Development of Construction Engineering Teaching Course by Using VR-AR: A Case Study of Polytechnic in Indonesia

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Abstract—The Covid-19 pandemic impacted the increasing use of Android smartphones in teaching and learning. This study aims to build markerless VR-AR (Virtual Reality-Augmented Reality) as Android-based teaching materials for construction engineering students at Polytechnic. VR-AR-based teaching materials that have been established can reduce the risk of spreading Covid-19 without reducing learning quality. This research used the V-model method, which is divided into two parts, particularly development and testing activities. Testing is performed by developers and examiners using ISO 25010. The test results of VR-AR-based teaching materials that have been established show that the teaching materials were very feasible in terms of functional suitability, compatibility, and usability. All functions of the VR-AR application operate smoothly and work successfully on various Android operating systems with different screen resolutions. Moreover, users were satisfied with the developed VR-AR-based teaching materials. They felt comfortable, fun, and excited when using the AR application.

Keywords—digital media, polytechnic, teaching material, education, VR-AR

1 Introduction

The current Covid-19 virus pandemic has paralyzed economies in several countries globally, without exception in Indonesia. To date (July 10, 2020), there have been 72,347 positive cases of Covid-19 and 3469 fatalities in Indonesia. A new record was set on July 9, 2020, precisely 2,657 positive cases, which was the highest record in a day [1]. The number of positive patients with Covid-19 is predicted to continue to grow until the end of 2020 if there is no self-control to cut Covid-19 transmission. Based on these conditions, the Indonesian government has issued several policies related to controlling to slow the spread of Covid-19, one of which is through policies of work, study, and worship from home. Karakose et al. revealed that the Covid-19 pandemic could directly impact the life quality of K-12 teachers and administrators [1]. The pandemic can also cause COVID-19-related psychological distress and depression among school teachers. Efforts are needed to increase the digital literacy competencies of education workers [2]. In Indonesia, the home learning policy instructed by the government creates difficulties for teachers who are not equipped for online learning; this is due to a lack of knowledge concerning the utilization of information technology (IT), the unequal quality of the internet in several regions in Indonesia, and the lack of teaching materials and learning models that support online learning. Based on a survey conducted by Indonesian Ministry of Education and Culture, the majority of polytechnic teachers still require teaching materials that can support the policy of home/online learning. There are only 37.65% of the learning modules available and tend to be normative-adaptive subjects for one particular skill competency.

The online teaching materials needed for productive subjects in Polytechnic are very complex, given that polytechnic must associate the learning context with industrial needs. For example, students with building construction skills competency must understand the sequence of construction projects [3], such as choosing the building structure and the roof frame joints' position. Under normal conditions, they can perform a survey in the field or industrial work practices. However, given the pandemic, this is impossible. Therefore, it is necessary to develop suitable teaching materials in a polytechnic with IT assistance; thus, they have a real picture/simulation without having to do activities outside the home. At present, Indonesia is competing with other developing countries such as China, Thailand, and Malaysia in technology and engineering. The rise of China as a significant power and a global economic player also requires Indonesia to take the opportunity because Asia is now an essential part of the world economy. Polytechnics in Indonesia has a vital role as one of the producers of human resources in engineering and has a learning system following industrial needs. One of the sectors that require many human resources is construction. The construction sector is one of the crucial sectors supporting economic growth in Indonesia. A study conducted by the Central Bureau of Statistics (BPS) shows that the construction sector is in the third position as the main source of Indonesia's economic growth. The growing construction sector made the Indonesian economy in 2016 grew by 5.01% and GDP by 10.38%, higher than the previous year [3].

Currently, teaching and learning activities have been supported by various forms of enhanced technology [4]. In 'new normal' working conditions, the schools must support digital transformation and technology-based professional development [4]. In the case of home learning problems, one of the innovative solutions is to adopt Virtual Reality-Augmented Reality (VR-AR). VR-AR is a visual technology that combines virtual objects with real objects; therefore, students can interact in real-time in the form of a 3D view. VR-AR has three characteristics, particularly interactive (increasing user interaction and perception of the real world), real-time, and 3D [5]. Previously, VR-AR has been implemented in various fields and is projected to continue to experience significant improvements; this is given that the VR-AR application is easy to use and has attractive visuals. The development of VR-AR in the industrial era 4.0 is now portable and wearable, thus providing more significant opportunities for its application to improve productivity and user experience. VR-AR is presently widely used for gaming and marketing purposes, whereas VR-AR can also be used for education [6].

