



Development and Effectiveness of Augmented Reality Learning Media to Enhance Vocational Education Quality in Roof Construction

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Abstract: Insufficient conceptual understanding of roof construction elements often leads to suboptimal learning outcomes in vocational education. The technical nature of structural components requires high spatial visualization, which conventional materials fail to provide. This study aimed to develop valid, practical, and effective augmented reality learning media to bridge this gap. Utilizing the ADDIE model (analysis, design, development, implementation, and evaluation), the research involved three-dimensional structural modeling and smartphone integration. Testing was conducted at SMK Negeri 5 Padang involving an experimental class ($n = 32$) and a control class ($n = 12$) within the Fundamentals of Construction and Housing Engineering subject. Data were gathered through validation sheets, practicality questionnaires, and pre-test post-test instruments. Results indicated high validity scores of 4.71 from media matter experts and 4.63 from subject experts, with practicality ratings of 95.76 percent from teachers and 93.00 percent from students. Statistical analysis via independent t -test revealed significant differences in post-test scores ($t = 2.24$, $p = 0.03$). Furthermore, the experimental group achieved a higher competency growth (N -gain 0.66) than the control group (0.51, $p = 0.01$). In conclusion, augmented reality is highly feasible for enhancing vocational learning outcomes by transforming abstract references into interactive visualizations.

Keywords: ADDIE; Augmented Reality; Learning Media; Learning Outcomes; Roof Construction Elements.

Introduction

Vocational education currently faces significant challenges in producing graduates who are relevant to global workforce requirements. The demand for industrial competency necessitates the mastery of demonstrable and measurable technical skills (Adiyanto et al., 2024). In alignment with 21st century technological advancements, learning processes in vocational high schools are required to utilize innovative media that effectively support conceptual understanding (Okpatrioka, 2023). Within the Fundamentals of Construction and Housing Engineering subject, which is a core element of the Kurikulum Merdeka, students must master roof construction elements. This material

requires an understanding of complex structural forms and the interrelationships between various components, which are ideally presented through detailed three dimensional (3D) technical visualizations (Ghofar et al., 2025).

Within the vocational programs of Building Modeling and Information Design, as well as Construction and Housing Engineering, a foundational learning element is the Fundamentals of Construction and Housing Engineering. This element encompasses several critical competencies, with the mastery of roof construction elements being a primary learning objective. Mastering these elements is paramount as it involves grasping the complex forms, functions, and intricate technical interrelationships between various structural components. Inherently, this material is three-

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dimensional (3D) and requires high-level spatial visualization to ensure a comprehensive conceptual understanding (Ghofar et al., 2025). However, despite this technical necessity, empirical observations reveal that the instructional process remains predominantly teacher-centered and heavily reliant on conventional two-dimensional (2D) media (Amirahma & Setyasto, 2024; Muskhir et al., 2024). According to Muskhir et al. (2024), these pedagogical limitations create a passive classroom environment where students frequently experience disinterest and significant levels of boredom. Static 2D visuals are fundamentally incapable of representing the volumetric depth and structural integration of roof elements, leading to a profound cognitive gap where students struggle to imagine constructions as they exist in real-world engineering (Mubarroq et al., 2024; Mukhtar et al., 2023). This problem is further compounded by the prohibitive cost of physical equipment and limited laboratory access, which prevents students from obtaining essential hands-on experience (Saputri et al., 2026; Thompson et al., 2026). The urgency of these shortcomings is underscored by low student completion rates in initial assessments, where a majority of students failed to achieve the minimum mastery criteria (Amirahma & Setyasto, 2024). Ultimately, the lack of interactive instructional variations directly contributes to a decline in learning motivation and suboptimal outcomes, signaling an immediate need for an immersive instructional transformation (Zaim et al., 2023).

