematic approach helps to ensure that the proposed LMS architecture is systematically derived from identified contextual, pedagogical, and technical requirements.

3.6. Architectural Design Method

The proposed Learning Management System (LMS) is modeled in a component-based, layered architecture, allowing the system to be organized into functional subsystems. Each subsystem (content delivery, data management, data synchronization, assessment) can be independently managed while still maintaining system coherence.

Architectural design is based on Design Science Research (DSR) principles, where design decisions are made in accordance with existing requirements and constraints (Hevner et al., 2004; Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, 2007). Some of these requirements and/or constraints include low-bandwidth, sporadic connectivity, and multiple types of user devices; all while providing competency-based education for Ethiopian TVT institutions (Isaacs, 2012; Ministry of Innovation and Technology, 2020; MOE, 2021; Unwin et al., 2010).

The architecture of the system is based upon a modular, service-oriented, and well-defined component/interface approach to meeting the stated requirements. As such, the following architectural strategies have been employed:

1. An API is used as a communication mechanism between services,
2. Asynchronous processing will be used for tasks that run in the background, and
3. A set of structured data flows employed to achieve efficiencies/reliability for the system.

Furthermore, the architectural design incorporates cloud native design principles for the system, such as elastic scalability, distributed resource management, and fault-tolerant solutions. These principles allow the system to adjust quickly based on changing user demands and physical resource limitations.

In addition to the cloud native design principles, the architectural design also employs an offline-first design strategy. As such, users have access to all learning content and are able to perform a set of key interactions with that content, even when there is limited or unstable connectivity, and have the ability to perform a synchronization after connectivity is restored.

Throughout the architectural design process, the architectural design artifacts were captured using a range of system model types (component diagrams, data flow models, and deployment architecture representations, etc.). Each of these will provide structure to visually represent the system behavior and interactions, which will be the basis for further validation and analysis.

3.7. Validation Strategy

This research employs a validation technique that is design-oriented, as determined by the Design Science Research (DSR) methodology. A means of evaluating the proposed Learning Management System (LMS) architecture using analytical and scenario-based evaluations rather than empirical testing with users was used to validate the system. The purpose of this validation process is to determine whether the developed system meets all technical and contextual requirements that have been identified in the research.

The validation process employs several different methods in order to be effective. First, requirement-based validation was performed to evaluate how the proposed architecture aligns with the requirements identified. This was done to ensure that the primary performance measures, including but not limited to low-bandwidth operation, offline access, scalability, and competency-based learning support, are covered within the design.

Second, scenario-based evaluations were conducted to evaluate the system's response to operational conditions typical of Ethiopian Technical and Vocational Education and Training (TVT) institutions and the system's capacity to sustain functionality and performance under the conditions described above. Performance evaluations were conducted using architectural reasoning to consider the operational conditions of disconnected devices, excessive users accessing the system simultaneously, limited capabilities for user devices, and asynchronous interactions between learners and other individuals.

Third, architectural evaluation criteria were utilized to determine the quality of the proposed system, which will include some of the following: scalability, reliability, performance efficiency, modularity, and adaptability. Each of the architectural components was assessed based on how they contribute to each of these quality attributes, thereby providing evidence for and justification of design decisions whilst ensuring that they align with the overall objectives of the proposed system.

Finally, the proposed architecture was evaluated through its ability to create improvements over existing LMS platforms' limitations, particularly with respect to context-awareness issues and infrastructure limitations, using comparative reasoning.

The multi-layered validation methodology outlined above ensures that the proposed architecture is not only conceptually sound but also technically and contextually valid/appropriate, regardless of whether or not the entire system has been implemented in a manner that is reflective of real-world implementations. This methodology is consistent with widely accepted best practices for validating designs in the field of design-based research, which indicates that artefact validity can be demonstrated through structured analytical justification and connections/relationships to established research literature (Richey, 2007).

3.8. Ethical Considerations

The paper has no experimental interventions, there are no personal data collections, and there are no humans involved in the research. Therefore, there is no ethical risk regarding data protection,

privacy, and consent for the use of data. There is adherence to the principle of academic integrity and appropriate citation of all sources that are not cited directly.

CHAPTER FOUR: SYSTEM ANALYSIS, DESIGN, IMPLEMENTATION, AND RESULTS

4.1. Introduction

In this Chapter, an analytical and architectural framework for the Cloud-Based Learning Management System (LMS) providing an institution for Technical and Vocational Training (TVT) in Ethiopia is defined. This Chapter attempts to define the overall architecture of the system using education, infrastructure, and context requirements resulting from the challenges and gaps identified in the previous Chapters. The attributes that are highlighted in this Chapter are modularity, scalability, low-bandwidth, and interoperability with current cloud-based system design principles. As opposed to other studies, this Chapter will focus on the reasoning, interaction of components, and design justification through an Architectural Design research approach (Richey, 2007).

4.2. System Analysis

This stage of the system analysis is essential in understanding the technical and operational background to my proposed cloud-based LMS, based on context and instruction, transforming them into system-wide requirements. This phase does not take the form of primary research; it takes the form of a compilation of the documented institutional, educational, and software weaknesses identified in the previous chapters. My goal is to make sure that the suggested structure is not based on assumptions but rather is based on reality and literature.

4.2.1. Contextual and Operational Constraints

Ethiopian Technical and Vocational Education and Training (TVT) systems face many infrastructure problems. For instance, the quality of Internet connection is one of the biggest hurdles TVT institutions face in getting access to online learning environments (i.e., intermittent, fluctuating bandwidth, or frequent interruptions) and in teaching and learning processes. (Ferede et al., 2022; Unwin et al., 2010).

Limited bandwidth and low data transmission capacity reduce the effectiveness of traditional LMS platforms designed for stable and high-speed internet environments (Isaacs, 2012). As a result, many TVT institutions experience difficulty accessing centralized LMS platforms consistently.

Another barrier to learning is that the learners/trainers use a wide range of different types of devices, including low-specification smartphones with little memory, little processing power, and low screen resolution, among other devices. These conditions require LMS architectures capable of supporting heterogeneous device environments while maintaining usability and accessibility.

In addition, variations in digital literacy and ICT readiness among teachers, students, and institutions also affect the effective adoption of LMS platforms within Ethiopian TVT environments (Camara Education, 2023b; MOE, 2021). These conditions require LMS architectures capable of operating within resource-constrained and heterogeneous educational settings.

Existing literature and policy reports consistently identify infrastructural limitations, low ICT readiness, and operational constraints as major barriers affecting LMS implementation in Ethiopian TVT institutions (Ferede et al., 2022; Unwin et al., 2010). Low digital literacy and low ICT readiness of teachers and students have also been reported (Camara Education, 2023b; MOE, 2021). Financial limitations, insufficient technical support personnel, and resistance to digital transformation further affect the sustainability and usability of LMS platforms within Ethiopian TVT environments. In addition, issues of policy and governance affect the level of preparedness and propensity to embrace technology in TVT institutions. *Figure 4.1* illustrates the contextual constraints affecting LMS implementation in Ethiopian TVT institutions.

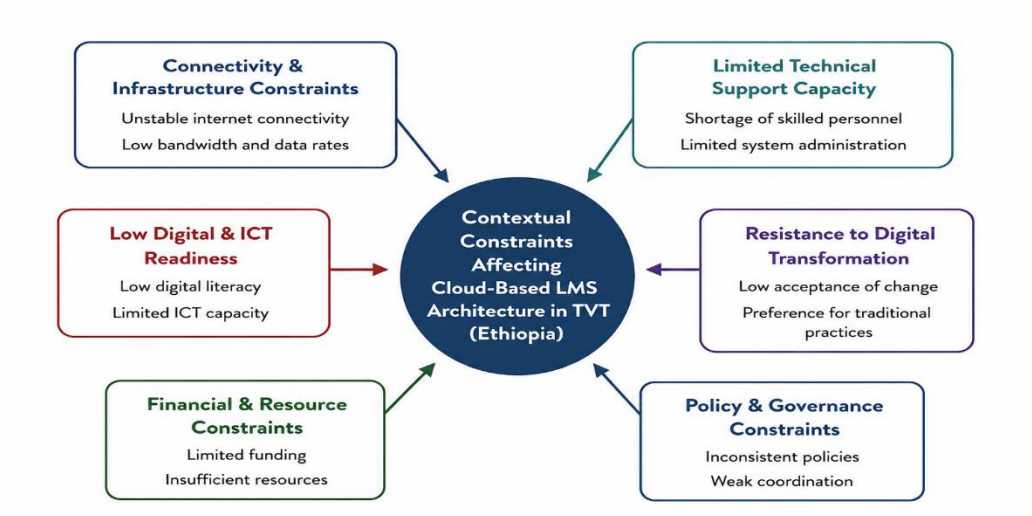


Figure 4.1: Contextual and Operational Constraints Affecting Cloud-Based LMS Architecture in Ethiopian TVT Institutions

4.2.2. Pedagogical and Functional Requirements

In addition to the physical infrastructure issues, there are also differences between the two systems of education in terms of the form of technical and vocational education and training (TVT). TVT is based on a competency-based training model where the emphasis is on practical skills and continuous assessment and learning outcomes, rather than on theory. (Abebe, 2023).

Learning and instruction should occur in modularized learning/teaching with units of competency that represent completion of learning components (learning modules). Continuous assessment for the instructor must take place in the LMS through multiple types of assessments (assessments for assignments, practical, cooperative, and theoretical assessments, and feedback).

The proposed LMS should have functionality to measure the progress of the learners and record the accomplishment of competencies, rather than a typical LMS that only serves to provide instructional content and final assessments (summative). The LMS must use a competency model to support the teachings of TVT and competency management within the LMS to allow the teacher to identify the competencies the learner should have, map the assessment activities to the learning outcomes, and monitor the learner's progress toward achievement of the competencies over time.

The above pedagogical requirements require that not only is the LMS a content delivery platform, but that it also serves as a learning and skill development system that corresponds to TVT education goals.

4.2.3. Derived System Requirements

Based on the needs identified in the context of the project, requirements for the new LMS have been determined through an open process. They reflect the limitations in the existing infrastructure, the users' needs, and the need to provide instruction based on skills. As a result, they are in keeping with TVT Institutes in Ethiopia. This study distinguishes and separates the requirements into functional and non-functional requirements.

4.2.3.1. Functional Requirements

The main functional requirements include the capabilities of the LMS that support teaching and learning, and interacting with the LMS. Users can have access to LMS features via a role in the LMS as Administrator, Instructor, or Student for their school. Course and content management includes modular courses, structured content to provide, and tracking students' progress.

