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Layered Software Architecture for the Development of Mobile Learning Objects With Augmented Reality

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ABSTRACT According to the m-learning paradigm, mobile learning objects (MLOs) are fundamental elements within the teaching-learning process. In this context, the integration of technology such as augmented reality (AR), incorporates an additional value to an MLO, generating by this, more interactive and attractive learning environments, which promotes higher involvement and engagement by being immersed in a virtually enhanced world. Our research postulates that the development of such MLOs must be based on standards, methodologies, and/or a layered software architecture which provide the adequate mechanisms to achieve the structure and quality attributes needed. Specifically, this paper presents the design and development of such architecture which allows obtaining MLO complying with the requirements and quality attributes. To achieve that, the architecture is composed of five layers: data persistence, learning personalization, interactivity, general structure, and standards. The layers are independent among them and the lower layers provide services to upper layers. In order to probe the benefits of the architecture, two prototypes of MLOs with AR were implemented and evaluated by a 20 master's degree students focusing on of pedagogical, technological, and usability aspects. The results show that the architecture contributes no only to integrate AR in MLOs but more importantly to obtain MLOs with the quality attributes required as a digital educational resource.

INDEX TERMS Mobile learning, software architecture, augmented reality, mobile learning objects.

I. INTRODUCTION

Derived from mobile devices popularization, more than 5 billion people have become users of this technology around the world [1]. Therefore, integrating them in educational activities seems not only feasible but it could contribute greatly to enhance learning experience. To achieve this, it is necessary to implement alternative methods from those used in traditional education. Mobile Learning Objects (MLOs) are used as a reference to optimize the creation and reuse of educational content. An MLO is defined as a digital educational resource, interactive, adaptable, and reusable in different contexts, aimed at reaching an educational objective, designed to be used in a mobile learning environment, and capable of supporting different learning approaches and interaction perspectives [2].

Given the existence of diverse educational subjects with different levels of abstraction and complexity, the use of audiovisual mechanisms improves the student's understanding by having new ways of content presentation. Learning objects with a high interaction level are more attractive to the user and facilitates the learning process according to [3]. In this context, the integration of an interaction technology such as Augmented Reality (AR) incorporates an additional value to the mobile learning objects and generates a different mechanism to obtain information and conjugating it with real environments captured by a camera. By doing so the student's interest and motivation is facilitated and increased promoting the understanding and learning of a topic [4]–[6].

An important problem to consider in the mobile learning objects construction is its development process which should be guided by standards and guidelines that contribute to an adequate structuring and compliance of quality attributes that the product should have [7]. In this regard, the use of a software architecture can strongly contribute to achieve these purposes. The IEEE organization (Institute of Electrical and Electronics Engineers) defines a software architecture as the fundamental organization of a system embodied in its components, the relationships between them, the environment and the principles that guide its design and evolution (IEEE 1471-2000). The main software architecture advantages are [8]: 1.- Define the basic technical guidelines that an application must have; 2.- Streamline overall development, providing a solid framework for developers; and 3.- Contribute to satisfy the quality requirements.

Some works have proposed software architectures to build MLOs [9], [10]–[12], [14]–[16]. However, these architectures lack elements to ensure requirements compliance of the MLOs such as portability, reusability, accessibility, usability, among others. Furthermore, these works neither consider standards and metadata in the MLOs which are fundamental in a learning management systems (LMS) nor evaluate its features in real scenarios [9]–[12], [14]–[16].

This paper presents a software architecture that models, based on an architectural pattern in layers, the characteristics and quality attributes of mobile learning objects with augmented reality such as personalization, reusability, portability, usability, durability, accessibility, lightness, modularity, among others. To achieve this, the design and development of our architecture considers the following requirements: 1.- quality features and attributes that learning objects must possess; 2.- characteristics to consider in the development oriented to mobile devices; 3.- integration guidelines in the learning object with augmented reality technology. The architecture layers are independent which means that each of them performs a specific function and lower layers provide services to the upper layers. The proposed architecture is formed by five layers: data persistence, learning personalization, interactivity, general structure, and standards. The objective of the data persistence layer is to handle the learning object content. The learning personalization layer is responsible for adapting the content according to criteria related to the apprentice and the device in which the learning object is meant to be used. The interactivity layer's purpose is to manage the interaction media available to the user. The general structure layer oversees the presentation of the different sections that compose the learning object, as well as its description. Finally, the standards layer deals with the main standards related to the learning objects development such as SCORM [13], LOM [13], among others. Based on our architecture, two prototypes of MLO with AR were implemented and evaluated by a group of 20 master's degree students in terms of pedagogical, technological and usability aspects. The results show that the architecture proposed in this work contributes to building quality MLOs with AR.

II. STATE-OF-THE-ART

Several works have proposed software architectures to build MLOs [9], [10]–[12], [14]–[16]. This section presents an analysis of those based on three perspectives. First, the features and quality attributes that the learning objects fulfill such as self-contained, personalization, standardized content, accessibility, portability, and reusability, see Table 1. Second, the level of compliance of mobile applications requirements such as lightness, extensibility, ease of testing and maintainability, modularity and data persistence, see Table 2. Third, type of integration of augmented reality technology with the learning object (see Table 3). Below is a detailed description of the analysis of the works proposed in the specialized literature.

Table 1 presents the comparative analysis of each of the related works regarding the features and attributes of quality that learning objects must possess. In the works proposed in [12], [14] and [16], the learning object generated does not require any external source to accomplish its objective, thus they comply with the self-contained feature. On the other hand, in [10]–[12] and [14] context information is used to adapt the content presented to the student.

TABLE 1. Related works analysis regarding the learning objects characteristics.