Empirical evidence from observations and interviews at the research site indicates that instruction is still heavily dominated by two-dimensional (2D) visual media, which are fundamentally inadequate for representing complex construction structures comprehensively. This limitation causes students to struggle with visualizing roof construction elements in real-world contexts, leading to significant cognitive barriers and persistent misconceptions regarding structural logic (Akhsan et al., 2023). These findings align with prior research stating that 2D visuals hinder students from perceiving the integrated nature of a construction, thereby decreasing the effectiveness of conceptual acquisition (Mubarroq et al., 2024; Mukhtar et al., 2023). Furthermore, E. Efendi & Asrizal (2025) the prevalence of teacher-centered practices and the lack of innovative instructional approaches contribute to the relatively low level of 21st-century skills among vocational students. Such instructional tendencies are reflected in traditional methods that frequently result in student boredom, disinterest, and passivity (Muskhir et al., 2024). The disparity between classroom learning outcomes and the actual skills demanded by Industry 4.0 creates a significant gap in vocational preparedness (R.

Efendi et al., 2025). These combined constraints have a detrimental impact on student performance, as observed in the majority of Grade X students within the Building Modeling and Information Design and the Construction and Housing Engineering programs, who failed to achieve initial learning completeness. Consequently, transforming the learning environment through interactive and immersive media is essential to bridge this pedagogical gap and improve overall educational quality (Amirahma & Setyasto, 2024; Saputri et al., 2026).

Furthermore, the ubiquitous presence of smartphone technology among students remains an underutilized pedagogical resource in vocational education. Instead of academic enrichment, these devices are predominantly engaged for non-educational purposes, such as mobile gaming (Raharjo & Pitaloka, 2020). Nevertheless, mobile technology offers transformative potential to facilitate learning beyond traditional classroom boundaries, allowing students to access interactive materials "anywhere and anytime" (Adji et al., 2023). This potential is empirically supported by the Digital 2025: Indonesia report, which indicates that smartphone penetration among users aged 16 and above has reached 99.5%, making mobile connectivity a standard for vocational learners (Kemp, 2025). Such pervasive access provides a strategic opportunity for implementing Augmented Reality based Mobile Learning (ARMOL) to bridge the Industry 4.0 skills gap (R. Efendi et al., 2025). Leveraging smartphones for AR-based simulations not only enhances instructional accessibility but also provides a cost-effective alternative to expensive physical infrastructure, thereby strengthening students' procedural understanding without the constraints of limited workshop equipment (Saputri et al., 2026). Consequently, E. Efendi & Asrizal (2025) the integration of innovative experience-based media is essential for designing a globally responsive vocational education that aligns with 21st-century competencies.

A transformative technology-based learning medium with significant potential to address these instructional gaps is Augmented Reality (AR). This technology interactively integrates two-dimensional and three-dimensional virtual objects into real-world environments, providing an immersive experience essential for construction skills training (Thompson et al., 2026). AR-based media offers a novel pedagogical approach by delivering visualizations that mirror physical reality from multiple perspectives, which is crucial for mastering complex structural components (Nilamsari & Dewi, 2023). According to Akhsan et al. (2023) this immersive depth allows students to examine objects in a concrete and realistic manner, thereby overcoming common misconceptions and enhancing

spatial visualization skills . In its application, Apriliano et al. (2023) argues that AR provides high accessibility when packaged as an Android-based smartphone application, ensuring that attractive 3D technical materials are evenly distributed to all students. This approach is further supported by evidence that smartphone-based AR simulations are highly effective in helping students visualize 3D objects realistically, while simultaneously fostering the self-efficacy required for independent technical learning (Taggart et al., 2023).

Extensive literature demonstrates that integrating AR into the learning process significantly bolsters student motivation, engagement, and conceptual retention. In Adji et al. (2023) research, the use of smartphone-assisted AR videos and simulations has been shown to elicit overwhelmingly positive student responses, as the technology facilitates a more autonomous and explorative learning environment. Furthermore, E. Efendi & Asrizal (2025) argues that AR creates an interactive pedagogical atmosphere that encourages students to become active participants, thereby fostering the digital literacy skills essential for modern technical professionals. This immersive approach provides students with a profound understanding of structural building images, a task that is notoriously difficult to achieve through traditional 2D media alone (Mukhtar et al., 2023). Additionally, AR serves as a highly effective instructional aid by providing detailed digital miniatures of construction elements (Ghofar et al., 2025), which significantly minimizes misunderstandings regarding complex structural logic (Akhsan et al., 2023). These digital representations allow for personalized learning experiences where abstract technical concepts are transformed into meaningful and concrete knowledge (Muskhir et al., 2024).