AR is usually developed on IOS and Android platforms. Both mobile operating systems have become a trend among people around the world. According to a survey conducted by Statcounter Global Stats [7], Android smartphones have the most users compared to other operating systems worldwide (June 2019–June 2020). Android smartphone users are 74.14%, followed by IOS at 25.26%, and the rest are other operating systems. Meanwhile, in Indonesia, Android smartphone users have reached 92.3%, followed by IOS at 7.5%, and the rest are other operating systems [8]. Android's advantages are that it is open-source; therefore, users can easily install third-party applications from the App market and even from unknown resources [9]. Indonesia is the fourth-largest smartphone market worldwide after China, India, and the United States [10]. The number of smartphone users in Indonesia is estimated to reach 81.87 million by 2020. A survey conducted by the Indonesian Ministry of Communications and Information Technology shows that 70.98% of students in Indonesia are smartphone users [11].

Based on the explanation above, this study aims to build VR-AR as teaching material for Polytechnic students in construction engineering. Construction engineering is useful for supporting human facilities and infrastructure, as well as being able to provide support for all work and various other matters related to human activities. The teaching materials in construction engineering are very suitable for producing three-dimensional objects, such as Roof Construction which requires great imagination from students before practicing. These materials will be developed into digital teaching materials that resemble real miniatures. This VR-AR-based teaching material is expected to encourage enthusiasm in learning construction engineering at Polytechnic; thus, learning objectives can be appropriately achieved, supports Indonesian government policies related to home learning policies, and can be adopted in the future even though the Covid-19 pandemic has ended.

2 Literature review

VR-AR technology has been implemented in many fields such as industry, engineering, and culture [12–14]. One example in the industry, Michalos et al. [15] has succeeded in creating VR-AR applications as a communication bridge between robots and operators (humans) in an industrial environment. This application provides VR-AR visualization of the assembly process, video, and text-based instructions, and production status updates. The application test results show that the VR-AR application can improve operator performance and integration in the assembly process. In entertainment, Yan and Hu [16] have successfully developed VR-AR applications for broadcasting, videography, and cinematography. The virtual graphics produced by VR-AR are dynamic; hence the original display is better than traditional broadcasting. Also, AR allows broadcasters to interact with additional virtual 3D models, which can improve broadcast performance. In education, Wulandari et al. [17] have accomplished making the Wood Practicum learning media using VR-AR for students majoring in construction engineering. This learning media can be operated on an Android smartphone with the help of markers. Students can see various joints in the construction field, which are utilized to build a wood product. The test results on this application using ISO 25010 indicated that the application of learning media was stated to be very feasible in functional suitability, compatibility, and usability aspects. While from the performance efficiency aspect, the application was considered feasible. In conclusion, this application is proven to improve students' cognitive abilities through digital simulations and is suitable as an alternative to digital teaching materials.

Similar to Wulandari et al. [17], this research aims to develop VR-AR-based teaching material for construction engineering students at Polytechnic. The difference is that the VR-AR in this research displays not only various kinds of joints but also a 3D view of the wood product object as a whole from the start to the end of manufacture, along with a description of the joints utilized. Also, the VR-AR made in this study is markerless. Markerless VR-AR tracks an object in the real world without the need to use a marker. This markerless method is supported by pattern recognition, a technique used to recognize a pattern of real-world objects. The use of markers for object tracking is replaced by the surface of an object [18]. The development of smartphones dramatically influences the development of markerless VR-AR. Before the rapid and sophisticated evolution of smartphones, VR-AR application development mainly utilized markers. However, markerless VR-AR technology is in demand, along with the development of camera and sensor technology [19]. One of the advantages of markerless VR-AR is the more accessible use of VR-AR since users can immediately experience 3D objects without continually capturing an artificial marker [20].