	Self-contained	Personalization	Standardized content	Accessibility	Portability	Reusability
[9]	x	✓	✓	✓	x	✓
[10]	x	✓	✓	x	x	x
[11]	x	✓	x	x	x	x
[12]	✓	✓	x	x	x	x
[14]	✓	x	x	x	x	✓
[15]	x	x	✓	x	x	✓
[16]	✓	x	x	x	x	✓

In the works proposed in [9], [10], and [12] standards are considered for the learning object structure. Regarding the works presented in [9] and [14]–[16], the learning object satisfies the reusability criterion since it can be used by diverse users in different teaching contexts. Finally, none of the works include the portability feature and, only [9] considers the accessibility aspect, we conclude that this is mainly due to the lack of metadata integration during the development process of the MLO. It is also noted that none of the works proposed in the literature considers or complies with all the desirable characteristics of a mobile learning object; which guarantee their efficiency [7], [17]–[20].

On the other hand, Table 2 presents the analysis of the works related to the fulfillment of the requirements to be considered in the development of applications for mobile devices. Based on this analysis, it can be highlighted that most of the analyzed works satisfy the requirements of modularity, ease of testing and maintainability, primarily due to the adoption of architectural styles or patterns, with the exception of the work presented by [16]. In this case it is noted that only the works proposed in [12] and [15] contemplate the extensibility property.

TABLE 2. Analysis of related works regarding mobile application requirements.

	Lightness	Extensibility	Modularity	Ease of testing and maintainability	Data persistence
[9]	x	x	✓	✓	✓
[10]	✓	x	✓	✓	x
[11]	✓	x	✓	✓	✓
[12]	x	✓	✓	✓	✓
[14]	✓	x	✓	x	✓
[15]	✓	✓	✓	x	✓
[16]	✓	x	x	x	✓

Finally, Table 3 presents an analysis of the related works which integrated guidelines in learning objects with augmented reality technology. In this regard, Vuforia is the augmented reality technology most used.

The approach presented in [12] uses the geographical positioning of real objects such as constructions, buildings and monuments to show information about them, unlike the works presented by [14] and [16]; which use markers such as QR codes or images to display multimedia resources such as documents, videos or three-dimensional representations.

This analysis shows that only the papers presented in [12], [14], and [16] consider the use of augmented reality in the mobile learning object. However, none of these works is aligned in an adequate form to the idea of learning objects due to the absence of metadata and the inclusion of sections (lessons, examples, exercises, evaluation). These works are basically focused on the content deployment.

TABLE 3. Analysis of related works regarding elements related to augmented reality.

	RA technology used	Type of RA used	Targets used	Displayed content
[12]	Vuforia	Geolocation	• Physical objects • Points of interest	• Information about the object • Evaluation
[14]	Vuforia	Artifact	Image	• 3D model
[16]	/	Artifact	QR	• PDF • Videos

III. ANALYSIS AND DESIGN OF THE ARCHITECTURE

In this section, we present the analysis and design of the architecture proposed in this work. The design of our architecture considered the requirements that arise from:

1.- Characteristics and quality attributes that the learning objects must possess and

2.- Requirements to be considered in the development oriented toward mobile devices and integration guidelines in the learning object with augmented reality technology.

The requirements considered for the design and development of the architecture proposed in this work are described in detail below.

A. REQUIREMENTS FOR MOBILE LEARNING OBJECTS

The requirements considered for the design of our architecture based on works related to the development of learning objects such as: methodologies [17], [18], good practice manuals [19] and research studies [7] were:

Visualize content: The apprentice should visualize the theory of the subject treated by the learning object.

Visualize examples: The apprentice should be able to visualize the examples regarding the subject treated by the learning object.

Solve exercises: The apprentice should carry out the available activities related to the subject treated by the learning object.

Perform evaluation: The apprentice should perform the evaluation corresponding to the topic addressed in the learning object.

Interactivity: The learning object should allow the incorporation of augmented reality technology for the interactive content deployment as a complementary learning mechanism.

Personalization: The learning object must consider the different learning styles: Active, Reflective, Theoretical, Pragmatic [22] and be able to present the corresponding content based on the student learning profile.

Accessibility: The object must be indexed for efficient localization and retrieval using metadata standards (e.g. LOM).

Standardized content: Some content model must be implemented, allowing homogeneous learning objects.

Granularity: The subject presented in the learning object must be as less divisible as possible for its use in different teaching contexts.

Reusability: The learning object must reach a specific objective to be used by different users in different teaching contexts.

Portability: The object can move or stay in different platforms transparently without any change in structure and content.

Durability: It must be supported by a mechanism (repository), which allows incorporating new content and modifications to existing ones, consequently decreasing the information obsolescence.

Usability: The use of the learning object must be effective, efficient and satisfactory to the user can meet specific objectives.

Self-contained: On its own, the learning object must be able to achieve the proposed objective. It can only incorporate links to digital documents that deepen or complement some content concepts.

Authorship: Incorporate the source of diverse authorship resources used in the teaching content, complying with existing copyright laws.

B. REQUIREMENTS FOR MOBILE APPLICATION WITH AUGMENTED REALITY

On the other hand, due to the development approach of learning-object oriented toward mobile devices, the following requirements were considered [20], [21]:

Navigability: Follow the principles of user interface design established by the platform in which the learning object was developed.

Lightness: The architecture must allow its execution in devices with limited capacity in processing and storage, although this results in loss of features.

Allow extensibility: The sensors in a device are different depending on the hardware used by manufacturers. With the wide variety of methods to obtain information, an architecture must be open to new ways of accessing sensors.

Modularity: Architecture should focus on the separation of responsibilities into single-purpose components.

Ease of testing and maintainability: The consistency in the components should facilitate the development of unit tests and maintainability.

Data persistence: The necessary components must be considered to control the data persistence of the learning object.

C. CONCEPTUAL DESIGN OF THE PROPOSED ARCHITECTURE

Considering the requirements described in the previous sections, a software architecture was designed based on an architectural pattern in layers, see Fig. 1. In our case, the layers are independent because each of them performs a specific function and the layers inferiors provide services to the upper layers. Our architecture is composed of five layers: data persistence, learning personalization, interactivity, general structure, and standards.