Despite the clear advantages of immersive technology, the development of Augmented Reality (AR) learning media specifically focused on roof construction elements within the newest vocational curriculum framework remains limited. While earlier studies have initiated AR exploration for construction courses in higher education (G. N. I. P. Pratama et al., 2022), there is a critical research gap regarding the development of specific, interactive 3D media for Grade X students in vocational high schools. Existing school resources generally rely on static visuals and lack immersive tools that are easily accessible for independent learning via smartphones (Adji et al., 2023). The novelty of this study lies in the development and empirical effectiveness testing of a contextualized AR learning media specifically tailored for "Roof Construction Elements" in vocational education. By integrating the ADDIE model, this research provides a

technical solution to the visualization barriers faced by vocational students, transforming abstract structural concepts into concrete digital miniatures. Therefore, this study aims to develop and test the effectiveness of AR-based learning media for roof construction that is valid, practical, and effective. The developed media is expected to enhance students' conceptual understanding and provide a scalable solution to improve vocational education quality, thereby supporting the achievement of SDG 4: Quality Education.

Method

This study employed a Research and Development (R&D) approach using the ADDIE development model, which encompasses the stages of analysis, design, development, implementation, and evaluation (Apriliano et al., 2023). The ADDIE model was selected because it provides a systematic and comprehensive framework for the development and validation of educational products (Hamid et al., 2025). In this research, the model was implemented through two evaluation approaches: formative evaluation, which was conducted at each stage to allow for continuous product refinement, and summative evaluation, performed after the implementation phase to measure the overall effectiveness of the Augmented Reality (AR) media. The specific stages and modifications applied in developing the AR learning media are systematically detailed in Figure 1, which illustrates the operational steps taken within each ADDIE phase to ensure media quality and effectiveness.



Figure 1. ADDIE Development Flowchart for AR Learning Media

The research was conducted at SMK Negeri 5 Padang. As depicted in Figure 1, the research stages are further elaborated as follows, Analysis: This phase involved needs analysis, student characteristic analysis, and material analysis. Data were gathered through classroom observations and interviews with vocational teachers at the research site to identify specific visualization barriers; Design: This stage focused on formulating learning objectives, designing storyboards, and developing research instruments, including validation sheets and practicality questionnaires using a five-point Likert scale; Development: The media was realized into an Android-based application and validated by an expert panel consisting of three validators (two university lecturers and one senior vocational teacher). Formative revisions were performed based on their feedback regarding content accuracy and technical functionality; Implementation: The finalized media was deployed at the research site involving two groups: an experimental class ($n = 32$) from the Building Modeling and Information Design program and a control class ($n = 12$) from the Construction and Housing Engineering program. Practicality was assessed by three subject teachers and the students during this phase; and Evaluation: Evaluation was conducted through a dual approach: formative evaluation performed during each preceding stage for continuous refinement, and summative evaluation conducted using pre-test and post-test instruments to measure the final effectiveness of the media.

To ensure the statistical validity of the findings despite the significant difference in sample sizes ($n = 32$ vs. $n = 12$), the selection of the control group was based on the total available population within the specific Construction and Housing Engineering program at the research site. To mitigate the risks associated with a small control sample, Levene’s Test for Homogeneity of Variance and Shapiro-Wilk normality tests were strictly performed prior to the hypothesis testing. These procedures confirmed that the data met the required parametric assumptions for an independent two-sample t -test. In cases where the data did not meet normality, a non-parametric Mann-Whitney U test was prepared as a robust alternative with decision criteria based on probability if the *Asymp. Sig.* (2-tailed) < 0.05 , then the null hypothesis (H_0) is rejected, and vice versa (Mukhtar et al., 2023).

