Markerless Augmented Reality in Construction Engineering Utilizing Extreme Programming

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Abstract. This study aims to build Android-based Markerless Augmented Reality as a learning media in the Construction field, specifically Bridge material for vocational students. This study applies the Extreme programming method, which consists of the Planning, Design, Coding, and Testing stages. The developers and potential users performed the tests. The Functional Usability test results using Black-Box testing reveal that all features in the application can operate successfully. In terms of compatibility, the application is declared very suitable for use. The application has proven successful in running on several kinds of Android smartphones with different versions and screen resolutions. Meanwhile, in terms of Usability, the application acquires an eligibility percentage of 84.2%. Users find it easy to operate the application since they can immediately run 3D objects wherever they are, without being limited by the presence of markers. They consider being freer to run AR applications. However, the Markerless application that has been built can only be operated on Android smartphones version 7.0 and above.

1. Introduction
Construction has a crucial role in human life. From the perspective of society, construction determines where and how people perform their daily activities. For example, in the United States, people spend an average of 90% of their time indoors [1]. The buildings and materials used in their construction and its completion have a profound impact on their occupants' health and well-being. From an economic point of view, the construction industry is expected to proliferate with revenues of around $15 trillion in 2025. Currently, more than 100 million people are working in construction worldwide [2]. Meanwhile, Indonesia is actively developing infrastructure; therefore, skilled human resources in construction are needed. One review aspect of the Indonesian government's focus is studying at the vocational high school (SMK) level, where the main objective is to produce graduates with a high
level of employment according to industry needs. To achieve the government's goals in preparing middle-level human resources who are productive, creative, innovative, and able to compete globally in the 21st century, education in Indonesia needs to be improved. One of the ways is through learning innovation at SMK.

One of the vocational schools that excel in the field of construction in Indonesia is SMK 2 Depok Yogyakarta. Based on observations, students in this field still use modules as teaching materials. The material discussed in the majority of the modules is in the form of various kinds of 2D and 3D building drawings, such as simple houses, multi-story buildings, bridges, dams, irrigation, and production infrastructure. This material requires excellent imagination, and students need innovative learning media that can help improve student understanding.

Augmented Reality (AR) is a technology that combines visual images with the real world, where the visual image will be displayed with the help of a particular device [3]. AR is a variation of Virtual Reality (VR). VR technology brings the user into a virtual environment, and the user will not be able to distinguish the real objects around the user. Through AR, users can see a virtual environment combined with the real world encompassing them. Therefore, AR adds to reality, instead of replaces it. AR will be beneficial for the world of education in presenting virtual 3D educational objects; therefore, it is expected that users can be more interested and understand the knowledge conveyed. AR is gaining popularity and the development of internet and smartphone technology, where AR applications can be downloaded and work in real-time using Android and iOS smartphones. Meanwhile, the number of Android smartphone users in Indonesia is the largest, reaching 92.3%, followed by iOS at 7.5%, and the rest are other operating systems [4].

AR is divided into two methods; specifically, Marker Based AR and Markless AR. Marker is an image file that will later function as a trigger, which will be recognized by the camera to operate AR applications [5]. Markers are uploaded to the Vuforia system, an AR Software Development Kit (SDK) for mobile devices that enables the creation of AR applications [6]. Marker-based AR has been widely applied in various fields such as education [7, 8], health [9, 10], culture [11, 12], entertainment [13, 14], industry [15, 16], et cetera. On the other hand, markerless AR methods are developing rapidly recently. This method does not require a marker to display 3D objects. Markerless AR tracks objects that exist in the real world without special markers [17]. The surface of a marker object replaces the use of markers as tracking objects as a tracking object. Markerless tracking is supported by pattern recognition techniques done by calculating the position between the user's camera and the real world without any reference, only using natural feature points such as lines, edges, and corners. The applications of Markerless AR have yielded positive results. For example, Renukdas et al. [18] have produced an Android-based Markerless AR for interior decoration. They stated that the AR method that has been applied could be developed and extended to the fields of architecture and civil engineering. Another example is the research of Hammady et al. [19]. They have successfully researched the user experience of markerless AR application at the Leeds museum and Egyptian museum in Cairo. The results show that 77% of participants from both museums felt that the use of AR technology in museums could increase their interest and excitement. More than 70% of participants agreed that AR technology encourages them to interact with one another.