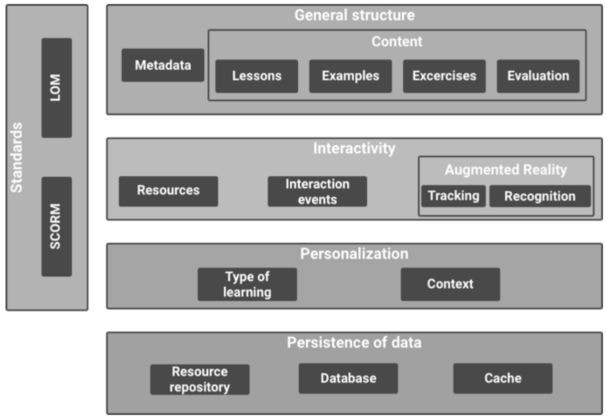

FIGURE 1. Design of layered software architecture for the development of mobile learning objects with augmented reality.

Layers of our architecture and components are described in detail:

Data persistence layer: The objective of this layer is the manipulation and storage of primitive data, as well as the multimedia resources (images, videos, animations, etc.) of which the learning object will be composed. This layer consists of three components whose functions are the following:

1) *Resources repository:* Manages multimedia elements such as images, animations, videos, and sounds.
2) *Database:* Directs the control and access to structured primary data that will be used in the learning object.
3) *Cache:* Preserves the information in the section of the learning object that the user is using in case of any interruption by an incoming task on the mobile device.

Personalization layer: This layer provides the most suitable content to present in the different sections of the learning object (lessons, examples, exercises, and evaluation) for the student based on the following set of information:

1) *Type of learning:* This component detects the learning style of the student and determines the quantity and type of concepts, examples, exercises, and evaluation that should be delivered to the student.
2) *Context:* This element obtains specific characteristics from the student (physical activity) and from the environment in which he/she is located (environmental sound) to establish the type of content to present.

Interactivity layer: This layer aims to control various aspects related to the interaction of the learning object with the student. This layer is composed of the following components:

1) *Resources:* It represents the fusion of the content to be presented and manipulated through the midpoints of interaction available on the student's mobile device.

2) *Interaction events:* This component is responsible for handling the basic interaction events of the mobile device such as clicks, gestures, drag, key pressure, among others.
3) *Augmented reality:* Sublayer that is responsible for operating the interactive factor for the augmented reality operation within the learning object. It consists of two components.
    a) *Tracking:* Its function is to detect and treat reading changes in the sensors occupied for user tracking (Accelerometer, gyroscope, GPS, etc.).
    b) *Recognition:* Its task is the detection by the camera of the marker (QR code, barcode, images, physical objects, etc.) for the identification of the assigned content.

General Structure layer: This layer is responsible for the structuring of different sections that form the learning object, as well as controlling the descriptive information that the learning object must include to achieve its use and management in educational content repositories.

1) *Content:* It implies the presentation of resources that are the sections (Theme, Examples, Exercises or Evaluation) composed of views with image files, animations, videos, sounds (specified by the SCORM standard). Within this section, the visual aspect of the Augmented Reality will also be managed depending on the pertinence regarding the subject to present or if it has not been disabled by the personalization layer.
2) *Metadata:* Define and attach the relevant information for the learning object specification. This information is categorized hierarchically and is organized according to the LOM standard through the XML metalanguage.

Standards layer: Due to the adoption of the design model of learning objects, it is necessary to consider a layer that includes the main standards that provide features such as the correct structuring regarding the learning object content and a greater reusability level within several LMS platforms. To achieve this, integration components of the SCORM and LOM standards were considered:

1) *SCORM:* The SCORM standard (Sharable Courseware Object Reference Model) specified by ADL is used as a guide to handling features such as the definition of the learning object structure, its packaging, and its distribution.
2) *LOM:* This standard (Learning Object Metadata) is considered for the metadata definition. LOM, defined by the IEEE (IEEE 1484.12.1 – 2002), provides a structure for the learning object description. Enabling the resource identification in a simpler way when published in the Learning Management Systems (LMS).

IV. ARCHITECTURE DEVELOPMENT

Based on the conceptual design described in section III-C, the architecture proposed in this work was implemented. It was used for the learning objects development with augmented reality in mobile devices with Android operating system versions 5.0 or higher (it has 84.8% of the current market). The architecture components diagram is described below, and the implementation is presented in detail later.

A. ARCHITECTURE COMPONENTS DIAGRAM

This diagram (Fig. 2) shows the main architecture elements in terms of software patterns, components and recommended technologies following the specialized literature. In our case, the component diagram of the proposed architecture was designed (see Fig. 2) based on the pattern Model-View-View-Model (MVVM) introduced by Google for Android applications [21].

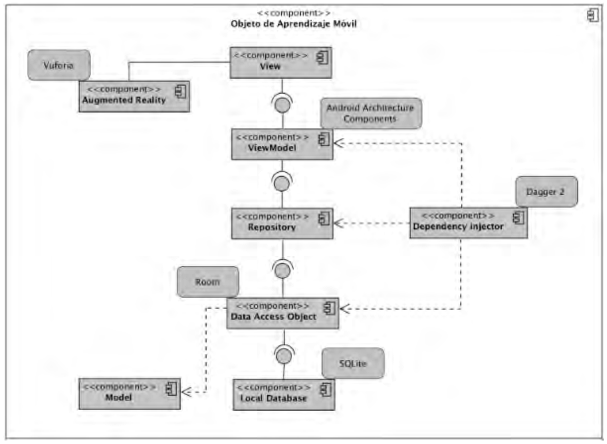

FIGURE 2. Architecture components diagram of the mobile learning object with augmented reality.

This software pattern has the following advantages:

1) Decoupling of the model behavior with the view allowing the change of status individually which has contributions in efficiency.
2) Separation of responsibilities to facilitate the realization of changes or additions of new functionalities.
3) Due to the granularity of the code, the execution of code tests is simplified.
4) It promotes the reusability of code or functionalities.