Validation and practicality data were analyzed through descriptive quantitative techniques to determine the media’s feasibility and usability categories. Meanwhile, the overall effectiveness of the Augmented Reality media was measured by comparing post-test scores and N -gain scores through an

independent t -test. This analysis determined the magnitude of improvement in students conceptual understanding between the experimental and control groups. The effectiveness of the AR learning media was tested using the following statistical hypotheses: H_0 : There is no significant difference in the average learning outcomes (post-test and N -gain) between students using AR learning media and those receiving conventional instruction. H_a : There is a significant difference in the average learning outcomes (post-test and N -gain) between students using AR learning media and those receiving conventional instruction.

The interpretation categories for validity, practicality, and N -gain scores are systematically presented in Table 1, Table 2, and Table 3.

Table 1. Validity score interpretation categories (likert scale 1-5)

Interval mean score	Category
1.00 - 2.49	Not feasible
2.50 - 3.32	Less feasible
3.33 - 4.16	Feasible
4.17 - 5.00	Very feasible

Table 2. Practicality level interpretation categories

Achievement level (%)	Category
81.00 - 100.00	Very practical
61.00 - 80.00	Practical
41.00 - 60.00	Quite practical
21.00 - 40.00	Less practical
0.00 - 20.00	Not practical

Table 3. N -gain score interpretation categories

Interval score	Category
$g > 0.70$	High
$0.30 \leq g \leq 0.70$	Moderate
$g < 0.30$	Low

Result and Discussion

Results

The first stage of the ADDIE-model is the analysis-phase, which produced empirical data to define the functional requirements of the media. The needs-assessment at the research-site conducted through teacher-interviews and a review of previous learning outcomes identified that roof-structural components and complex structural-interrelationships are the most abstract materials, consistently posing significant visualization-barriers for students. These findings establish that the required solution is not merely conventional digital media, but an Android-based interactive three-dimensional tool specifically designed

to bridge the spatial-visualization gap in structural engineering.