The competency-based assessment methods used within TVT institutions must also be considered to support the learning and teaching philosophy at the TVTs. The assessment tools outlined in this section of this plan should allow the instructors to review the students' competencies and evaluate their practice.

Further, the LMS needs to support offline access so that students can download and synchronize their information once they have connectivity again. In order for students to continue to learn even when they lose connection, asynchronous mechanisms such as offline assignment submission, delayed synchronization of assessment records, local content caching, and background upload of learner activity data must be supported.

The functional requirements were derived from the pedagogical requirements of competency-based TVT education and the operational realities of Ethiopian educational institutions. Existing studies emphasize the importance of role-based learning environments, modular course

organization, competency assessment mechanisms, and flexible access to learning resources (Abebe, 2023; Al-Fraihat, 2020). Furthermore, literature on digital learning in developing countries highlights the need for offline access and asynchronous learning mechanisms to address connectivity limitations and support learning continuity (Fabito et al., 2021; Isaacs, 2012; Unwin et al., 2010).

Table 4.1: Functional Requirements

Requirement ID	***Requirement Description***	***Source Context***
FR1	Role-based access control (Admin, Instructor, Student)	LMS platforms require differentiated user roles and permissions to support administration, instruction, and learning activities (Al-Fraihat, 2020; García-peñalvo, 2011)
FR2	Modular course and content management	TVT curricula are organized into competency units and modular learning structures that require modular course management capabilities (Abebe, 2023; MoLS Occupational Standards Manual, 2023)
FR3	Competency-based assessment and progress tracking	Competency-based education requires continuous assessment, competency verification, and learner progress monitoring rather than only final examinations (Abebe, 2023)
FR4	Offline access to learning materials	Intermittent connectivity and infrastructure limitations necessitate offline access mechanisms to ensure learning continuity (Isaacs, 2012; Unwin et al., 2010)
FR5	Asynchronous interaction and synchronization	Asynchronous learning and delayed synchronization improve accessibility in low-bandwidth and unstable network environments (Fabito et al., 2021; Manninen, 2014)

4.2.3.2. Non-Functional Requirements

The LMS architecture is influenced by the non-functional requirements placed on it. Non-functional requirements describe how the LMS performs in terms of quality attributes and the use limitations associated with using the system in Ethiopian TVT institutions through the network and infrastructure supporting the LMS. Non-functional requirements were derived from infrastructural, technical, and operational constraints identified in Ethiopian TVT institutions. Previous studies indicate that cloud-based educational systems operating in resource-constrained environments must emphasize scalability, reliability, bandwidth efficiency, security, and adaptability to diverse user devices (Ferede et al., 2022; Isaacs, 2012; Unwin et al., 2010). Additionally, cloud-native and service-oriented architectural approaches recommend modularity and maintainability as essential quality attributes for long-term sustainability and system evolution (García-peñalvo, 2011; Hevner et al., 2004).

The ability to scale is one of the non-functional requirements for the LMS. With the increase in users and institutions utilizing the LMS, it needs to be able to accommodate large numbers of users without compromising the delivery of services. A reliability guarantee is one of the essential non-functional requirements for the LMS because the network and power supply may be unstable. The LMS should maintain operational continuity and support recovery mechanisms under unstable network and power conditions. Bandwidth-efficiency requirements emphasize minimizing data consumption through mechanisms such as caching, compression, and optimized content delivery to support low-bandwidth environments and low-end user devices. The non-functional security requirements for the LMS include authentication, authorization, and data protection mechanisms to maintain the integrity and confidentiality of user data. The non-functional requirements of

maintainability and modularity need to be considered so that the LMS can continue to evolve and grow over time without requiring changes to its structure.

Table 4.2: Non-Functional Requirements

Requirement ID	***Requirement Description***	***Source Context***
NFR1	Scalability to support increasing users and institutions	Cloud-based LMS architectures should support elastic scaling and increasing numbers of users through cloud-native infrastructure (García-peñalvo, 2011; Hevner et al., 2004)
NFR2	High availability and reliability	Educational systems operating under unstable infrastructure require resilient and highly available architectures (Isaacs, 2012; Unwin et al., 2010)
NFR3	Bandwidth-efficient operation	Low-bandwidth environments require optimized content delivery, caching, compression, and lightweight communication mechanisms (Dhawan, 2020; Fabito et al., 2021)
NFR4	Device adaptability and lightweight interface	LMS platforms must support heterogeneous devices, including low-specification smartphones and computers commonly found in developing countries (Ferede et al., 2022; Isaacs, 2012)
NFR5	Security (authentication, authorization, data protection)	Secure user authentication, authorization, and data protection are fundamental quality attributes of modern LMS architectures (Al-Fraihat, 2020; García-peñalvo, 2011)
NFR6	Maintainability and modular system design	Modular and service-oriented architectures improve maintainability, extensibility, and long-term system evolution (García-peñalvo, 2011; Hevner et al., 2004)

4.2.4. Requirement to Architecture Mapping

An established mapping structure is used between contextual issues, system specifications, and architectural solutions to answer each identified limitation and requirement for the proposed LMS architecture that meets identified needs. The mapping will serve as a conduit to identify the specific issues of the problem domain and the proper, logically justified solution for architectural design. The relationship between constraints, requirements, and architectural strategies is shown in *Table 4.3.*

Table 4.3: Mapping of Constraints, Requirements, and Architectural Responses

Identified Constraint / Requirement	***Implication for System Design***	***Architectural Response***
Intermittent internet connectivity	Continuous server dependency is unreliable	Offline-first architecture with local storage and synchronization
Limited bandwidth availability	High data consumption reduces usability	Adaptive content delivery, compression, and caching mechanisms
Heterogeneous user devices	The system must support low-spec devices	Lightweight client interfaces and responsive design
Competency-based TVT pedagogy	Need for continuous skill tracking	Integrated competency management module
Increasing number of users/institutions	The system must scale efficiently	Cloud-based, scalable architecture with modular services
Low ICT readiness and digital literacy	Complex interfaces reduce usability	usability Simplified and responsive user interface
Unstable infrastructure	Risk of service disruption	Distributed system design with fault tolerance mechanisms

The elements shown in the following sections correspond to requirements identified by the system analysis. This requires a design that can be based on needs and constraints within the school

context. *Figure 4.2* shows the process through which constraints or requirements influence architectural decisions.

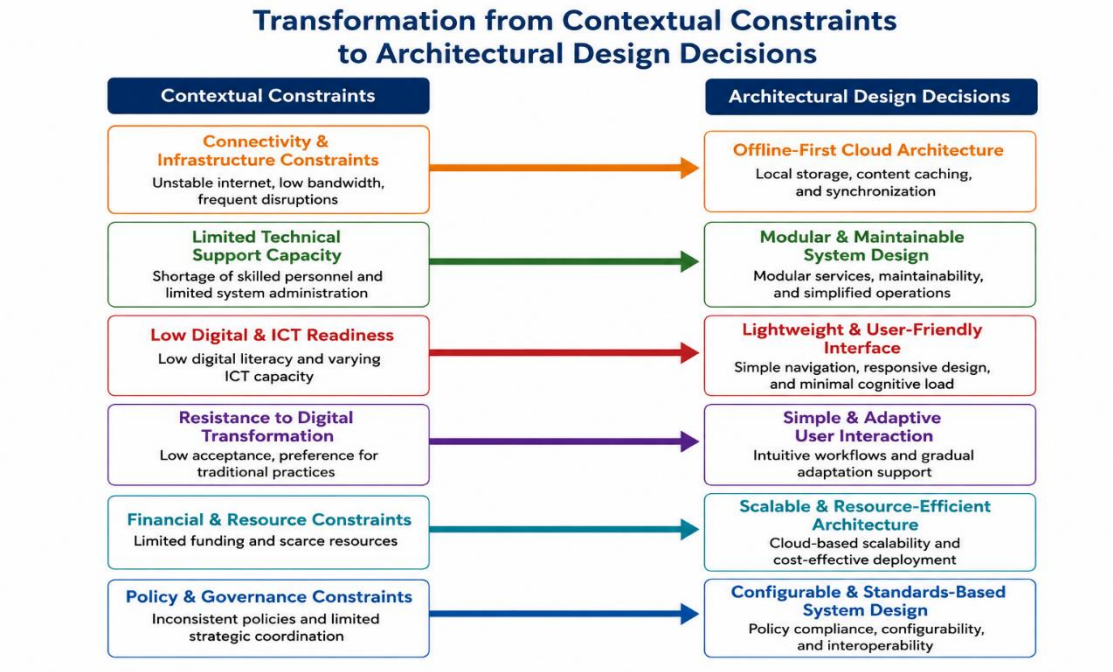


Figure 4.2: Transformation from Contextual Constraints to Architectural Design Decisions

From a conceptual design to the physical design of the system that meets the physical and operational needs has been transformed, as illustrated in *Figure 4.2*. For example, where the devices can be connected (due to the type of devices used), how much data can be transferred (due to bandwidth limitations), and what the nature of the devices used is (device heterogeneity) will influence the architecture of the system. For example, when devices experience internet disconnection, the system should support offline-first operation and local content caching to maintain learning continuity under unstable connectivity conditions. The transformation from contextual constraints into architectural design decisions enables the proposed LMS architecture to address the operational realities of Ethiopian TVT institutions. Infrastructure limitations, unstable connectivity, heterogeneous devices, and competency-based educational workflows directly influenced the selection of architectural strategies such as offline-first synchronization, lightweight interfaces, modular services, and scalable cloud-native deployment mechanisms.

4.3. Proposed Context-Aware Cloud-Based LMS Architecture

4.3.1. Architectural Overview

The proposed architecture presents a context-aware cloud-based LMS architecture tailored for Ethiopian TVT institutions operating under low-bandwidth, intermittent connectivity, heterogeneous device environments, and competency-based educational workflows. The architecture adapts cloud-native architectural principles through offline-first synchronization, asynchronous processing, lightweight service interaction, and competency-oriented learning support. It satisfies both the functional and non-functional requirements discussed in *Section 4.2.3.* It allows for significant scaling, modularity, and resilience throughout the entire architecture, as well as online-first interactions and competency-based learning. Figure 4.3 shows the five layers of the architecture:

1. Client Layer,
2. Edge and Delivery Layer,
3. Microservices Application Layer,
4. Cross-Cutting Services Layer, and
5. Data and Storage Layer.

Each layer meets specific system requirements while also maintaining separation of concerns between layers.