3 Methods

This study uses the Software Development Life Cycle (SDLC) method. SDLC is a software development method that can be applied in a systematic manner that allows the completion of the project in the desired time and maintains the software's quality according to standards [21]. There are various SDLC models, such as Waterfall, V, RAD, Prototype, et cetera. This study chooses to implement the V-model. This model has the advantage of estimating costs and monitoring high quality [22].

The V-model stood for the Validation/Verification model and was first proposed by Paul Rook in 1980 [23]. This model demonstrates the correlation between development activities and testing activities. Unlike another modelling, the V-model testing process is much more complicated, given that it is divided into several more specific parts. The flow of stages in the V-model can be examined in Figure 1 [24].

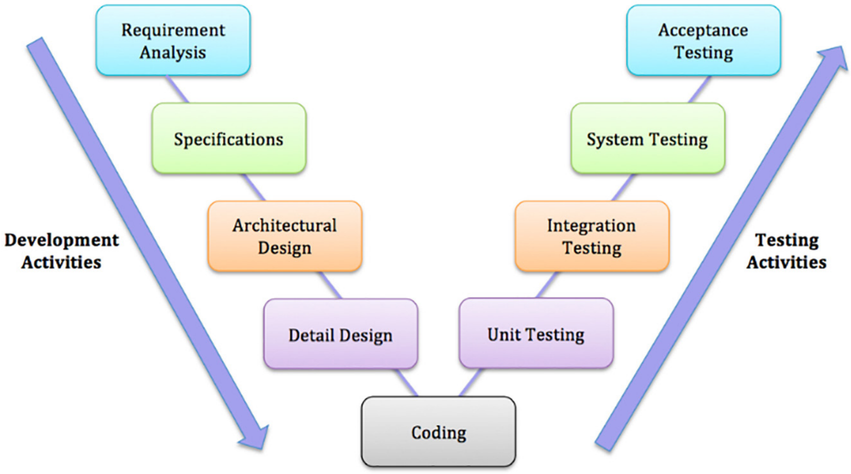

Fig. 1. V-model

Figure 1 shows the system development process includes a requirement analysis, requirements specification, design specification, and program specification. Meanwhile, the testing process comprises acceptance testing, system testing, integration testing, and unit testing. Within the development activities and testing activities, there is a coding process. The following are the stages of developing VR-AR teaching materials for the field of construction engineering using the V-model.

- Requirements Analysis: Developers attempt to get information on user needs related to the design of teaching materials using VR-AR, particularly from construction engineering in Polytechnic.
- Specification: Developers create a user requirement list, which will be the basis for forming VR-AR based teaching materials that can be applied to Android smartphones.
- Architectural Design: Based on the user requirement list generated from the previous stage, the developers will describe the VR-AR application workflow that was constructed using Unified Modelling Language (UML) modelling. UML is a set of modelling conventions used to describe a software system associated with objects [25].
- Design Details: Developers will invent a more detailed design, including a user interface using a storyboard and a user experience design based on user needs.
- Coding: Developers apply detailed designs from the previous stages, employing a programming language. The software that will be used to create VR-AR-based teaching materials is Unity 3D.
- Testing: The V-model consists of several sequential testing. Testing will be performed by developers and examiners using ISO 25010 [26], the international standard testing for devices manufactured by the International Organization for Standardization (ISO). This standard is based on developments in Information and Communication Technology (ICT), such as the development of microprocessors, memory, displays, and storage media [27]. This study uses four of the eight aspects in ISO 25010, particularly functional suitability, compatibility, performance efficiency, and usability. These four aspects were selected, given of their compatibility with the V-model

testing aspect. Functional suitability is the degree to which a product can provide the functionality required when it is utilized. Compatibility is the extent to which a product can efficiently perform the required functions with another product or system without causing the product to be harmful. Performance efficiency is the level of effectiveness and efficiency in a product or system modified by the developer. Usability is the extent to which a product can be used by users to achieve effective, efficient, and satisfying goals in the user's context.