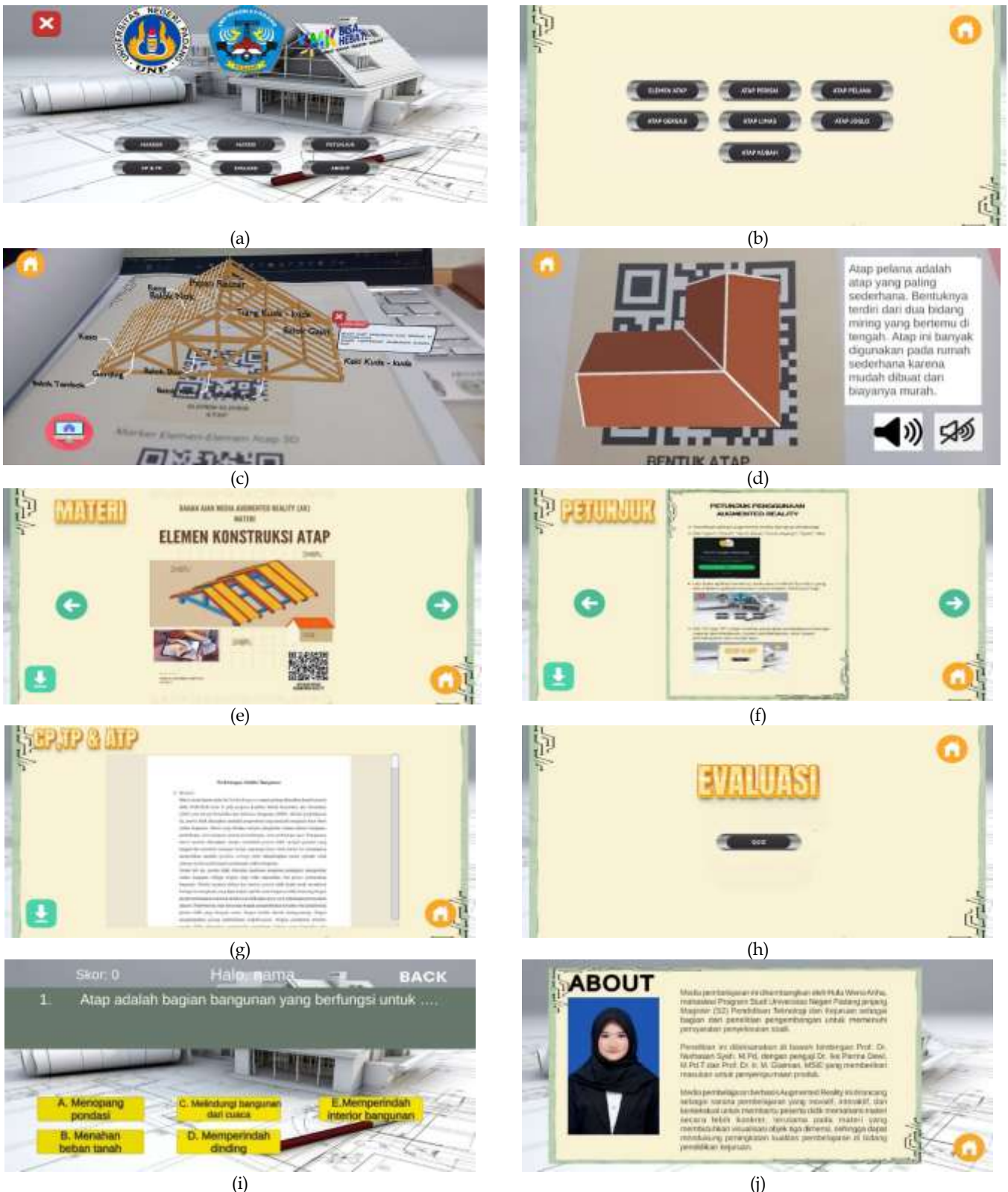


Figure 3. Marker Page: (a) Main menu page; (b) Object Selection Menu; (c) Roof Element Detail Visualization; (d) 3D Roof Shape Visualization; (e) Material page; (f) Instructions page; (g) Curriculum information (CP & TP) page; (h) Quiz main menu; (i) Question item; and (j) About page

In the design stage, the empirical findings from the analysis phase were translated into a technical blueprint. This phase involved formulating learning objectives and compiling instructional materials in alignment with the Fundamentals of Construction and Housing Engineering elements within the Kurikulum Merdeka framework. The primary focus of this stage was the creation of a storyboard and interactive flowchart that mapped out the user journey. The design prioritized spatial transition, ensuring that students could easily navigate between the 2D technical drawings on the marker and the 3D visualizations in the application. This blueprint covered several functional modules: the Main Menu, Marker Page, Material Page, Instructions, Curriculum Information (CP & TP), Evaluation and an About page.

The development phase focused on the technical realization of the design into a functional Android-based application. High precision 3D assets of roof structural components were modeled using SketchUp and Blender 3D to ensure geometric accuracy, while the Augmented Reality tracking and interactivity were managed through the Unity 3D engine. The finalized product specifically visualizes various wooden roof construction elements, covering structural components and diverse forms such as gable, pyramid, tent, joglo, dome, and saw roofs. The interface of the developed AR learning media, which integrates various functional modules from the main menu to the about page, is presented in the Figure 2.

Following the technical completion of all functional modules, the AR learning media prototype underwent a comprehensive validation process as part of the formative evaluation phase. This stage was crucial to ensure that the media was pedagogically and technically feasible for classroom use. The validation was conducted by an expert panel consisting of three specialists (two university lecturers and one senior vocational teacher). The results of the expert validation are presented in Table 4.

Table 4. Expert validation results

Validation aspect	Average score	Category
Media design	4.71	Very feasible
Subject matter	4.63	Very feasible
Overall average	4.67	Very feasible

Based on the data in Table 4, the developed augmented reality learning media achieved an overall average score of 4.67. This result indicates that the media is in the Very feasible category, meaning it is scientifically accurate and technically sound for instructional use in roof construction elements. The media expert provided a high score of 4.71, highlighting the intuitive navigation and the high quality of the 3D

asset rendering. Meanwhile, the subject matter experts gave a score of 4.63, particularly praising the accuracy of the wooden roof structural miniatures. Following the validation, minor revisions were made based on qualitative feedback, such as improving the 3D model textures and ensuring the clarity of labels for each roof structural element to enhance visual representation.