Based on the explanation above, this study aims to build an Android-based Markerless AR as a learning media in the construction field for students of SMK (Vocational School) 2 Depok Yogyakarta.

2. Method
This study uses one of the Agile Programming software development methods, specifically Extreme Programming (XP) [20]. Agile Programming is based on iterative development, where requirements and solutions develop through collaboration between organized teams.

XP utilizes an object-oriented approach as a development paradigm and includes a set of rules. The development team formed in XP is a small or medium-sized team, to overcome unclear requirements and rapid requirements change [21]. XP focuses on coding and relies heavily on the skills of the developer [22]. The use of XP can produce high-quality products with simple designs [23]. Figure 1 presents the stages of activities in XP, particularly Planning, Design, Coding, and Testing.
Figure 1. Stages of Extreme Programming [20]

a. Planning
The planning stage was accomplished by creating a “user story” that describes the output, features, and functionality of the software to be created.

b. Design
XP supports refactoring where the system software is modified in such a way as to changed the code structure and simplified the code.

c. Coding
The coding phase began with building a series of tests (unit tests) using the test-driven development method, after which the developer must focus on implementation to pass the test. In XP, the term Pair Programming was also introduced where the program writing process was executed in pairs. Two programmers worked together on one computer to write program code. By performing this, real-time problem solving and real-time quality assurance will be obtained.

d. Testing
Testing was accomplished by testing the code on unit testing. In XP, there is also an Acceptance Test or commonly called a Customer Test. This test was performed by customers who focused on the system's features and functions as a whole.

3. Result and discussion

3.1. Planning
At this stage, the development team maps user needs, which will later be used to construct software development. To that end, the team conducted observations and interviews with several teachers and students majoring in Building Drawing Engineering, SMK 2 Depok, Yogyakarta. Based on the interview, one of the materials that require high imaginative ability is Bridge material. Teachers and students need IT innovation in learning media to increase their interest and excitement, especially in Bridge material. The developer plans to build Markerless AR containing Bridge material. There will be a submenu where users can see the various Connections utilized to build a Bridge that is displayed as 3D objects.

3.2. Design
At this stage, the developer creates a Markerless AR Bridge application design using the Unified Modeling Language (UML). The system design is illustrated through Use Case diagrams, Sequence Diagrams, and Activity diagrams. Figure 2 exhibits an Activity diagram of the application to be built. To operate Markerless AR Bridge, users must first install the application. After that, the user can open the application, starting with the main menu option. Through the main menu, users can select a
submenu to view 3D Bridge objects and their various Connections. In this process, the system loads the 3D objects that have been stored in the application database, then displays them to the user.

![Activity Diagram](image)

**Figure 2.** Activity Diagram

### 3.3. Coding

At this stage, the developer arranges programming to build a Markerless AR Bridge. Programming applying Unity 2019.2.19f1 software, Java JDK, Android SDK, AR Foundation package, and ARCore XR Plugin contained in the Unity package manager. The Android platform was chosen, given that this platform is open to developers to create applications according to their needs.

The writing program code process is achieved in pair programming, where two programmers work collectively to complete a unit. The two programmers discuss and correct each other when there are errors during the coding process. Figure 3 explains the process of making a Bridge Truss in Blender 3D, while Figure 4 presents the process of making one of the joints used on a Bridge Truss.

![Blender 3D](image)

**Figure 3.** Bridge Truss
During the Markerless AR Bridge development process, users can also provide input to the programmer on the application. Based on this input, the developer prepares refactoring, making changes to the software code to improve the quality of the application without changing the way the program works. Refactoring is performed to follow the changing requirements during the application development process; this is the specialty of Extreme Programming. After all the 3D objects are established, the programmer exports the 3D objects to Unity. Figure 5 presents a 3D Bridge Truss object that has been exported to Unity.