Our architecture at the component level is made up of the following elements:

1) *View:* It represents the logic of configuration and management of the different user interfaces that will form the MLO.
2) *Augmented Reality:* Set of elements related to the augmented reality engine.
3) *View Model:* It controls the data related to the view component and separates the life cycle between these components.
4) *Model:* It represents the range of information that the learning object will include.
5) *Repository:* They abstract the operations to data for the different information sources (databases, web services, cache, etc.).

6) *DAO (Data Access Object):* It contains the operations of insertion, updating, deletion and obtaining, to manipulate the information in the database.
7) *Dependency Injector:* Construction and reusability of objects required by several classes, eliminating instantiation in each of these.
8) *Local Database:* Database implemented on the user's mobile device.

Fig. 2 shows the different technologies that were used to implement each component that integrates our architecture such as Vuforia, Dagger2, Room, and SQLite.

B. DESCRIPTION OF THE ARCHITECTURE IMPLMENTATION

Following, the main classes for the implementation of each architecture's layers are described. It should be noted that the architecture implementation was carried out using the Android platform because this is the main operating system used by users of mobile devices with 84.8% of the current market.

Persistence layer: The main functioning of this layer is related to the storage and manipulation of information and resources to be used in the learning object locally and externally. To achieve these functions, the following components were developed (see Fig. 3):

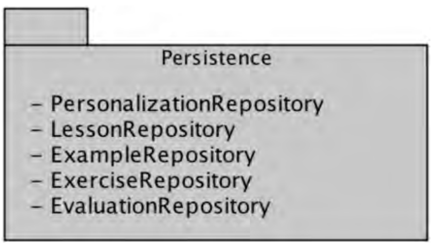

FIGURE 3. Classes that determine the persistence layer.

1) *Repositories:* These components are aimed to manage operations for obtaining, inserting, updating and deleting data. For this architecture, these operations are performed to the local database from the mobile device. However, if it is required to operate with another data source such as web services, the necessary logic must be defined within these components. The repositories implemented were the following: Personalization Repository, Lesson Repository, Example Repository, Exercise Repository, and Evaluation Repository.
2) *Database access.* Due to the use of the Room persistence library proposed by Android developers [23], the implementation of the main class is required, where it is expected to include a list of abstract entities and methods that return an instance of the data access objects that allow operations to perform on the database hosted in each of the repositories.

Personalization layer: This layer aims to provide content (lessons, examples, exercises, and evaluation) suitable for the student using the mobile learning object based on the following context information: physical activity, environmental sound, and type of learning. To provide these services, it is necessary to implement the components described below (see Fig. 4):

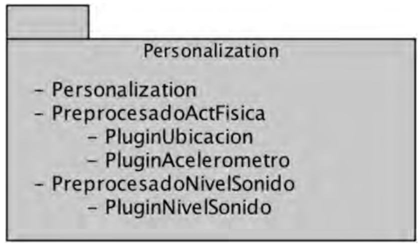

FIGURE 4. Classes that determine the personalization layer.

1) *Pre-processing of physical activity:* This class determines the user's physical activity through the mobile device from a series of values obtained by a plugin for the device accelerometer and its speed, this magnitude is calculated by the device location (using a location plugin) captured twice with a certain delay.
2) *Pre-processing of sound level:* This class aims to obtain values in decibels through the microphone of the mobile device (using a sound plugin), to generate a representation of the ambient sound in which the mobile device is located.
3) *Personalization class:* This class has the task of obtaining information, both the student's physical activity, and the environment sound in which he/she is located and from these values generate a list of integers that, in conjunction with the type of student learning, represent the type of content (lessons, examples, exercises, and evaluation) preferable for presentation to the student.

In this case, the classes used to generate the physical activity and environmental sound data were obtained from the project proposed in [20].

Interactivity layer: In this layer, the required components for the management of the learning object interactivity must be considered (see Fig. 5). According to the development guides from Android platform, this aspect should include activities (Activity) and fragments (Fragment) components since these elements are linked to the user interfaces and the user interaction logic should be controlled. Some of the main activities and fragments implemented are listed below:

1) *PersonalizationActivity:* Responsible for preparing the presentation of the questionnaire for students to identify their type of learning and capture the answers that the student enters.
2) *LessonActivity:* This activity shows the lesson content selected by the user of the available lessons menu, this content is obtained from the corresponding repository (*LessonRepository*) and is structured using HTML

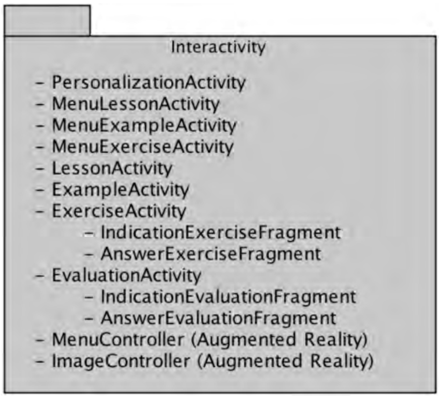

FIGURE 5. **Classes that determine the interactivity layer.**

allowing the visualization of text, images, videos and other resources.

3) *ExerciseActivity:* This activity contains and displays the fragment for the indications of the exercise (*IndicationExerciseFragment*) and the fragment for the results entry (*AnswerExerciseFragment*).
4) *AnswerExerciseFragment:* In this fragment, it must implement the necessary input elements so that the student can enter the results of the exercise.
5) *ExampleActivity:* This activity controls the visualization of the example selected by the student from the list presented in *MenuExampleActivity*.
6) *EvaluationActivity:* It is used as a container of the fragments for the indication of the evaluation (*IndicationEvaluationFragment*) and for the evaluation answers capture (*AnswerEvaluationFragment*).