Unlike conventional LMS architectures primarily designed for stable infrastructure environments, the proposed architecture incorporates contextual adaptation mechanisms, including offline synchronization, local caching, asynchronous submission handling, competency-based practical assessment support, and lightweight client interaction suitable for resource-constrained TVT environments.

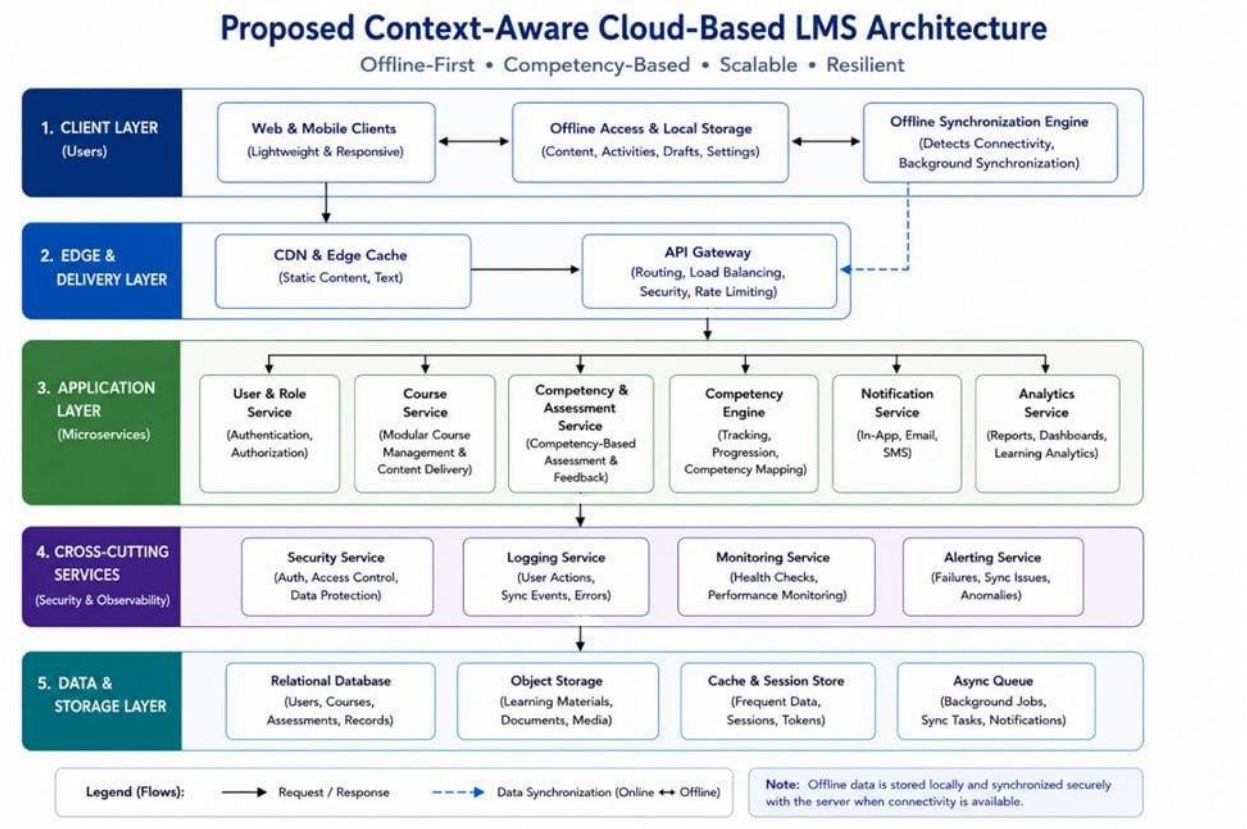


Figure 4.3: Proposed cloud-based LMS architecture

4.3.2. Client and Edge Layer

Client is the user interacting with the system through web or mobile channels. In order to handle device diversity, the system has a responsive and lightweight interface suitable for low-end phones and desktop computers.

A Content Delivery Network (CDN) and edge layer are implemented for bandwidth constraints. The edge layer is responsible for sending static content, text-first content, or low-resolution media over a network of cache nodes distributed geographically. This reduces data transfer and latency, improves system response, and reduces the dependence on central servers.

This offline-first synchronization mechanism represents a contextual adaptation specifically intended for Ethiopian TVT environments where internet connectivity may be unstable or unavailable for extended periods. Once the internet is available, it synchronizes data in the background.

4.3.3. Application Layer (Microservices Architecture)

The application layer uses microservices to increase the modularity, scalability, and maintainability of the application. Each service can be independently deployed, deployed, and perform a specific domain-related function.

The User and Role Service handles access through role, allowing for secure authentication and authorization. Course Service handles the delivery of modular content aligned with TVT. The Competency and Assessment Service supports competency-based TVT evaluation workflows, including practical assessment tracking, modular competency progression, and continuous learner performance monitoring aligned with TVT assessment practices.

An API Gateway is the entry point into the system to manage requests, load balancing, and security. It facilitates communication between clients and backend services.

4.3.4. Data and Storage Layer

Data Layer is designed to meet a wide variety of storage needs while delivering performance and reliability.

Relational databases (PostgreSQL) are used to store structured data such as user profiles, course information, and assessment records. A Redis cache is used to store frequently accessed data to reduce system load and response time.

In order to safely store large volumes of unstructured data, such as multimedia learning material, object storage, such as Amazon S3 or MinIO, is used. Background processing is handled through asynchronous worker queues responsible for synchronization operations, media processing, notification handling, and delayed task execution.

4.3.5. Cross-Cutting Concerns: Security and Observability

Security and observability are architectural concerns that span across all layers of the proposed LMS, assuring protection, monitoring, and control for all operations in online and offline environments.

The system uses the User and Role Service to authenticate and authorize users and provides access control according to TVT institution policies. Secure connections are established over HTTPS and with a token when a connection is available. The API Gateway provides a centralized point for validating requests, providing access controls, and regulating traffic between services.

In addition to the standard security features, the system has offline security features to handle intermittent connectivity. In offline mode, users authenticate using a locally cached time-bound authentication token from their last online session, which allows them to access the system temporarily and not use it permanently. Only pre-authorized actions, such as content access, progress, and draft submission, are allowed.

All data generated during offline mode is stored locally in a secure format and is considered unverified until synchronization occurs. Upon reconnecting to the server, the Sync Engine transmits the locally stored data to the backend through the API Gateway for server-side validation, authentication check, and integrity verification. Inconsistencies, conflicts, or unauthorized modifications are detected and corrected at this stage, maintaining data integrity during offline operations.

Observability provides visibility into both online and offline system behavior. Logging captures user actions, synchronization events, and system errors, so you can follow what's going on. Monitoring monitors service availability, synchronization success rates, and system performance. Alerting you when the system is down, in the background, or showing other abnormalities.

Observability is critical for asynchronous operations such as offline synchronization and background task processing. By monitoring these processes, the system ensures that late operations are performed correctly and that problems due to poor connectivity are detected and corrected quickly.

Security and observability as cross-cutting concerns ensure system reliability, protect sensitive data, and permit controlled operation both while connected and when disconnected, making the architecture well-suited to the infrastructure of Ethiopian TVT institutions.

4.4. System Model and Prototype Description

This section describes the system model and prototype of the proposed cloud-based Learning Management System (LMS). Although the previous section discussed layers and major services of the system, the purpose of this section is to explain how the architecture is organized as an actual system and how its major components interact to support learning in the Ethiopian TVT context.

In this study, the system model refers to the logical representation of the LMS with its domains, interaction boundaries, and flow of data and control across the system. The prototype is not a ready-made implementation, but instead a structured design representation to show the practicality, coherence, and utility of the architecture. In keeping with the design-oriented nature of the research, the prototype supports statistical validation by making the abstract design more visible and examinable.

4.4.1 Conceptual System Model

The conceptual system model describes the LMS as a collection of related domains that support the delivery of instructional activities, learning interactions, assessment administration, and data handling. The model does not focus on specific software or deployment tools but rather on functionality and logic.

The proposed system can be understood in four main domains: the client domain, the application domain, the data management domain, and the infrastructure and support domain, as shown in *Figure 4.4*.

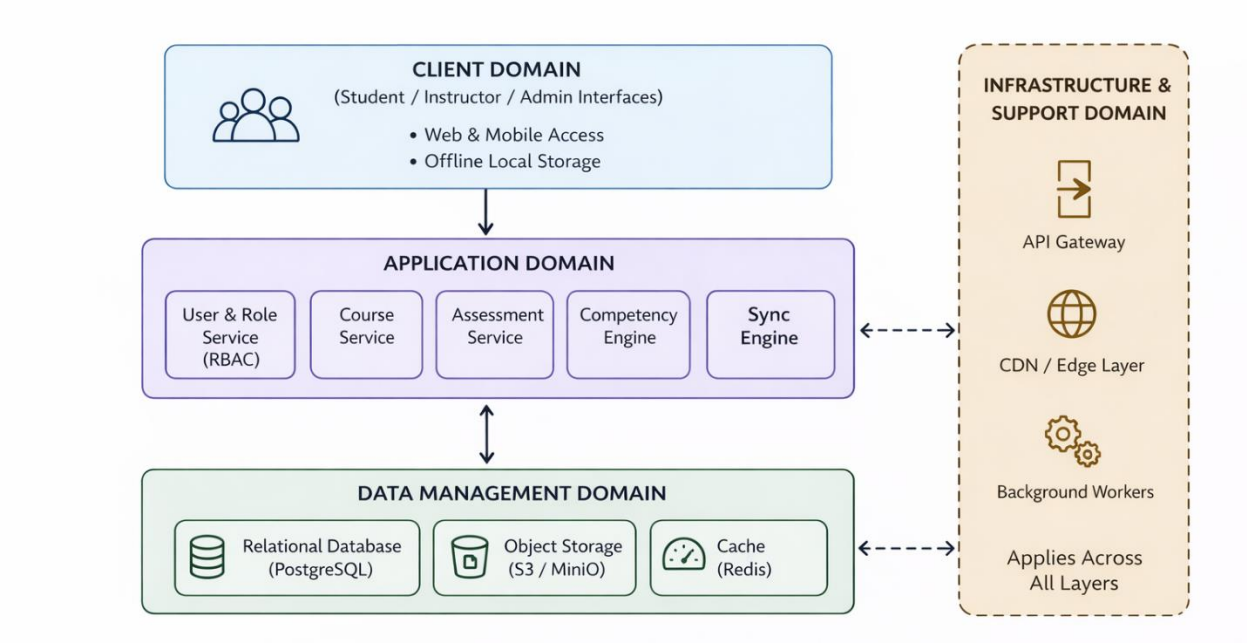


Figure 4.4: Conceptual System Model of the Proposed LMS

The client domain is essentially the interfaces through which students, instructors, and administrators interact with the LMS. It can be accessed online or offline, via a mobile device, and is optimized for low-bandwidth use and devices with limited storage space. The client domain also houses temporary data for users when connectivity is disrupted.