Before the application proceeds to the next stage (testing stage), the programmer performs unit testing of all programming code to remove bugs. Figure 6 is the Markerless AR Bridge application that has been completed and is ready to operate on an Android smartphone.

On the Markerless AR Bridge application's main page, there is a sub-menu to the 3D object camera page, which is the core of the application. On this page, users required to scan items on a flat surface such as tables, chairs, sofas, laptops, et cetera. After the scanning process is successful, the item's surface will display a black border, which the user can tap to bring up the 3D Bridge Truss object. Furthermore, the 3D object can be moved by the user on the smartphone screen for user's convenience. On the application screen, there are ten kinds of Connection options used to build a Bridge Truss. When the user selects a Connection, the application will display the Connection's location on the Bridge Truss. The user can also see an animation of Connection installation.
3.4. Testing
Testing was using ISO 25010. This standard is an international standard in software testing [24]. ISO 25010 testing aspects that are applied at this stage are Functional Suitability, Compatibility, and Usability. Functional suitability testing functions to determine the extent to which a product or system suffices needs when employed in certain conditions. Compatibility testing aims to determine the extent to which an application can perform its functions efficiently with other systems without harming the system. Usability testing was performed to determine the extent to which the application can be utilized by users to achieve goals effectively, efficiently, and with satisfaction in the user's context.

3.4.1. Functional Suitability Testing. This test utilizes the Black-Box testing method, which was performed by two experts in the multimedia field. The testing was arranged by filling out a questionnaire that was prepared following the analysis of functional requirements. Based on the test results, all features in the questionnaire were answered “1”, meaning that all features can work correctly. The summary of the results from the Functional Suitability test is presented in table 1.

| No | Features                      | Examiner Score | Maximum Score |
|----|-------------------------------|----------------|---------------|
|    |                               | Examiner 1     | Examiner 2    | Total |         |
| 1  | Main Menu Page                | 1              | 1             | 2     | 2      |
| 2  | AR Camera page                | 1              | 1             | 2     | 2      |
| 3  | Instruction page              | 1              | 1             | 2     | 2      |
| 4  | Bridge Truss 3D Object        | 1              | 1             | 2     | 2      |
| 5  | Connection 1                  | 1              | 1             | 2     | 2      |
| 6  | Connection 2                  | 1              | 1             | 2     | 2      |
| 7  | Connection 3                  | 1              | 1             | 2     | 2      |
| 8  | Connection 4                  | 1              | 1             | 2     | 2      |
| 9  | Connection 5                  | 1              | 1             | 2     | 2      |
| 10 | Connection 6                  | 1              | 1             | 2     | 2      |
| 11 | Connection 7                  | 1              | 1             | 2     | 2      |
| 12 | Connection 8                  | 1              | 1             | 2     | 2      |
| 13 | Connection 9                  | 1              | 1             | 2     | 2      |
| 14 | Connection 10                 | 1              | 1             | 2     | 2      |
|    | Total                         | 14             | 14            | 28    | 28     |

Furthermore, the results of the testing above were analyzed by the following formula.

\[
\text{Feasibility Percentage(\%)} = \frac{\text{Observed Score}}{\text{Expected Score}} \times 100\% = \frac{28}{28} \times 100\% = 100\% \quad (1)
\]
The percentage of eligibility obtained was 100%, which was then converted using Table 2 [25]. The conversion results conclude that the Functional Suitability testing in the Markerless AR Bridge application can be declared "Very Feasible".