On the other hand, the augmented reality implementation was carried out adopting the Unity development platform in conjunction with the augmented reality engine Vuforia. In this case, it is required the creation of classes to control the interaction of both a menu which can direct the different scenes available, as well as a class for the control of multimedia components (text, images, audio, video) that will be presented to the user once the target is focused by the device camera:

1) *MenuController class:* In case of having more than one scene (set of multimedia elements for the representation of a scenario using augmented reality) it is necessary to implement a class that controls the menu for select them. This class contains the FixedUpdate method for controlling the events of the physical buttons of the mobile device, e.g., in case the user presses the ‘‘back’’ button, the application returns to the menu or terminates. It also includes a changeScene method; which must be called by the buttons when they are pressed and start the scene corresponding to these.
2) *ImageController class:* For each of the augmented reality scenes from which the mobile learning object is going to be composed, a class of this type must be implemented, in which it is first necessary to declare variables for the variety of multimedia resources that form the scene. These resources can range from simple text to images, audios, and videos as required. The Start method must be used to define the initial state of the declared resources. The OnGUI method monitors the events that may occur in the scene (such as when a button is pressed) so in this element, it is essential to implement the logic to change texts, change images, play videos or audios, among others, as required.

General Structure Layer: In this layer are defined the model-view type components (see Fig. 6) necessary for each of the sections that constitute the learning object content (Theme, Examples, Exercises, Evaluation). The implementation of these classes is carried out to manage the data that will be manipulated in the user interfaces of each learning object sections.

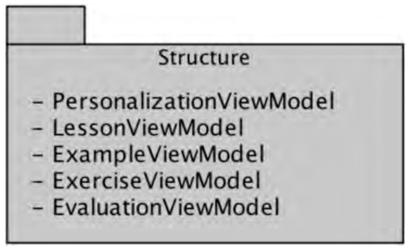

FIGURE 6. **Classes that determine the structure layer (content).**

In these components, it can manage information for each section such as Titles, Content (text), Indications, Results, Questions, Answers and Resource Locations (images, audios, videos). On the other hand, as already mentioned above, for the description of learning object characteristics, the Learning Object Metadata (LOM) standard was used, which can be generated through a file in XML format where each of the nine categories with their respective descriptive elements is represented.

From our point of view, the most important advantages of our software architecture are the following: a) define the basic technical guidelines that an MLO with RA must have; b) streamline overall development, providing a solid framework for developers; and c) Contribute to satisfy the requirements that arise from quality attributes that the mobile learning objects must possess.

C. DEVELOPMENT OF MLO’S WITH AR BASED ON THE PROPOSED ARCHITECTURE

In our case, two mobile learning objects with augmented reality were created using the architecture proposed in this paper with the aim of subsequently conducting a product-oriented evaluation. The results obtained in such assessment are presented in section V. The topics that were addressed in the created mobile learning objects were: 1.- Global times and states; and 2.- Algorithm for ring selection. These topics are part of the distributed systems subject of the applied computing master’s degree from the National Laboratory on Advanced Informatics (LANIA). Next, it describes in a general way the MLOs developed with our architecture.

The access point for the created learning objects is a user interface which displays the subject to be treated and a menu with the four different sections where the user can access: Lessons, Examples, Exercises, and Evaluation. Fig. 7 shows the main menu interfaces of the constructed objects.

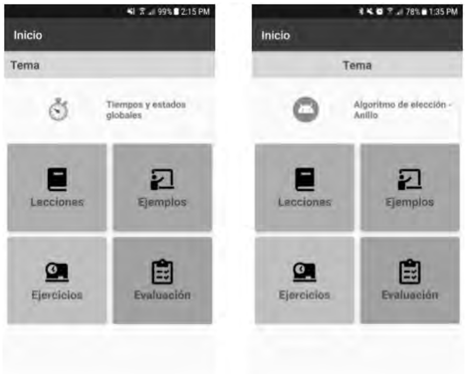

FIGURE 7. The main menu of the two MLO's with AR developed.

Within the main menu, the first section available is the learning object lessons, after this section is accessed a list of topics and subtopics are displayed. Later, when selecting any of the topics or sub-topics available in the learning object, the corresponding content will be shown to the student, see Fig. 8. The content used to represent the selected topic or subtopic will depend on the analysis carried out by the personalization module based on the information about the type of learning, student physical activity and noise level of the environment.

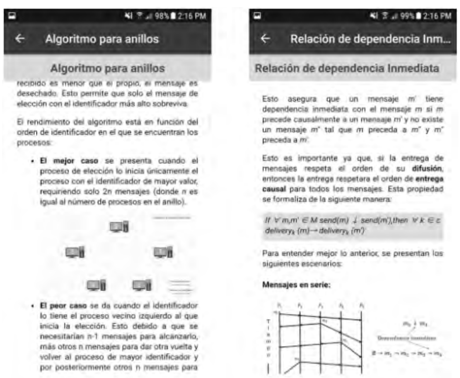

FIGURE 8. Lessons examples.

On the other hand, the examples represent an important section for the understanding of the theoretical part that is presented in the mobile learning object. Therefore, in this MLO section, the augmented reality technology was integrated, due to this technology can provide a high level of interaction and allows the student to experiment, observe from different perspectives, solve questions and practice the acquired learning. In our case, this section has a menu through which different examples that use AR can be accessed. When selecting any of the available examples of the MLO, the student will have to focus the camera towards the target that has been defined for this resource. This objective will have to be printed preferably to obtain a better experience. After the student has focused the device camera towards the printed target, it will begin to show the preestablished content and the student will be able to start interacting with the resource through augmented reality. In the created MLO examples shown in Fig. 9, the execution of a causal message delivery algorithm is presented through this technology. In this case, the student can observe a series of steps to be performed in the algorithm scenario. As can be seen in Fig. 9. AR elements are presented using text elements that explain the procedure that is being carried out, graphic elements that allow the general scenario to be represented, and tables where the data and calculations that are performed in the steps of the algorithm as the student interacts with the MLO.

FIGURE 9. Example with deployment of content with augmented reality.

Exercises section is another option within the main menu of the MLO and shows the MLO exercises for the student. After choosing some exercise by the student, the object will show a screen with the instructions to solve it, see Fig. 10.