Once the media was declared feasible by the expert panel, the research proceeded to the implementation phase to assess its practicality. Practicality testing was conducted to evaluate the usability and pedagogical effectiveness of the AR application from the perspective of both teachers and students. This assessment involved three subject teachers and 32 students from the experimental group. The results of the practicality assessment are presented in Table 5.

Table 5. Practicality level assessment categories

Respondent group	<i>n</i>	Achievement level (%)	Category
Subject teachers	2	95.76	Very practical
Students	32	93.00	Very practical
Overall average	34	94.38	Very practical

Based on Table 5, the AR learning media achieved an overall average practicality score of 94.38%, placing it in the 'Very practical' category. The subject teachers gave an exceptionally high score of 95.76% because the 3D visualizations significantly facilitated the explanation of roof structural elements across various forms, such as gable, pyramid, and joglo roofs. Similarly, student responses reached 93.00%, indicating that the interactive interface was intuitive and easy to navigate. These results confirm that the developed media is not only feasible in theory but also highly usable in a real classroom environment.

The final stage of the evaluation was the effectiveness test, which aimed to measure the impact of the AR learning media on student learning outcomes. Effectiveness was determined by comparing the post-test and *N*-gain scores between the experimental class, which utilized the AR media, and the control class, which received conventional instruction. The assessment was conducted using a validated instrument consisting of 20 objective questions that had undergone prior item analysis. The descriptive statistics of the average learning outcomes for both groups are summarized in Table 6.

Table 6. Comparison of learning outcomes between experimental and control classes

Class	<i>n</i>	Mean	SD
Experimental	32	84.22	9.93
Control	12	76.25	12.08

Table 6 shows that the experimental class achieved a higher mean score of 84.22 compared to the control class which obtained a score of 76.25. The standard deviation in the experimental group reached 9.93 while the control group showed a wider distribution at 12.08. This difference suggests that the use of AR learning media provided a significant pedagogical advantage. The superior performance in the experimental class occurred because augmented reality allowed students to interactively visualize complex roof structural elements that are typically abstract in static technical drawings.

To determine whether this observed difference was statistically significant, an independent two sample *t*-test was performed. Prior to the hypothesis testing, prerequisite analyses for normality and homogeneity were conducted. The normality of the data was evaluated using the Shapiro-Wilk test, applying the criteria that the data is normally distributed if the *Sig.* value is > 0.05; conversely, if the *Sig.* value is < 0.05, the data is not normally distributed. The results of the normality analysis are presented in Table 7.

Table 7. Normality test results for learning outcomes

Data group	Statistic	Sig.	Description
Post-test experimental	0.95	0.10	Normal
Post-test control	0.97	0.95	Normal

Based on the results in Table 7, all data groups achieved a significance value (*Sig.*) greater than 0.05. This confirms that the learning outcome data for both the experimental and control groups are normally distributed. Following the normality test, the homogeneity of variance was evaluated using Levene’s test, as presented in Table 8.

Table 8. Homogeneity of variance test results

Variable	Levene statistic	df1	df2	Sig.	Description
Learning outcomes	0.13	1	42	0.40	Homogeneous

The homogeneity test in Table 8 resulted in a significance value of 0.40 ($p > 0.05$), indicating that the data variances between the experimental and control classes are equal. Despite the difference in sample sizes ($n = 32$ vs. $n = 12$), these results confirm that the data satisfies the requirements for a parametric analysis. The disparity in group size was determined by the actual population available at the research site, the experimental and control classes represented the entire accessible student body, thus utilizing a total sampling approach within the school’s existing structure. Accordingly, an independent sample *t*-test was performed to determine the significance of the difference

in learning outcomes between the two groups, with the results summarized in Table 9.