The services provided in the application domain are the core capabilities of the LMS (user and role management, course service, assessment service, competency tracking, and communications). This area is the logic center of the LMS where user requests are processed, business rules are applied, and instructional tasks are executed. These services were separated into functional units to allow scalability, maintenance, and alignment with competency-based TVT operations.

The data management system e-learning system stores and retrieves structured and unstructured data. Structured data such as user records, course metadata, assessment results, and competency progress are stored in a relational database. Unstructured data, such as media and learning material, is stored in object storage. Caching supports faster access to frequently accessed data and fewer requests for data in a bandwidth-limited environment.

Infrastructure and support provide security and resilience in the event of unstable connectivity and varied system load. Services included in this domain include the API Gateway, content delivery and edge caching, synchronization support, background processing, observability, and security.

Together, these domains provide a system model that emphasizes separation of concerns, distributed service coordination, and context-aware delivery. This model is particularly useful in places where the need for continuing learning is paramount, despite the infrastructural failures.

4.4.2. User Interaction and Functional Flow

The functional flow also incorporates competency-based TVT workflows that differentiate the proposed LMS from conventional content-oriented LMS platforms. In the proposed system, instructional activities are organized according to the academic hierarchy commonly used in Ethiopian TVT institutions, including departments, programs, levels, and modular courses. Administrators configure institutional structures and assign instructors to specific competency modules and courses through the User and Role Service.

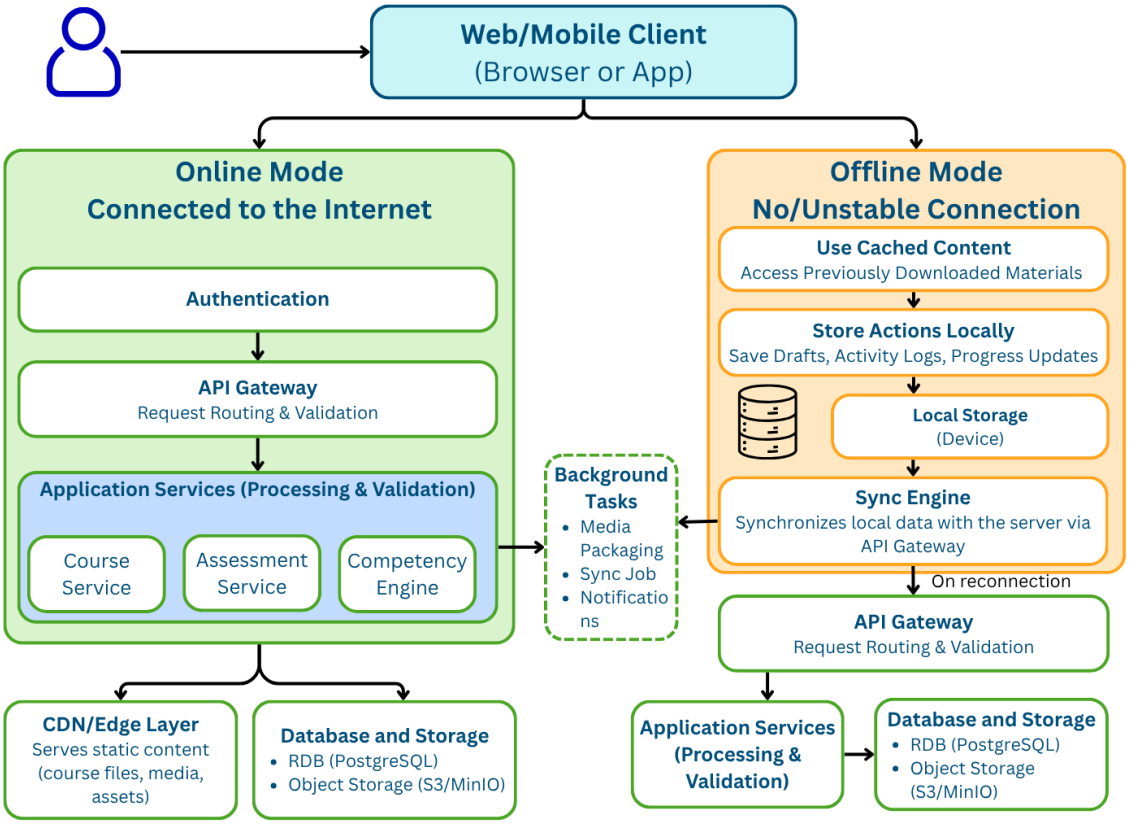


Figure 4.5: Functional Flow of Users' Online and Offline Interaction in the Proposed LMS

During the learning process, the instructor facilitates the delivery of modular learning content, applied exercises, theoretical tests, and group grading assignments using the Course and Assessment Services. Rather than relying on a traditional LMS that only delivers content and final tests, the proposed architecture embeds competency tracking within the learning process. Assessment activities are linked to competency units through the Competency Engine, which allows the system to track over time a learner's progress, applied skill attainment, assessment performance, and competency completion.

The Competency Engine also supports the assessment requirements of TVT learning, which includes recording competency achievements, continuous assessment results, and tracking a learner's progress across different modules and levels. This allows the instructor to not only assess a student's theoretical performance but also their practical competency attainment, which is a requirement in TVT learning. Based on the collected assessment records, the system can implement grade calculation, progression, GPA/CGPA, and generate transcripts.

In addition to numerical grading, the proposed LMS supports competency-status evaluation using the TVT assessment logic of Competent (C) and Not Yet Competent (NYC). This allows the system to distinguish between academic score calculation and practical competency verification. For example, theoretical, practical, and cooperative assessment components can be evaluated against minimum competency thresholds before a learner is considered competent. As a result, learner progression is not based only on total marks, but also on whether the required competency criteria have been achieved.

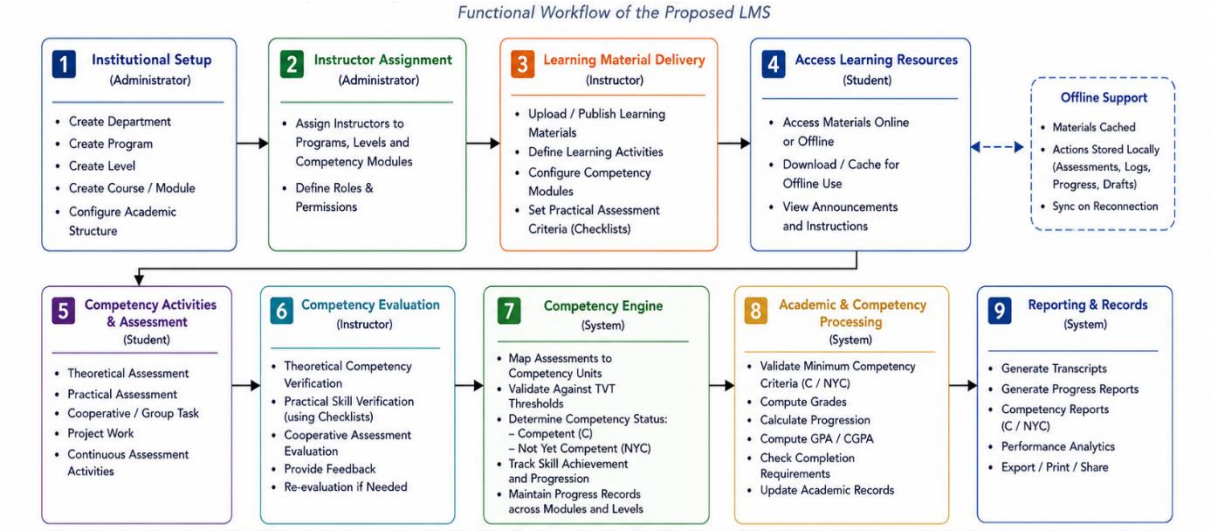


Figure 4.6: Functional workflow of the proposed LMS

In blended and offline learning environments, competency-based learning and assessment activities (e.g., practical assessment drafts, learner progress updates, activity and assessment logs) can be saved locally and synchronized when the network connection is restored. This ensures continuity of competency-based learning and assessment processes in the often-unstable network environment of Ethiopian TVT schools.

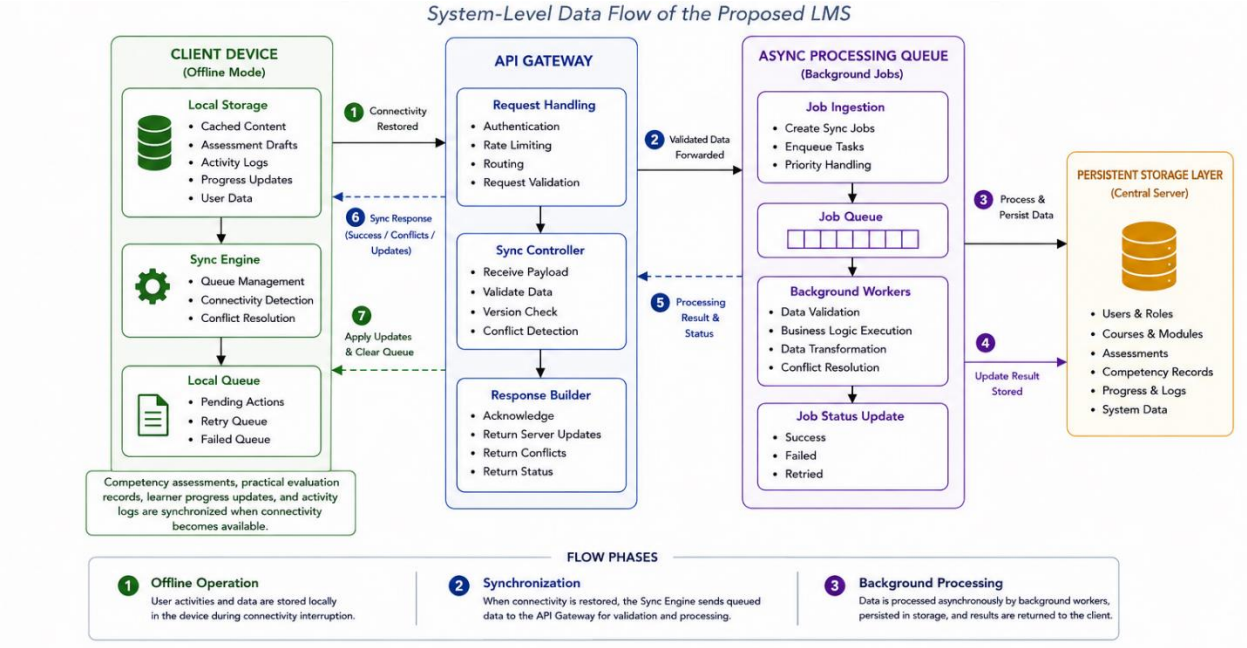


Figure 4.7: Offline Synchronization and Background Processing Flow

4.4.3 Prototype Representation and TVT Workflow Integration

A further representation of support and rationale for the proposed system, its architecture, is a prototype of the proposed cloud-based LMS. The prototype intends not to build a production-level implementation but to show the workings of the architectural, workflow, and contextual adaptations of the proposed system within Ethiopian TVT