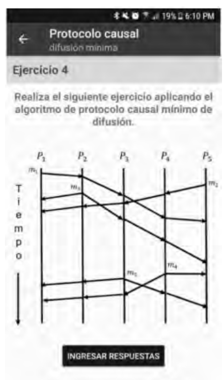

FIGURE 10. Example of an exercise with its indications.

In this interface, the student can also enter the answers that he/she considers pertinent in accordance with the proposed exercise. To do this, the student must press the "Enter answers" button to go to the next screen where the appropriate indications for the entry of the results will be shown first. When concluding with the entry of the answers, the learning object will verify the answers and generate a feedback for the student, see Fig. 11.

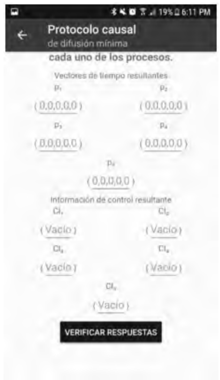

FIGURE 11. Feedback to the student based on the entered answers.

Finally, the evaluation section consists of steps like the exercises section. First, indications for carrying out the evaluation are presented to the student, see Fig. 12.

FIGURE 12. Evaluation section of the developed MLO.

After the student enters the answers, the "Verify answers" button should be pressed. Subsequently, the learning object will calculate the correct answers and based on these calculate the evaluation percentage; which is notified to the student and will provide feedback, see Fig. 13.

FIGURE 13. Score and feedback on the MLO evaluation.

V. ASSESSMENT OF THE MLO-AR ARCHITECTURE

The assessment was carried out based on two approaches, the first consisted of making a qualitative comparison between our architecture and other related works, which is shown in subsection V-A. The second approach assessments the quality of the product resulting from our architecture. To estimate the quality of the MLOs developed with our architecture, two assessment instruments proposed by [24] and [25], were used, the first instrument assessments the quality of a mobile learning object in pedagogical and technological aspects; the second instrument assessments different usability criteria according to ISO 9241-11 [26]. The results of the second approach are presented in subsection 5-B.

A. QUALITATIVE COMPARISON OF THE ARCHITECTURE

In this section, we present a qualitative comparison of our architecture with other similar works based on various desirable criteria that an architecture for the development of mobile learning objects with RA should consider, see Table 4. These comparison criteria were selected from the research carried out in works related to the development of mobile

TABLE 4. Qualitative comparison between our architecture and related works.

	Attributes	ALS-CPL	S-O AMLE	C-B M LMS	MOIAR	MLO-AR
Attributes of learning objects	Incorporation of augmented reality	x	x	x	✓	✓
	Metadata	✓	x	x	x	✓
	Content structuring	✓	✓	✓	✓	✓
	Personalization	✓	✓	✓	✓	✓
	Accessibility	✓	x	x	x	✓
	Standardization	✓	✓	x	x	✓
	Granularity	✓	x	x	x	✓
	Reusability	✓	x	x	x	✓
	Portability	x	x	x	x	✓
	Usability	x	x	x	✓	✓
	Self-contained	x	x	x	✓	✓
	Durability	✓	✓	x	✓	✓
Attributes of mobile devices	Interactivity	x	x	x	✓	✓
	Lightness	x	✓	✓	x	✓
	Extensibility	x	x	x	✓	✓
	Modularity	✓	✓	✓	✓	✓
	Ease of testing and maintainability	✓	✓	✓	✓	✓
	Data persistence	✓	x	✓	✓	✓

learning objects such as methodologies [17], [18], manuals of good practices [19] and other studies related to the development of mobile applications and learning objects [7], [20]. The descriptions of these criteria can be found in sections III-A and III - B. Additionally, the following comparison criteria were considered:

Incorporation of augmented reality: this quality refers to whether the work incorporates augmented reality technology.

Metadata: the quality that refers to the use of some metadata model for the indexing and search of the learning object.

Integration of components (content, activities, and evaluations): this quality refers to whether the work incorporates the content structure defined by some standard.

Specifically, Table 4 shows the comparison of the main related works found in the specialized literature against our architecture:

1) ALS-CPL - An Adaptive Learning System Architecture based on a Granular Learning Object Framework [9].
2) S-O AMLE - Contributions for the Architectural Design of Mobile Learning Environments [10].
3) C-B M LMS - A Cloud-Based Framework for Personalized Mobile Learning Provisioning using Learning Objects Metadata Adaptation [11].
4) MOIAR - Augmented Reality for Location - Based Adaptive Mobile Learning [12].

From the exercise carried out in Table 4, it can be seen that all the analyzed works consider the following characteristics: 1.- They share the use of content elements, this is due to the inclusion of elements such as lessons, examples, exercises, and evaluations in the learning object composition and this structure are obtained from standard in some works (ALS-CPL and SO AMLE); 2.-personalization functions, because these works use various variables such as location, prior knowledge, and student skills, among others, for the delivery of personalized content to the student; and 3.- modular decomposition, due to these works are supported by some architectural pattern or style for the functionalities separation (test and maintainability).

On the other hand, only the ALS-CPL architecture and our MLO-AR architecture consider the use of metadata, this implies that MLOs created through the S-O AMLE, C-BM LMS and MOIAR architectures will lack the possibility of being managed by learning management systems to search for a greater number of students which can generate less reuse of these resources. Another point to note is that only the works of ALS-CPL, S-O AMLE and our MLO-AR architecture contemplate the adoption of standards for both content and metadata formulation; which is a requirement to achieve the resource publication in the available learning repositories.

Another important feature of software products for educational purposes in terms of quality is the usability. However, only the works proposed in MOIAR and our MLO-AR architecture contemplate it. Nevertheless, in the case of MOIAR, no type of evaluation is described or proposed for this quality feature. Another characteristic observed in the works, excepting MOIAR and MLO-AR architectures, is that the content and information resources to be used in the learning object are obtained from external sources, so the self-content feature is not achieved in these cases.