### Table 2. Percentage of Eligibility.

| No | Percentage of Achievement (%) | Interpretation          |
|----|-------------------------------|-------------------------|
| 1  | 0% - 20%                      | Very Less Feasible      |
| 2  | 21% - 40%                     | Less Feasible           |
| 3  | 41% - 60%                     | Rather Feasible         |
| 4  | 61% - 80%                     | Feasible                |
| 5  | 81% - 100%                    | Very Feasible           |

#### 3.4.2. Compatibility Testing.
Compatibility testing applies an observation method in testing to install, run, update, and uninstall the application. The testing applies an instrument in the form of a checklist. Application operated on several kinds of Android smartphones with different versions and screen resolutions. Table 3 shows that the application has been operating successfully on all tested devices.

### Table 3. Results Summary of the Compatibility Test

| No | Device         | Android Version | Screen Resolution | Succeed | Failed |
|----|----------------|-----------------|-------------------|---------|--------|
| 1  | Galaxy S8      | 9.0 (Pie)       | 2960 x 1440       | 1       | 0      |
| 2  | Galaxy S9      | 9.0 (Pie)       | 2220 x 1080       | 1       | 0      |
| 3  | Galaxy S9      | 8.0 (Pie)       | 2960 x 1440       | 1       | 0      |
| 4  | Galaxy A8      | 8.0 (Oreo)      | 2220 x 1080       | 1       | 0      |
| 5  | Galaxy J5 (2017) | 8.0 (Oreo)    | 1280 x 720        | 1       | 0      |
| 6  | Redmi Note 8 Pro | 9.0 (Pie)     | 2340 x 1080       | 1       | 0      |
| 7  | Realmi 5 Pro   | 9.0 (Pie)       | 2340 x 1080       | 1       | 0      |
| 8  | Galaxy J8      | 8.0 (Pie)       | 1480 x 720        | 1       | 0      |
|    | Total          |                 |                   | 8       | 0      |

Furthermore, the results of the testing were analyzed using the following formula.

\[
\text{Feasibility Percentage(\%)} = \frac{\text{Observed Score}}{\text{Expected Score}} \times 100\% = \frac{8}{8} \times 100\% = 100\% \tag{2}
\]

Based on the conversion utilizing Table 2, it can be concluded that the Compatibility testing in the Markerless AR Bridge application can be declared as "Very Feasible".

#### 3.4.3. Usability Testing.
Usability testing was performed using a questionnaire of the USE Questionnaire [26], which contains 30 questions. There are four criteria used in the questionnaire questions: Usefulness, Ease of Use, Ease Of Learning, and Satisfaction. The testing was conducted by 30 students of class X, Building Drawing Engineering Department, SMK 2 Depok Yogyakarta. Students tried the application on each of the smartphones they own. The percentage of eligibility obtained based on the results of filling out the questionnaire is as follows.

\[
\text{Feasibility Percentage(\%)} = \frac{\text{Observed Score}}{\text{Expected Score}} \times 100\% = \frac{3788}{4500} \times 100\% = 84.2\% \tag{3}
\]

The result of the feasibility calculation is 84.2%. Furthermore, the results are converted using Table 2, which concludes that the Usability testing in the Markerless AR Bridge application can be declared "Very Feasible." The majority of feedback obtained from users is that they find it easy to operate the application. They can immediately display 3D Bridge objects wherever they are without the need to track marker images. They can also run the application in indoor or outdoor environments. However, some obstacles occurred, mainly that some smartphones have not supported the application due to inadequate specifications (the application can only run on Android versions above 7.0). This is due to markerless programming, which requires high specifications.
4. Conclusion
This research has succeeded in building Markerless AR Bridge as a learning media in the construction field that can be operated on an Android smartphone. The Extreme Programming method can be implemented to develop a Markerless AR application. The method consists of the Planning, Design, Coding, and Testing stages. The results of the Black-Box testing show that all application features can operate successfully. Meanwhile, in terms of compatibility, the application can operate on various versions of Android devices. Also, Usability testing concludes that the application is very feasible to use. Users find it easy to operate the application given that they can immediately run 3D objects wherever they are, without being limited by the presence of markers. They consider it to be freer to run AR applications. However, the Markerless application that has been built can only be run on Android smartphones version 7.0 and above.

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