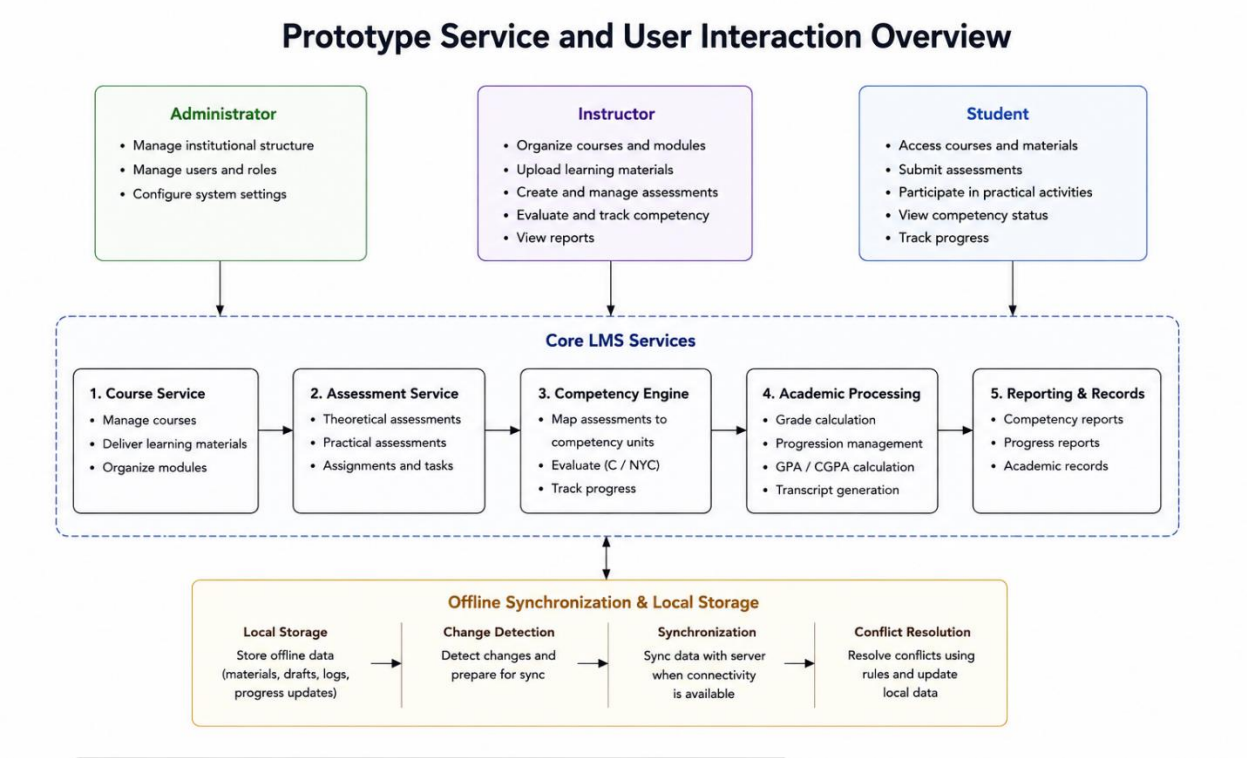


Figure 4.8: Prototype Service and User Interaction Overview

The prototype encompasses the key user roles, services, and processes outlined in the proposed design. For the student interface, the prototype demonstrates accessing modular course content, downloading materials for offline use, taking competency-based assessments, and checking one's learning progress. For the instructor interface, the prototype illustrates organizing courses, setting up competency-based assessments, evaluating practical skills, recording assessments, and verifying a student's competencies. For the administrative interface, the prototype represents configuring institutions, managing administrative structures, and controlling access.

In contrast to traditional, content-based LMS systems, this prototype embeds competency-based TVT processes directly into the system workflow. The prototype depicts how competency units, practical assessments, theoretical assessments, cooperative assignments, and learner progression history are linked through the Competency Engine to track competency achievement, verify practical skills, and monitor a learner's module-by-module, level-by-level progress.

The prototype also demonstrates the inclusion of offline-first learning support in the proposed architecture. Learning content, assessment drafts, updates on learner progress, and competency-related activities can be stored temporarily in a local device and then synced automatically when a connection is available. Through this mechanism, the prototype demonstrates how the architecture addresses issues of intermittent internet connectivity and unstable infrastructure in the Ethiopian TVT institutions.

In addition, the prototype demonstrates the interaction of the major architectural services within the prototype. Services for course delivery, competency assessment, synchronization, API Gateway, background processing, and storage represent themselves as an integrated architecture, as opposed to independent functions. Support services for security, asynchronous processing, monitoring, and synchronization are also represented within the prototype.

In architectural research, designs are not required to be built to be valid; they must be coherent, feasible, traceable, and contextually valid. For this reason, the prototype carries interpretive value. The prototype structurally and operationally depicts how the proposed architecture meets the previously identified functional and non-functional requirements in Section 4.2.

Overall, the prototype demonstrates that the proposed architecture can support competency-based TVT education, blending and offline learning, low-bandwidth content delivery, learner progression tracking, and scalable service organization for a resource-constrained educational environment. The above-mentioned factors provide design-level evidence that the proposed architecture is suitable for the operational and educational context of TVT colleges in Ethiopia.

4.4.4. Functional Prototype Implementation and Demonstration

In order to prove the feasibility of the proposed cloud-based LMS architecture, a prototype including the major architectural components, workflow, and educational processes was implemented as a part of the system analysis and design phases. The prototype served as a practical realization of the proposed architecture and proved that the identified requirements can be implemented into a working system for use in remote and blended learning for Ethiopian TVT institutions.

The implementation is cloud-based, supported by a PostgreSQL database hosted by Supabase. The developed prototype includes role-based access and separate pages for the admin, teacher, and student. The implemented features reflect the academic structure and competency-based training used in Ethiopian TVT institutions.

From the administrative perspective, the prototype facilitates the management of academic hierarchy, including departments, programs, levels, and courses. The admin user can manage student and instructor accounts, assign instructors to courses, monitor academic activities, manage learner progression, and generate institutional reports. These functions provide a centralized system to manage academic operations while ensuring consistency across different programs and levels.

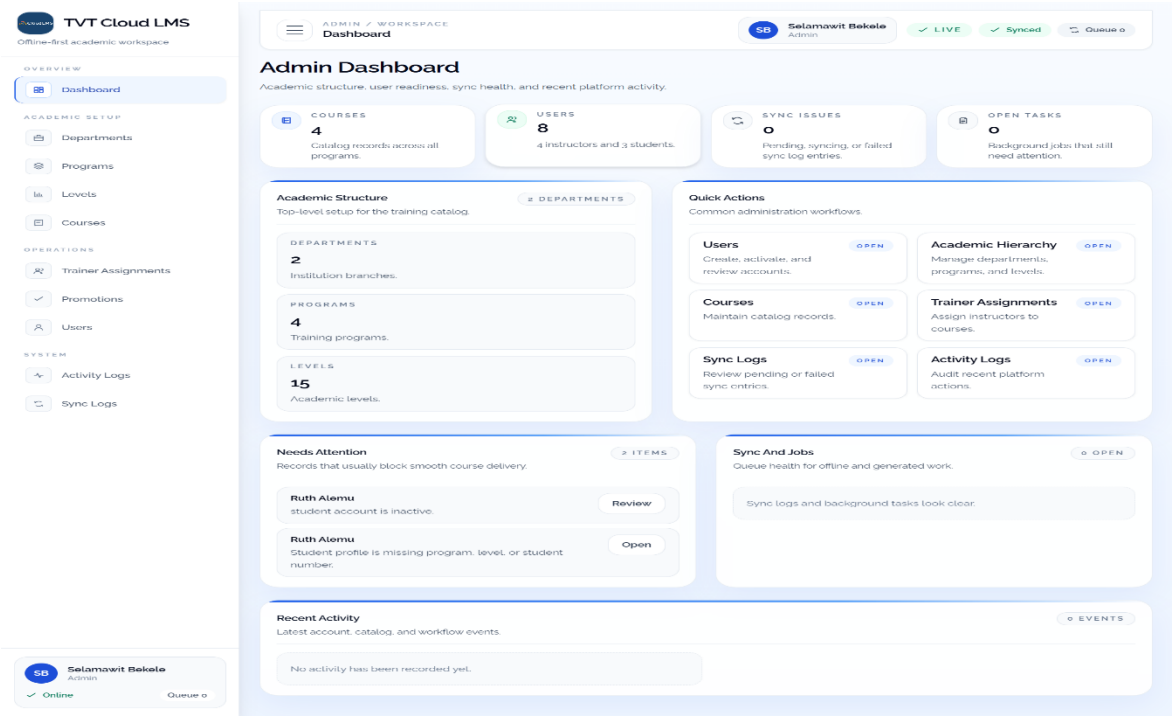


Figure 4.9: Administrative Workspace

The instructor workspace, provides tools for managing courses, distributing learning materials, organizing modules, administering assessments, evaluating competencies, and monitoring the progress of learners. The instructor can upload learning resources, create and review student assessments, evaluate competencies, manage live learning sessions, and generate academic reports. The assessment tool reflects the competency-based grading style in TVT institutions where

theoretical, practical, and cooperative assessments contribute to the determination of learners' competency.