Based on the analysis carried out, it can be observed that the work proposed in MOIAR fulfills several desirable criteria of an architecture focused on the generation of MLOs with AR. Nevertheless, this architecture lacks several important criteria that a learning object should consider such as metadata, accessibility, standardization, granularity, reusability, portability and lightness. Therefore, our work is characterized by modeling all the desirable criteria that an architecture focused on the development of MLOs with AR should consider.

B. PRODUCT-ORIENTED ASSESSMENT

The couple of MLOs developed based on the architecture proposed in this paper were provided to 20 students of the master's in applied computing (Generation 2017 - 2019) from LANIA to use them as a complementary educational resource in the topic of Distributed Systems that they were studying at that moment. The themes addressed in the learning objects were: 1.- Times and global states (MLO-1); and 2.- Algorithm for ring selection (MLO-2). The students used both MLOs for 30 days. After their use, two evaluation instruments were applied to assess the quality of the product (MLOs); the first one proposed by [24] allows to verify if the mobile learning object contemplates and satisfies certain fundamental pedagogical and technological quality elements and the second one proposed by [25] allows to assess diverse usability criteria of MLO based on ISO 9241-11 [26], [27], and [28].

1) ASSESSMENT OF TECHNOLOGICAL AND PEDAGOGICAL ASPECTS

The instrument proposed in [24] was used as a product-oriented assessment to determine whether the developed MLOs satisfies pedagogical and technical aspects. The percentages and the six dimensions considered by this instrument are as follows: functionality 25%, efficiency 10%, usability 25%, confidentiality 10%, maintenance 15%, and portability 15%. The set of answers to questions about each aspect are: completely disagree, disagree, neutral, agree and totally agree, whose weights are 1, 2, 3, 4 and 5, respectively [24]. The instrument defines a minimum value for each dimension to be considered as valid. Each participant evaluated each dimension and a general rating was calculated as follows:

$$\textit{overall rating} = (\textit{Overall rating of the dimension} \\ * \textit{percentage assigned to the dimension})$$

If the overall rating is greater than the minimum specified for the dimension it is classified positively, otherwise, it is classified as not acceptable according to [24].

The results obtained for each dimension are presented below:

1) *Functionality:* The average score in this dimension for the first MLO was 16.35 and for the second of 17.16, which in both cases exceeds the minimum defined score of 12 points. This result indicates that MLOs consider: the specification of learning objectives, relevance, and validity of content, support of learning styles and standardization.
2) *Efficiency:* The average score in this dimension for the first MLO was 1.27 and for the second 1.31, which in both cases exceeds the minimum defined score of 0.9 points. This indicates that the MLOs consider the following: optimization of the use of hardware and software resources to download and deploy the resource, the MLO size and typical learning time.
3) *Usability:* The average score in this dimension for the first MLO was 34.54 and for the second of 34.7, which in both cases also exceeds the minimum defined score of 23.25 points. This indicates that both MLOs comply with: content granularity, content clarity, compliance with spelling and grammar rules, logical sequence of the contents, clarity in the learning activities definition, visibility of the text, navigability within the object, among others.
4) *Reliability:* The average rating in this dimension for the first MLO was 0.71 and for the second 0.85. Both values exceed the minimum score defined with 0.6 points. Results indicate that the MLOs satisfy the following: use of warning messages in actions that cannot be canceled and cause errors and restore the state in which the learner was before an error occurred.
5) *Maintainability:* The average score in this dimension for the first MLO was 3.13 and for the second 3.22 exceeding in both cases the minimum score of 2.25 points. This result shows that the MLOs consider: adaptation to diverse educational contexts, ease of change and updating of the MLO, presence of the metadata and presence of the LO in Repository.
6) *Portability.* The average rating in this dimension for the first MLO was 2.61 and for the second 2.86. These values are above the defined minimum score of 2.25 points. This indicates that the MLOs comply with the following: compatibility with different versions, specifications of technical requirements, independence of Software and Hardware.

After the compilation of the results for each dimension, the sum of the scores was performed to obtain the general score from the 20 students for each MLO. Table 5 shows the obtained results.

Below is shown the intervals defined in the evaluation instrument proposed in [24] to assess the MLOs according to the obtained general scores:

1) *Excellent.* 56 – 69
2) *Very good.* 42 – 55
3) *Good.* 29 – 41
4) *Regular.* 15 – 28
5) *Bad.* less than 14

TABLE 5. Overall score of each MLO assigned by the 20 students.

Student	Overall score for the first prototype	Overall score for the second prototype
1	60.85	61.6
2	53.1	59.1
3	65.2	67.8
4	56.2	60.55
5	54.5	63.2
6	62.4	62.1
7	52.8	53.55
8	53.6	58
9	59.05	65.3
10	55.35	54.3
11	64.35	63.15
12	55.45	56.25
13	57.35	59.9
14	62.2	62.2
15	62.75	62.6
16	58.25	53.6
17	58.05	54.55
18	63.3	66
19	55.7	57.15
20	61.9	61.3

Based on these intervals, it was obtained that 13 students evaluated the first MLO as excellent, and 7 with a very good rating, see Fig. 14. On the other hand, in Fig 15 shows the evaluations for the second MLO. In this case, 16 students give an excellent rating and 4 a very good rating.

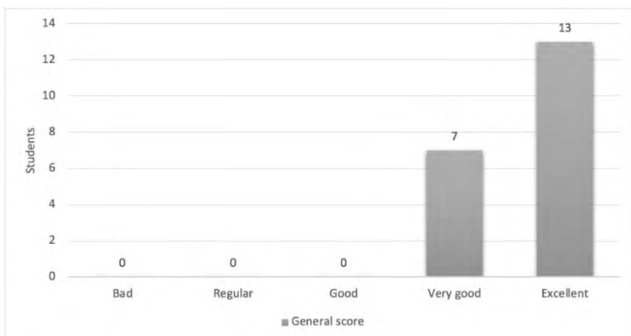

FIGURE 14. Quality assessment of the first developed MLO.