4 Results

4.1 Requirement analysis

Developers identified user needs regarding the characteristics of teaching materials coveted during the Covid-19 pandemic. Observations and interviews were performed offline and online between developers and teachers, technicians, and 10 students of construction engineering. The identification results show several conclusions regarding the conditions and needs of the user, particularly:

- Respondents find it challenging to understand teaching materials in the form of modules that contain drawings of building construction in 3D. Moreover, since the online learning model implemented due to the Covid-19 pandemic, students have experienced many obstacles in visualizing these images in their respective homes
- The most challenging material for respondents to understand is Roof Construction; this is given that the construction of a roof of a building consists of various joints and sophisticated materials. Roof construction in buildings is essential since it functions as a cover for the entire space under it against the influence of temperature, wind, rain, dust, and protection purposes.
- Respondents feel bored in doing online learning. They need more attractive and comfortable to use learning models or teaching materials, such as via an Android smartphone, to increase their intention toward home learning.

4.2 Specifications

After the user's needs are identified, the next step is for the developers to determine the product specifications for the teaching materials to be developed. The material to be made using VR-AR teaching materials is concerning roof construction. This material is adapted to the syllabus obtained from the previous stage. Roof construction teaching materials consist of roof structures, roof coverings, and roof attachments.

4.3 Architectural design

Developers design the architecture of roof construction teaching materials utilizing UML, which is illustrated through several diagrams. First, the Use-case diagram describes system functionality that can be accessed by users. Second, an activity's diagram that contains an image of the overall system flow from application installation to application closing. Finally, the sequence diagram describes the flow of system functionality based on the use-case diagram.

4.4 Detail design

Developers design each component of the product to be developed using a storyboard. Roof construction teaching materials consist of three main parts: the main menu page, the camera page, and the application-use instruction page. The VR-AR camera page is the core of the teaching material. On the VR-AR camera page, users can observe 3D objects from a house as a whole. The 3D object will appear markerless in the center of the smartphone screen. On the left side of the screen, there are various features that the user can see to describe the construction of a house from start to finish, especially the construction of the roof. Meanwhile, on the right side of the screen, there are various options for the Joints of the roof construction that can be selected to display the animation.

4.5 Coding

This stage is building VR-AR of roof construction based on a detailed design utilizing a programming language. Developers apply tools that function to create applications for the Android platform, particularly Unity 2019.2.19f1, Java JDK, and the Android SDK. Unity is used to create a VR-AR application layout that will be created. The coding phase begins with installing the VR-AR Foundation and AR Core XR Plugin packages discovered in the Unity package manager. All 3D objects built for this AR application use Blender 3D software. This software functions to make the appearance of 3D objects as real and as close as possible to the original. Figure 2 shows the process of making one of the 3D objects, particularly the Roof Frame. Whereas Figure 3 is the process of making a 3D object's easel joints on the roof frame.