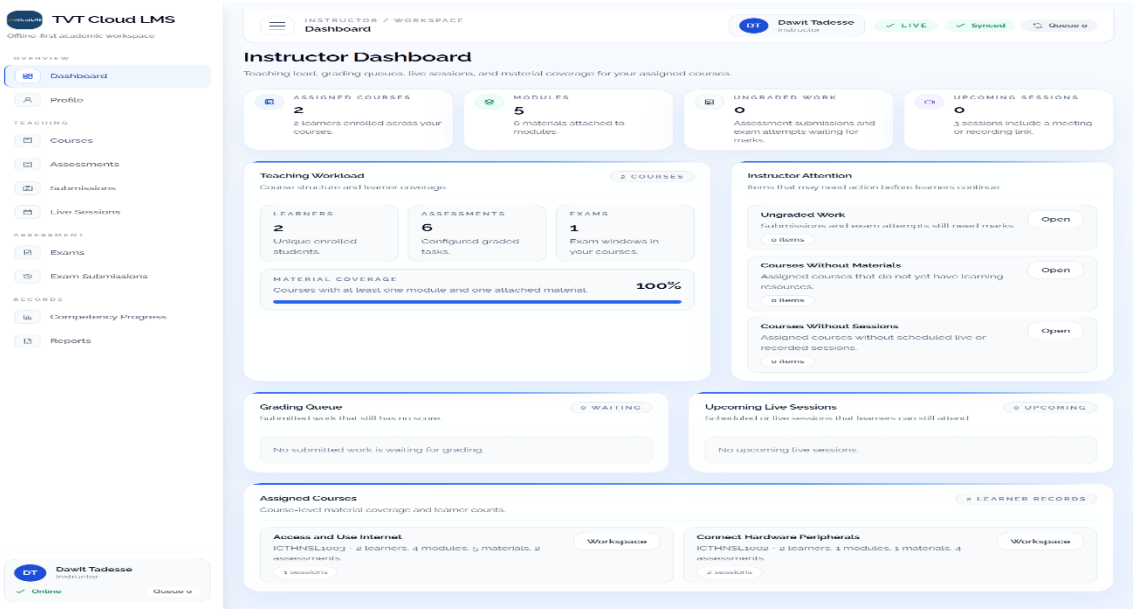


Figure 4.10: Instructor Workspace

The student workspace provides access to the student's enrolled courses, learning content, assessments and exams, competency progress, reports, and transcripts. Students can participate in learning activities, submit assignments, complete examinations, join live learning sessions, monitor competency achievement, and track their academic performance through GPA and transcript reporting functionalities. The prototype includes a sync mechanism to enable an offline-first and interrupted-connection learning experience.

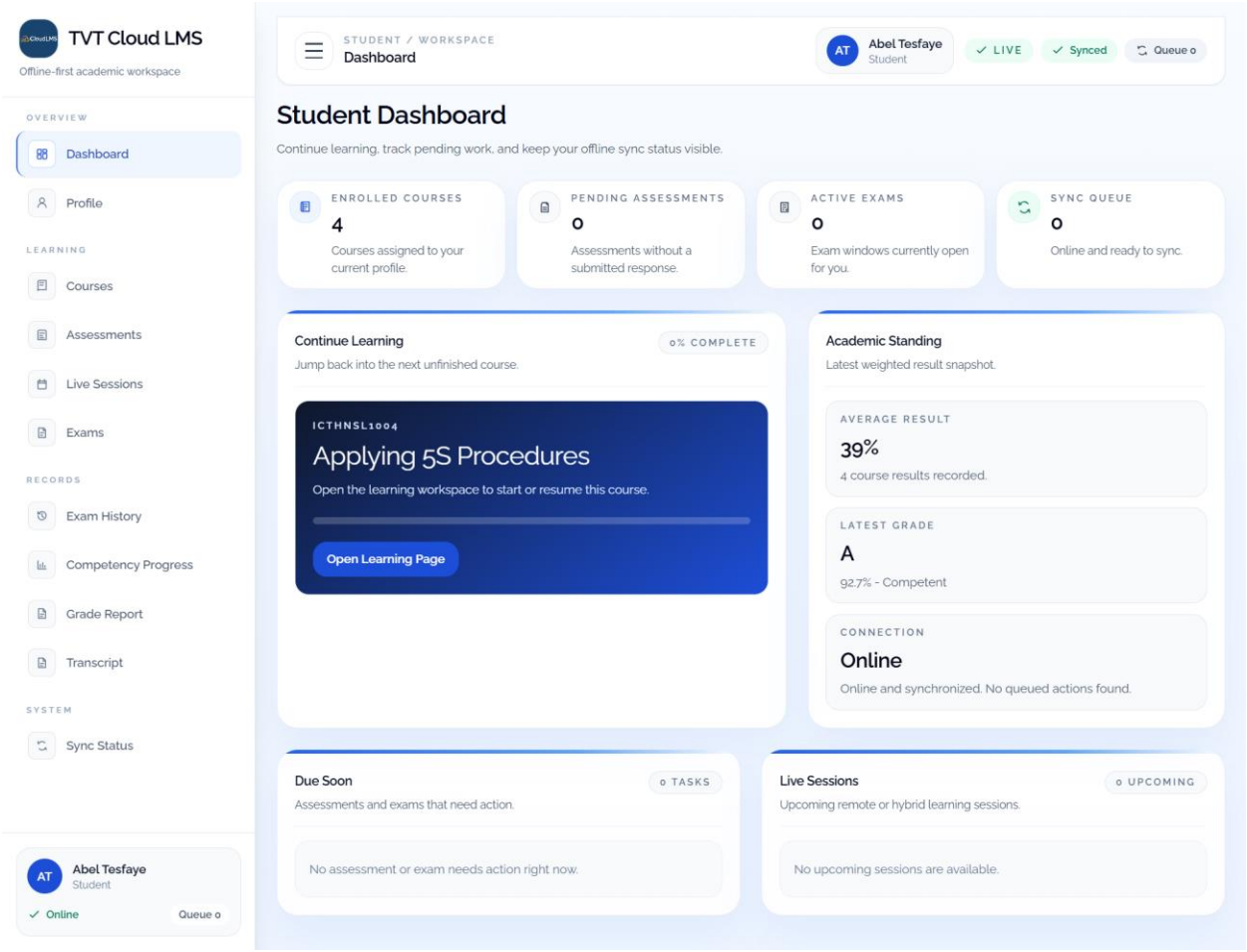


Figure 4.11: Student Learning Workspace

In addition, the implemented prototype demonstrated some of the architectural features, such as role-based service access, competency-based assessment management, academic progression tracking, learning content management, reporting services, and cloud-based data management. Features for remote and blended learning, such as a live session, online test, and synchronization, were integrated to align the system with the operational realities of Ethiopian TVT institutions.

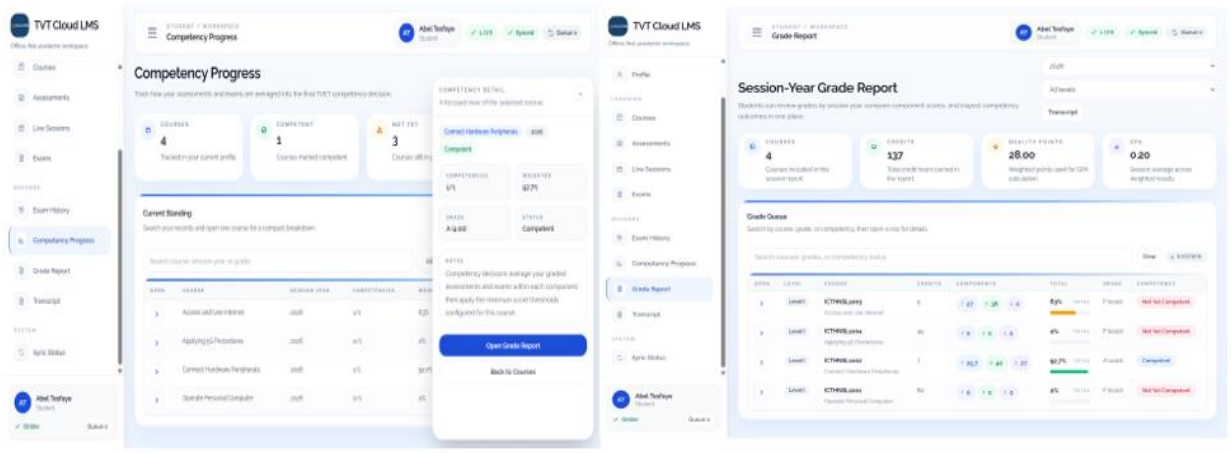


Figure 4.12: Competency and Grade Reporting

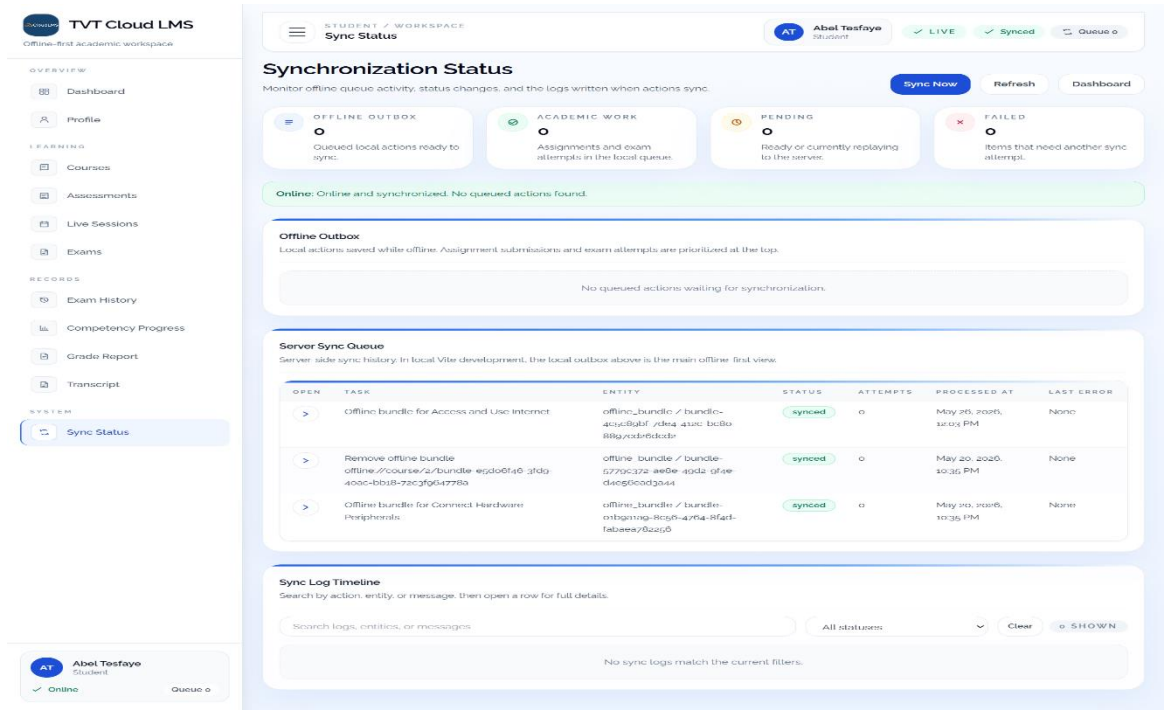


Figure 4.13: Offline Synchronization Monitoring

Overall, the functional prototype confirms the practical applicability of the proposed architecture and illustrates how the architectural components can interact to support institutional administration, instructional activities, learner engagement, competency assessment, and academic reporting within a unified cloud-based learning environment. Although the prototype does not represent a full-scale production deployment, it provides substantial evidence that the proposed

architecture can effectively support the functional and pedagogical requirements identified throughout this research.