Table 9. Independent sample *t*-test results

Data group	<i>t</i>	df	Sig. (2-tailed)
Post-test scores	2.24	42	0.03

Based on the results in Table 9, the *t*-test produced a significance value (*Sig.*(2-tailed)) of 0.03, which is less than 0.05. This result indicates that the null hypothesis (H_0) is rejected and the alternative hypothesis (H_a) is accepted. This confirms that there is a significant difference in learning outcomes between students who utilized the AR learning media and those who received conventional instruction. The *df* value of 42 correctly represents the total sample size ($N = 44$), and the significant *p*-value demonstrates that the developed media effectively enhanced students’ conceptual mastery of roof construction.

To measure the magnitude of competency improvement, an *N*-gain analysis was performed. This analysis determines the growth in student understanding from pre-test to post-test. The descriptive results of the *N*-gain scores, categorized based on the criteria in Table 3, are presented in Table 10.

Table 10. Descriptive results of *N*-gain scores

Class	<i>n</i>	Mean	SD	Category
Experimental	32	0.66	0.16	Moderate
Control	12	0.51	0.12	Moderate

Based on the data presented in Table 10, the experimental class achieved a mean *N*-gain score of 0.66, while the control class obtained a mean of 0.51. According to the interpretation criteria in Table 3, both groups fall into the moderate category. However, the experimental group’s score is notably higher and approaches the high-effectiveness threshold (0.70). This substantial increase indicates that the AR media has a stronger impact on students’ competency growth by providing interactive 3D visualizations, which allow students to develop better spatial reasoning and a clearer understanding of roof structural elements compared to static 2D materials.

To determine the appropriate statistical test for comparing these gain scores, a normality check was performed using the Shapiro-Wilk test. The results of this analysis are summarized in Table 11.

Table 11. Normality test results for *N*-gain score

Class	Statistic	df	Sig.	Category
<i>N</i> -gain experimental	0.96	32	0.31	Normal
<i>N</i> -gain control	0.80	12	0.01	Not Normal

As illustrated in Table 11, the normality test yielded different results for the two groups. The experimental

group's *N*-gain score followed a normal distribution with a significance value of 0.31 ($p > 0.05$). However, the control group's *N*-gain score achieved a significance value of 0.01, which is below the 0.05 threshold, indicating that the data is not normally distributed.

This non normality in the control group is likely attributed to the smaller sample size and the higher variance in students' initial competency growth. According to statistical conventions, when the normality assumption is violated in at least one group, a parametric *t*-test is no longer appropriate. Therefore, the hypothesis testing was conducted using the Mann-Whitney U test, a non-parametric method that provides a more robust and accurate comparison for non-normal data and unequal sample sizes. The results of this analysis are summarized in Table 12.

Table 12. Mann-Whitney U test results for *N*-gain scores

Statistical parameter	Value
Mann-Whitney U	85.50
Z	-2.81
Asymp. Sig. (2-tailed)	0.01

The statistical analysis in Table 12 confirms a significant disparity in competency growth between the two groups. The Mann-Whitney U test yielded a Z-score of 2.81 and an Asymp. Sig. (2-tailed) of 0.01, which is below the 0.05 significance threshold. This finding indicates that the null hypothesis (H_0) is rejected, proving that the experimental group achieved a more profound *N*-gain compared to the control group.

This improvement stems from the application's interactive features, which facilitate detailed roof component inspection from multiple perspectives. By transforming static 2D references into manipulatable 3D models, the media successfully bridged the spatial visualization gap, leading to superior conceptual retention of complex construction elements. These results validate the application as a highly effective instructional tool for the Fundamentals of Construction and Housing Engineering subject.