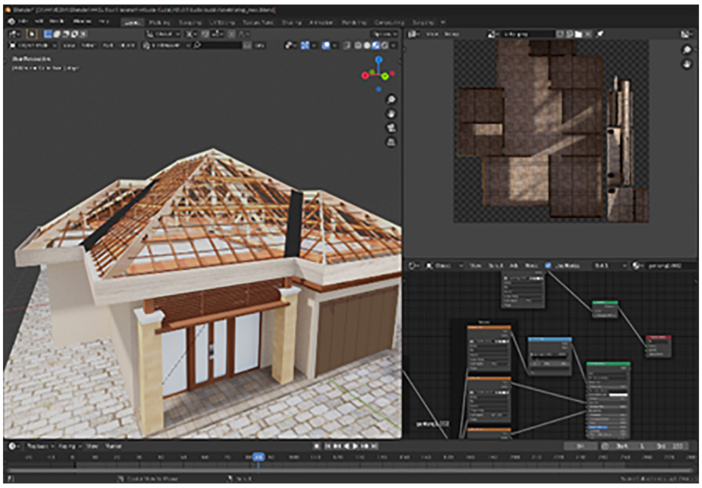

Fig. 2. Constructing 3D roof frame objects

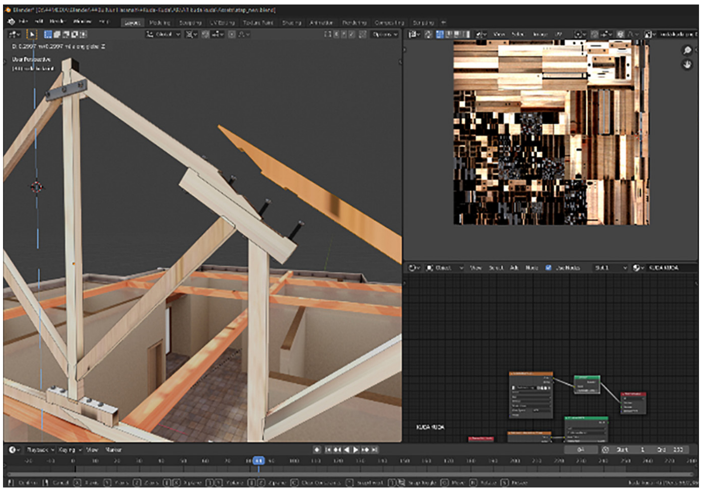

Fig. 3. Building a 3D object easel joint

Next, all the 3D objects that have been built are exported to Unity. After the application has been created, the final step of the coding stage is to 'build' the application on Android. The roof VR-AR construction built consists of the main page, VR-AR camera page, and an instruction page. The keynote of learning roof construction lies on the VR-AR camera page. This page will display various kinds of 3D objects utilized for the construction of a house, especially the construction of the roof of the house. Users do not need to use markers to run VR-AR camera pages. Users only need to scan flat surface items such as tables, chairs, sofas, et cetera. Then the user taps the ea to bring up a 3D object. Figure 4 displays the VR-AR camera page. On the left side of the screen, there are various choices of 3D objects needed for house construction, particularly floor, wall, blocks, ceiling, nok and jural, gutter, gording, swirl, battens, and roof tile. If the user prefers to display all 3D objects simultaneously, it will appear as a whole house building. While on the right side of the screen, there are various kinds of Joint options from the roof construction that can be selected to display the installation animation in detail.

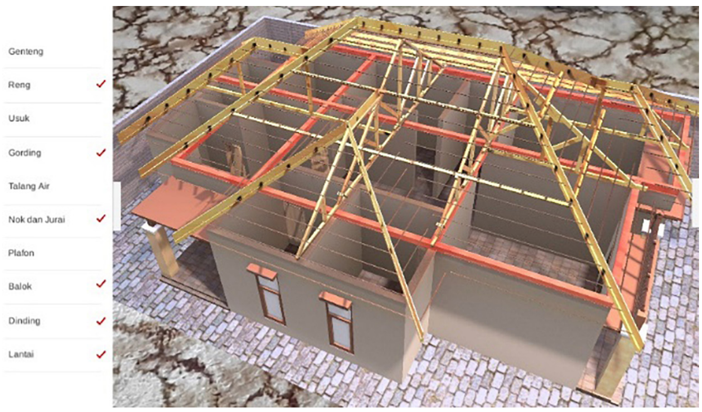

Fig. 4. Camera page displaying several 3D objects from a house

4.6 Testing

Unit and integration testing was performed sequentially by the developers to ensure that VR-AR-based roof construction teaching materials have been built following the detail and architectural design specified in the previous development activities. Furthermore, the system and acceptance testing were performed by examiners exercising four aspects of ISO 25010. This testing phase was executed to ensure whether the teaching material follows the results of the previous specification and requirement analysis.

5 Discussions

The functional suitability test was conducted by three multimedia experts who understand software systematics. The testing adopts a test case as a testing instrument. The test case is in the form of a table consisting of a list of functions that exist in roof construction teaching materials. The value '1' of the examiners states that the application features have operated smoothly [28, 29]. Based on the test results, the developer performs descriptive data analysis with the following formula.

$$\text{Feasibility Percentage (\%)} = ((\text{Observed Score})/(\text{Expected Score})) \times 100\%$$
$$= (57/57) \times 100\% = 100\%$$

The results of the calculation of the feasibility percentage were converted into a statement [30]. The feasibility percentage obtained is 100%; thus, it can be concluded that from the aspect of functional suitability, roof construction teaching materials can be declared very feasible.