4.5. Design Validation and Architectural Justification

Because of the design-led nature of the study, the proposed cloud-based Learning Management System (LMS) architecture was validated by analytic evaluation and architectural reasoning rather than user experience. In design and development research, a product is validated by the coherence within it, the ability to satisfy the requirements, and how it solves the context-related problem (Richey, 2007).

The validation of the proposed architecture is therefore measured on its ability to meet key system requirements derived from the problem analysis and literature review. Four criteria were used: scalability, availability and resilience, bandwidth efficiency, and instructional alignment. These criteria reflect the technical limitations of low-resource environments and the instructional needs of competency-based TVT education. In addition, the validation considered whether the proposed architecture adequately supports competency-based TVT workflows, offline learning continuity, and modular academic structures specific to Ethiopian TVT institutions.

The architectural justification, therefore, depends on how the specific design features meet each criterion. Scalability is achieved by separating concerns into separate services, which allows for independent scaling of key services like course delivery, assessment, and competency tracking. Reliability is increased with the use of distributed cloud infrastructure, asynchronous processing, and fault tolerance, which prevents system failure upon partial disruptions.

The use of offline-first interaction, local caching, and optimization of the delivery of content at the edge helps make the application not dependent on constant connectivity. Instructional alignment is made possible by the use of a competency-based learning progression model and learning workflows that reflect TVT instructional practices.

Through this analysis, the architecture can be demonstrated to be logistically consistent, technically feasible, and suitable for use in environments with intermittent connectivity and limited digital infrastructure.

4.5.1. Scalability Validation

Scalability of the proposed LMS architecture is largely demonstrated by its cloud-native modular design that enables independent provisioning and scaling of core service components. Key services, such as Course Service, Assessment Service, Competency Engine, and User Management, are loosely coupled and processed separately.

The separation of concerns provides scalability for individual services, enabling them to scale on demand without affecting the entire system. Services associated with assessment can scale independently during examinations, while content delivery can scale during learning sessions. An API Gateway also allows for scalability by directing request flows, loading, and service orchestration.

Previous studies have demonstrated that cloud-based LMS systems outperform on-premises systems when it comes to handling dynamic workloads and large numbers of users (García-peñalvo, 2011). In the context of Ethiopian TVT colleges, where the number of users varies between enrollment and assessment, such an architecture would be advantageous in facilitating elastic scaling with minimal infrastructure and administration overhead. The architecture also supports institutional scalability across departments, programs, levels, and competency modules, allowing multiple TVT institutions to operate within a unified but modular academic structure.

4.5.2. Availability and Resilience Validation

The proposed LMS is able to function reliably and is designed to be distributed, asynchronous, and user-first. The system is designed such that there are few single points of failure and the components of the system are spread out across cloud-based services.

Asynchronous task execution, via background processing, ensures that resource-intensive operations such as media packing, synchronization, and notifications do not interrupt real-time user interaction. This improves system responsiveness and fault tolerance in high-load scenarios.

One way in which the software can be resilient is its offline-first feature, where users' activities are stored locally and synchronized with the server when they reconnect. This ensures that when the network goes down, students can continue learning even when there is no internet connection. Practical assessment drafts, competency evaluation records, and learner progression updates can

also be stored locally and synchronized after reconnection, ensuring continuity of competency-based assessment workflows. Such design features are especially relevant in developing countries, where the connectivity is often poor, as research on digital education in Africa has shown. (Unwin et al., 2010; Isaacs, 2012). Through these mechanisms, the architecture maintains service availability and operational continuity despite infrastructural limitations.

4.5.3. Bandwidth Efficiency Validation

Bandwidth efficiency is achieved through both adaptive content delivery and data optimization techniques. The architecture prioritizes light content formats, such as text or compressed media, to reduce data consumption.

Local caching enables the reuse of previously downloaded information without having to download it again. A Content Delivery Network (CDN) allows static resources to be served from closer sites with lower latency and more bandwidth. And users can access learning materials offline without using the Internet.

Research indicates that LMS platforms designed with asynchronous access and optimized content delivery perform more effectively in low-bandwidth environments (Dhawan, 2020; Fabito et al., 2021). By incorporating these principles, the proposed architecture ensures efficient operation for TVT learners who primarily rely on mobile devices and limited data connectivity. The lightweight client architecture further improves accessibility for students using low-specification smartphones and limited computing devices commonly available in Ethiopian TVT environments.

4.5.4. Pedagogical Alignment Validation

The proposed architecture is closely aligned with the competency-based training model used in TVET. To this end, a competency engine has been integrated, which connects assessment activities with learning outcomes to allow continuous monitoring of the learner's progress.

The proposed architecture specifically supports competency-based evaluation practices used in Ethiopian TVT institutions through competency mapping, practical assessments, observational checklist evaluations, and tracking competency statuses through a progression model of

Competent (C) and Not Yet Competent (NYC). In contrast to existing LMS platforms with a focus on learning content delivery and final exams, the proposed architecture incorporates competency tracking, continuous assessment, practical skill grading, and academic progression.

Unlike conventional LMS platforms that mainly emphasize content delivery and final examinations, which reward learners' skills based on demonstrated competence rather than passive participation. This addresses the limitations of the LMS that TVT institutions have in place (Abebe and his colleagues, 2023).

It also provides functionality such as modular course design, continuous assessment, and instructor-led learning pathways as outlined in instructional design models like ADDIE (Branch, 2009), as well as learning theories such as constructivism and connectivism. (Vygotsky, 1978; Siemens et al., 2019). Through these capabilities, the system ensures that technical design decisions are directly aligned with pedagogical requirements.

4.5.5. Validation Summary

To consolidate the architectural validation of the proposed LMS, *Table 4.4* summarizes the key validation criteria, the corresponding architectural mechanisms, and the justification for each.

Table 4.4: Summary of Design Validation and Architectural Justification

Validation Criterion	***Architectural Mechanism***	***Justification***
Scalability	Modular microservice-based architecture; API Gateway; independently deployable services	Enables horizontal scaling of core services such as course delivery, assessment, and competency tracking based on workload demand across multiple institutions and users
Availability & Resilience	Distributed cloud infrastructure; asynchronous background processing; offline-first synchronization	Reduces single points of failure and ensures continuity of learning, assessment, and competency tracking during network disruptions

Bandwidth Efficiency	Content compression; CDN integration; local caching; offline content access; lightweight client interfaces	Minimizes bandwidth consumption and supports effective access for low-bandwidth environments and low-specification user devices
Pedagogical Alignment	Competency engine; competency-based assessment workflows; modular academic hierarchy; continuous assessment and progression tracking	Aligns the system with competency-based TVT pedagogy through practical assessment support, competency evaluation (C/NYC), learner progression monitoring, GPA/CGPA computation, and modular training structures

4.6. Limitations of the Proposed Architecture

Despite the strengths of the proposed cloud-based LMS architecture, several limitations remain regarding implementation feasibility, infrastructure dependency, and the scope of validation.

First, the study focuses primarily on architectural design and analytic validation rather than full system implementation and real-world deployment. Although the architecture was evaluated through architectural reasoning and requirement traceability, empirical measurements such as throughput, latency, fault tolerance, and user satisfaction were not experimentally assessed. Consequently, the findings remain conceptual and design-oriented rather than performance-based.

Second, the proposed architecture assumes the availability of minimum digital infrastructure, internet connectivity, and access to computing devices, which may not be consistently available across all Ethiopian TVT institutions. Limitations related to unstable connectivity, insufficient hardware resources, low-specification devices, and varying levels of digital literacy may affect practical deployment and adoption. Although the offline-first architecture reduces dependency on continuous internet access, infrastructural limitations cannot be eliminated.

Third, the modular and microservice-oriented architecture introduces additional deployment and management complexity compared to traditional monolithic systems. The architecture requires technical expertise in areas such as service orchestration, distributed system management, cloud

deployment, monitoring, and synchronization management. These operational requirements may present challenges for institutions with limited technical support capacity or limited cloud infrastructure experience.

Fourth, although offline synchronization is a critical feature for low-connectivity environments, it introduces challenges related to data consistency, synchronization conflicts, and concurrent updates. Situations involving multiple updates to the same records before synchronization may require advanced conflict detection and resolution mechanisms to maintain data integrity. Such synchronization strategies were conceptually modeled in this study but were not fully implemented or experimentally validated.

Finally, pedagogical validation in this study was limited to architectural alignment with competency-based TVT principles rather than empirical measurement of learning outcomes. Although the proposed architecture was designed to support competency-based assessment, practical skill evaluation, continuous assessment workflows, and learner progression tracking, the actual educational effectiveness of the system remains unverified. Future studies should therefore focus on prototype implementation, real-world deployment, usability evaluation, performance benchmarking, and empirical assessment within operational TVT environments.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The primary purpose of this study was to design and analyze a scalable cloud-based LMS architecture that fits the operational and pedagogical requirements of Ethiopian Technical and Vocational Training (TVT) institutions. The study was motivated by the fact that most existing LMS platforms favor institutions that have reliable internet access, adequate digital infrastructure, and content-centric learning models. The existing platforms do not consider the realistic circumstances of Ethiopian TVT institutions, where there is intermittent connectivity, limited bandwidth, diverse user devices, and competency-based training programs.