2) USABILITY ASSESSMENT OF MLO'S

The procedure and instrument proposed in [25] were used to evaluate the MLOs created in terms of the following usability criteria: congruence between the real world and the system, consistency and standards, recognition instead of memory, flexibility and efficiency of use, minimalist and aesthetic design, efficiency in error handling, clarity of purpose and objectives, navigability, interactivity, activities, motivation,

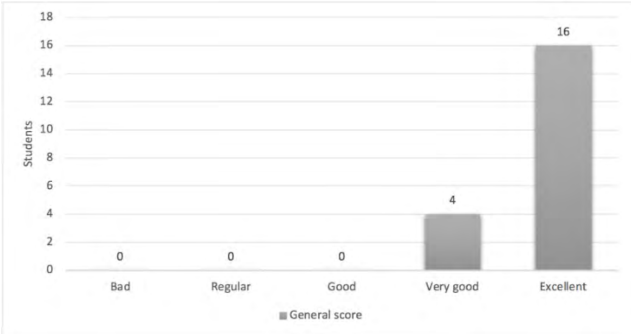

FIGURE 15. Quality assessment of the second developed MLO.

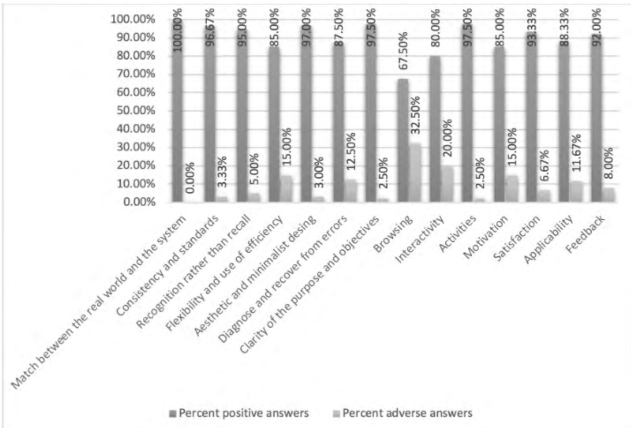

FIGURE 16. Usability results of the first developed MLO.

satisfaction, applicability and feedback. The usability evaluation tool proposed in [25] is composed of 47 questions. Each of these questions is answered based on the following scale of assessment: strongly agree, agree, nothing and disagree. This assessment instrument was answered by 20 MCA graduate students. To simplify the presentation of the results, the answers are grouped to strongly agree and agree as FAVORABLE responses and nothing and disagree as UNFAVORABLE responses.

Fig. 16 shows the results for the first MLO in terms of favorable and unfavorable responses obtained from the instrument application. The best-evaluated criteria with a favorable perception superior to 89% were: Congruence between the real world and the system, Consistency and standards, Recognition instead of memory, Minimalist and aesthetic design, Clarity of purposes and objectives, Activities, Satisfaction, and criteria related to the Feedback. On the other hand, the criteria of Flexibility and efficiency of use, Efficacy in error handling, Interactivity, Motivation and the criterion linked to the Applicability of the learning object obtained over 80% favorable rating. Finally, navigability was the least favored criterion, as it received a 67.5% positive rating against a 32.5% unfavorable rating. In this case, the students commented that in the examples section no navigation elements were presented as an option to return to the main menu; therefore, the corresponding corrections were done.

On the other hand, the results obtained in the usability evaluation of the second MLO are presented in Fig. 17. In this case, the criteria evaluated with a favorable perception of more than 89% were: congruence between the real world and the system, Congruence and standards, Recognition instead of memory, Minimalist and aesthetic design, Efficiency in error handling, Clarity of purposes and objectives, Navigability, Activities, Motivation, Satisfaction, Applicability and Feedback. On the other hand, the criteria of Flexibility and efficiency of use and Interactivity obtained a favorable score higher than 80%. In general, the results obtained for the second MLO were better compared to those of the first MLO.

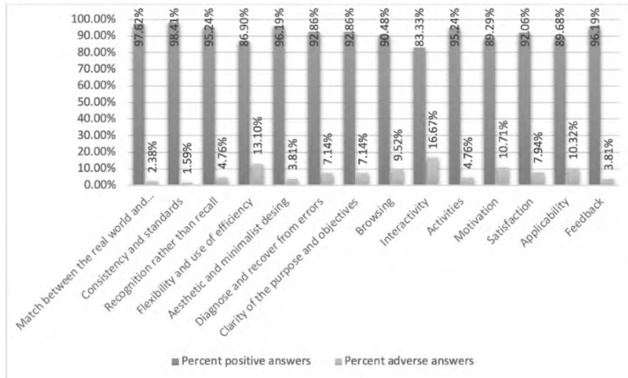

FIGURE 17. Usability results of the second developed MLO.

VI. CONCLUSIONS AND FUTURE WORK

In this work, a layered software architecture to develop MLOs with AR was presented. Our software architecture models based on a layered architectural pattern, the characteristics and desirable quality attributes of mobile learning objects with augmented reality such as customization, reusability, portability, usability, durability, accessibility, lightness, modularity, among others. The architecture described in this paper is composed of five layers: data persistence, learning personalization, interactivity, general structure, and standards. The objective of the data persistence layer is to manage the content that the learning object will contain; the personalization layer is responsible for adapting the content according to criteria related to the apprentice and the device in which the learning object is being used; the interactivity layer is responsible for managing the interaction media available to the user; the general structure layer is responsible for the presentation of the different sections that compose the learning object, as well as its description; and finally, a layer of standards is included to consider the main standards related to the development of learning objects such as SCORM, LOM, among others. Our architecture was evaluated from two approaches. The first consisted of a qualitative comparison, which showed that our architecture is characterized by other works for modeling all the desirable criteria that an architecture focused on the development of mobile learning objects with AR should consider. The second approach evaluated the quality of the MLOs built based on our architecture. The results obtained in the second approach show that the architecture presented in this paper contributes to developing quality MLOs with AR in terms of pedagogical, technological and usability aspects.

We expect that the architecture can be used and tested to generate quality MLO with AR. As future work, we consider implementing the architecture on the iOS platform.

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