Compatibility testing was performed on various devices and operating systems. Developers performed observations on the experiment of installing, operating, and uninstalling roof construction teaching materials on several versions of the Android operating system with different screen resolutions. The presents compatibility test results, where teaching materials are proven to be successfully operated in a combination of Android versions. Based on the test results, the feasibility percentage can be calculated as follows.

$$\text{Feasibility Percentage (\%)} = ((\text{Observed Score})/(\text{Expected Score})) \times 100\%$$
$$= (8/8) \times 100\% = 100\%$$

Furthermore, the results of the calculation of the feasibility percentage are converted into a statement [30]. The feasibility percentage obtained is 100%; hence the teaching materials for Roof Construction can be stated as very feasible from the aspect of compatibility.

Performance Efficiency testing uses the average CPU and memory usage in executing all functions in the application. This testing uses Test droid, a performance testing software that allows testing the software's performance on various handsets. Testdroid will display CPU usage and memory by the device you want to use. The average amount of CPU usage using the standard of one of the mobile application analysis tools, Little Eye, is 15% of the total usage. The five devices' CPU usage is still below the Little Eye standard (<15%), and there is no memory leak. Memory leak is one that can reduce the performance value of an application. If memory leak occurs, the Android system will stop the application (force close) due to lack of memory. Therefore, the roof construction teaching materials can be declared feasible from the aspect of performance efficiency.

Usability testing was performed by potential users, 35 students. They try to operate the application of Roof Construction teaching materials using an Android smartphone. After that, the respondents filled out a questionnaire of the USE Questionnaire [31], which uses four dimensions, particularly the dimensions of usefulness, ease of use, ease of learning, and satisfaction. Based on the results of filling out the questionnaire, the percentage of eligibility is obtained as follows.

$$\begin{aligned}\text{Feasibility Percentage (\%)} &= ((\text{Observed Score})/(\text{Expected Score})) \times 100\% \\ &= (4465/5250) \times 100\% = 85\%\end{aligned}$$

The calculation result of the feasibility percentage is 85%. Based on the percentage conversion, roof construction teaching materials can be stated in the very feasible category from the Usability aspect. As for the dimension with the highest value from users is Satisfaction. Users were satisfied with the developed VR-AR based teaching materials. They felt comfortable, fun, and excited when studying roof construction. At the same time, their suggestions for future developments were for the developers to add a feature for selecting a roof model by the user.

When the global pandemic COVID-19 began, educational settings were not ready to convey virtual knowledge in Indonesia [32]. However, the quality of education plays a key role in the national educational system [33]. So digital technologies can be used to increase educational quality and augmented reality applications enable real virtual 3-D environments [34,41], especially for technical sciences where the research results of developed technologies for the metallurgy industry might be used as content for 3D educational applications [35–40]. This creates a real motivational environment for future engineers-researchers.

6 Conclusions

This research has successfully fabricated a VR-AR-based teaching material for Polytechnic's students in the era of the Covid-19 pandemic. The teaching material that has been established is one of the materials in construction engineering, particularly roof construction. The quality of learning is closely related to the availability of learning resources. This teaching material can be utilized as an attractive and easy-to-use home learning resource for respondents during the Covid-19 pandemic. The main advantage of adopting these teaching materials is that students do not need to attend offline laboratories or workshops to practice. Respondents simply download the roof construction application and install it on their smartphones. Thus, VR-AR-based teaching materials that have been built can reduce the risk of spreading Covid-19 without reducing learning quality.

The test results of the roof construction teaching materials confirm that the VR-AR-based teaching materials are very feasible in terms of functional suitability, compatibility, and usability. All functions of the VR-AR application operate smoothly, and the application is successfully run-on various versions of the Android operating system with different screen resolutions. Moreover, users were satisfied with the developed VR-AR-based teaching materials. They felt comfortable, fun, and excited when studying roof construction. At the same time, their suggestions for future developments were for the developers to add a feature for selecting a roof model by the user. From the performance of efficiency aspect, the AR application is declared feasible, after the application is proven to use less than 15% CPU on various kinds of Android smartphones. Meanwhile, from the usability aspect, the AR application is considered feasible for users to support the context of Industry 4.0 [39].

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