By analyzing the existing literature, policy documents, research on cloud-based LMS, and practices of TVT schools, the study identified contextual, technical, and pedagogical factors that cloud the design of LMS in the Ethiopian TVT sector. These factors were translated into the system's functional and non-functional requirements to inform its architectural design.

Based on the findings from the previous phase, the proposed context-aware cloud LMS architecture aims to incorporate cloud-native design principles, offline-first learning support, asynchronous processes, competency-based assessment processes, scalable service granularity, and efficient content delivery. The architecture comprises client, edge delivery, application, data, and cross-cut layers to help the separation of concerns, scalability, resilience, and maintainability.

A system model and prototype demonstration were developed to show how the developed system architecture can support institutional structures, competency-based assessments, learner progress, academic management, and blended learning practices in the Ethiopian TVT (Technical and Vocational Training) Colleges. The prototype also demonstrated how offline synchronization and competency tracking can support continuity of learning.

The proposed architecture was validated through various techniques, such as an analytical evaluation, requirements traceability, architectural evaluation, scenario-based evaluation, and a review of similar solutions. The validation results showed that the proposed architecture sufficiently addresses the identified architecture challenges for scalability, availability, resilience,

bandwidth efficiency, and pedagogy. Overall, the findings show that the cloud-native architectural style application, coupled with competency-based TVT workflow, can serve as a feasible and fitting supporting architecture for remote and blended learning in Ethiopian TVT institutions.

Overall, the study concludes that a context-aware cloud-based LMS architecture can provide a scalable, resilient, and pedagogically aligned solution that can address the unique operational realities of TVT institutions in Ethiopia. While the architecture needs to be further evaluated through implementation and testing in the field, the study provided a solid architectural base for future endeavors.

5.2. Achievement of Research Objectives

The first objective, which is to identify infrastructural, operational, and instructional design elements for the intended cloud-based learning management system for TVT colleges in Ethiopia, was addressed by analyzing existing literature, policy documents, and practices. Some of the challenges identified included intermittent connectivity, bandwidth issues, device diversity, and competency-based testing.

The second objective was to design a scalable, cloud-based LMS architecture that enabled competency-based, remote, and blended learning in low-bandwidth environments. This objective was fulfilled by designing a context-aware architecture that included cloud-native components, offline-first synchronization, adaptive content, competency management, and modular services.

The third objective was to generate a conceptual model of the system, identifying the system's components, interactions, and data flow. This objective was fulfilled by creating architectural models and workflow models that depict the interactions between users, services, storage components, and synchronization mechanisms in the proposed LMS.

The fourth aim was to build a functioning prototype that showcased some of the LMS's workflow and key competency-based educational processes. Developing a prototype for supporting academic hierarchy, competency assessment workflow, learner progression, grade management, transcript generation, and blended learning addressed this aim.

The fifth objective was to assess the proposed architecture for scalability, resilience, bandwidth efficiency, and suitability for the Ethiopian TVT institutions. The fifth objective is fulfilled through the validation of the architecture and plausible arguments to show the feasibility and appropriateness of the proposed design.

5.3. Contributions of the Study

The study contributes to both educational technology research and cloud-based system architecture design.

From a theoretical standpoint, this study adds to the existing LMS scholarship by outlining how architectural design expectations for a cloud-native LMS can translate to an environment with low-stakes connectivity, low bandwidth, and competency-based instructional models.

Methodologically, the research shows the applicability of Design Science Research and design-oriented validation methodologies in developing and evaluating educational system designs without the need for extensive piloting.

On the practical side, the research proposed a context-aware cloud-based LMS architecture for TVT institutions in Ethiopia. The proposed architecture, unlike many existing LMSs, integrates competency-based assessment workflows, academic hierarchy management, offline-first learning, asynchronous synchronization, scalable service composition, GPA/CGPA calculation, transcript generation, and blended learning, among others, in one architecture.

In addition, the study presents a model prototype that can be used as a reference model for the upcoming LMS development efforts for TVT institutions in Ethiopia, as well as for other institutions operating under similar circumstances.

5.4. Recommendations

The findings of this study suggest several recommendations.

First, policymakers and educational institutions should consider a context-aware LMS design that addresses infrastructural issues, rather than directly implementing traditional LMSs that are suited to different environments.

Second, any future LMS development efforts for Ethiopian TVT colleges should include support for offline-first learning, bandwidth optimization, and competency-based assessment to align with local educational practices and realities.

Third, institutions preparing for digital transformation should develop supporting infrastructure, such as access to the internet, digital literacy, and support, to fully reap the benefits of cloud-based educational systems.

Fourth, LMS developers should design systems with a modular and extensible architecture, enabling institutions to customize and extend the functionality of the system to meet their changing educational and administrative needs.

Finally, educational authorities and TVT institutions should adopt the integration of digital assessment tools based on competencies to effectively monitor and support learner outcomes.

5.5. Future Research Directions

Future research should focus on the implementation and deployment of the proposed architecture in an operational TVT (Technical and Vocational Training) setting to assess its effectiveness in real-world scenarios.

Empirical performance evaluations involving system throughput, response time, synchronization efficiency, scalability, and fault tolerance tests across multiple institutions and users should be conducted in future studies.

Future research can also explore more sophisticated synchronization strategies for conflict resolution, distributed data consistency, and secure offline authentication in low-bandwidth or offline environments such as schools.

Further research should assess the educational efficacy of competency-based LMS structures by evaluating learner outcomes, competency attainment, user satisfaction, instructor acceptance, and institutional adoption.

Finally, future work may consider the integration of new technologies such as artificial intelligence, learning analytics, adaptive learning, virtual labs, and recommendation engines to advance remote and blended learning in Ethiopian TVT institutions.

References

Abebe. (2023). *Ethiopian Journal of Technical and Vocational Education and Training*. *1*.

Abebe, G., H/Selassie, B., Degefu, Y., Kassie, G., & Atnafu Yenealem, & A. K. (2023). *Ethiopian Journal of Technical and Vocational Education and Training Federal TVT Institute*. *1*.

Al-Fraihat, J. & S. (2020). Evaluating E-learning Systems Success: An Empirical Study Dimah. *Computers in Human Behavior*, 102, 67–86. https://doi.org/https://doi.org/10.1016/j.chb.2019.08.004

Bassam, A., & Alshorman, A. (2018). *Attitudes of Faculty Members and Students towards the Use of the Learning Management System in Teaching and Learning*. *17*(3), 1–15.

Branch. (2009). *Instructional Design (The ADDIE Approach)*. https://doi.org/https://doi.org/10.1007/978-0-387-09506-6

Camara Education. (2023a). *Camara Education Ethiopia signed a new project agreement with the Federal Ministry of Education July 17, 2023*.

Camara Education. (2023b). *SIGNED A NEW PROJECT AGREEMENT WITH THE FEDERAL*.

Dhawan, S. (2020). Online Learning: A Panacea in the Time of COVID-19 Crisis. *Journal of Educational Technology Systems*, *49*(1), 5–22. https://doi.org/10.1177/0047239520934018

Fabito, B., Trillanes, A., & Sarmiento, J. (2021). Barriers and Challenges of Computing Students in an Online Learning Environment: Insights from One Private University in the Philippines. *International Journal of Computing Sciences Research*, *5*(1), 441–458. https://doi.org/10.25147/ijcsr.2017.001.1.51

Ferede, B., Elen, J., Van Petegem, W., Hunde, A. B., & Goeman, K. (2022). Determinants of instructors' educational ICT use in Ethiopian higher education. *Education and Information Technologies*, *27*(1), 917–936. https://doi.org/10.1007/s10639-021-10606-z

García-peñalvo, F. J. (2011). *Opening Learning Management Systems to Personal Learning*

Environments. *July*.

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). “Design science in information systems research.” MIS quarterly (2004): 75-105. *Source: MIS Quarterly*, *28*(1), 75–105.

ICog, A. C. C. (2023). *Bridging the Digital Divide : A Journey Through Addis Ababa ’ s TVET Colleges*. https://icog.ghost.io/bridging-the-digital-divide-a-journey-through-addis-ababas-tvet-colleges/

Isaacs, S. (2012). Turning on Mobile Learning in Africa and the Middle East. *UNESCO Working Paper Series on Mobile Learning*, 2–32. http://unesdoc.unesco.org/images/0021/002163/216359e.pdf

Manninen, J. (2014). Blended learning: Research perspectives, Volume 2. *International Review of Education*, *60*(6), 867–870. https://doi.org/10.1007/s11159-014-9458-5

Ministry of Innovation and Technology. (2020). Federal democratic Republic of Ethiopia. In *Photogrammetric Engineering and Remote Sensing* (Vol. 69, Issue 3). https://doi.org/10.1201/9781003307785-63

MOE. (2020). Esdp Vi). *2021-11-Education-Sector-Development-Plan-Ethiopia*, *Esdp Vi*, 2013–2017.

MOE. (2021). *Education Sector Development Programme VI (ESDP VI)*. *Esdp Vi*, 2013–2017.

MoLS Occupational Standards Manual. (2023). *MoLS Occupational Standards Manual*.

MoSHE. (2020). *Digital Skills Country Action Plan (DSCAP) for Higher Education and TVET (2021-2030)*. 1–11. https://www.academia.edu/44994814/Digital_Skills_Country_Action_Plan_2030_for_Higher_Education_and_TVET_Institutions

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). D Esign S Cience in I Nformation. *MIS Quarterly*, *28*(1), 75–105.

Richey, K. (2007). *Design and Development Research*.

Siemens, G., Onderwijsdagen, S., Age, D., Design, E., Downes, S., & Verhagen, P. (2019). Connectivism : a new learning theory ? *Journal of Instructional Technology and Distance Learning*, *2*(1), 1–5. http://elearning.surf.nl/e-learning/english/3793

Unwin, T., Kleessen, B., Hollow, D., Williams, J. B., Oloo, L. M., Alwala, J., Mutimucuio, I., Eduardo, F., & Muianga, X. (2010). Digital learning management systems in Africa: Myths and realities. *Open Learning*, *25*(1), 5–23. https://doi.org/10.1080/02680510903482033

Vygotsky. (1978a). Mind in society: The development of higher psychological processes. *Harvard University Press*, 503–503. https://doi.org/10.4324/9781315867519-201

Vygotsky, L. S. (1978b). Mind in society: The development of higher psychological processes. Harvard University Press. *Accounting in Australia (RLE Accounting)*, 503–503. https://doi.org/10.4324/9781315867519-201

Yirga Adamu, A. (2024). Digitalization of Higher Education in Ethiopia. *Journal of Comparative & International Higher Education*, *16*(2), 13–24.