Discussion

Based on the overall results, the developed augmented reality learning media has achieved a high validity score of 4.71 for media design and 4.63 for subject matter through the systematic application of the ADDIE development model. These findings indicate that the roof construction material is accurately aligned with the Learning Outcomes and Learning Objectives of the Independent Learning Curriculum at SMK Negeri 5 Padang, successfully conveying complex structural logic that traditional resources often fail to provide. The media is superior as its 3D visualization enables students to scrutinize specific parts, functions, and roof

shapes typically abstract in static 2D references (A. J. Pratama et al., 2023). Interactive rotation and zoom features allow visual verification of complex details, facilitating active-exploration in the Fundamentals of Construction and Housing Engineering subject (Indahsari & Sumirat, 2023; Hafis et al., 2025). This bridges the gap between classroom-theory and real-world conditions, consistent with findings that user-friendly, augmented-reality-based tools make abstract concepts concrete (Qorimah et al., 2022; Wibowo et al., 2022). Ultimately, the responsive tracking system and integrated materials enhance students spatial abilities and conceptual understanding (Trikotama et al., 2024).

In addition, the augmented reality learning media is practical for teachers and students, evidenced by scores of 95.76% and 93.00%, respectively, which fall into the Very-Practical category. This high practicality is directly linked to the integration of Learning Outcomes and Learning Objectives with interactive 3D visualizations of parts, functions, various roof forms. The teacher score reflects the efficiency of marker scanning and self evaluation tools within a single application, which minimizes the instructional burden and ensures high usability for seamless navigation (Al Hanif & Santosa, 2022). The media is superior because students can rotate and zoom into 3D miniatures to observe technical details, such as gording and rafters, which are impossible to scrutinize in static 2D drawings (Tuwoso et al., 2021; Hamid et al., 2025). Such results align with Harta et al. (2021), who emphasize that augmented reality-based media provides high usability and ease of use in vocational environments. Consequently, this mobile based technology supports the concept of learning anytime and anywhere without physical classroom limitations (Trikotama et al., 2024). Furthermore, this immersive approach fosters active engagement and provides a meaningful student-centered learning experience (Oksila et al., 2025; Sugihartini & Swisnandy, 2025).

The results of this study confirm the effectiveness of the developed augmented reality media in improving student learning outcomes for roof construction elements. Statistical analysis reveals a significant disparity where the experimental group achieved a higher mean post-test score of 84.22 compared to the control group at 76.25. The independent sample *t*-test produced a significance value of 0.03 which is below the 0.05 threshold confirming that the media has a substantial impact on learning achievement. Specifically, the increase in scores occurred because augmented reality allowed students to scrutinize the detailed structure and function of wooden roof truss components including purlins rafters and battens which are traditionally obscured in static 2D drawings. By

providing interactive 3D simulations that can be explored in a real-life digital context the media bridged the spatial visualization gap identified in the analysis phase. This finding is supported by Hafis et al. (2025) and Zebua et al. (2025), who emphasize that interactive-visualizations and multi dimensional media are essential to overcome learning difficulties in mastering complex building structural elements that often appear abstract to vocational students.

To further measure the magnitude of competency growth as suggested by the reviewer an *N*-gain analysis was performed. The results show that the experimental group achieved a mean *N*-gain of 0.66 while the control group reached 0.51. Because the data distribution was not normal the non parametric Mann Whitney U test was employed resulting in a significance value of 0.01. This significant difference in gain scores proves that augmented reality provides a more profound growth in student understanding compared to conventional instruction. As argued by Hamid et al. (2025) and Trikotama et al. (2024) the superiority of augmented reality lies in its ability to facilitate independent exploration and real time interaction with virtual objects. By rotating and zooming into roof miniatures students are not merely passive recipients of information but active constructors of knowledge. Furthermore, Sugihartini & Swisnandy (2025) emphasize that such immersive technology leads to better long term memory retention. Accordingly, the high validity practicality and effectiveness scores obtained in this study validate the augmented reality application as a robust instructional tool for the Fundamentals of Construction and Housing Engineering subject.

Previous research confirms that augmented reality media is both a valid and effective tool for improving academic achievement, while also meeting rigorous practicality standards in vocational environments (Ismaeel & Al Mulhim, 2021; Sugihartini & Swisnandy, 2025). As a disruptive innovation in the Education 4.0 era, this technology is highly suitable for technical subjects (Putra et al., 2021). This study echoes such empirical evidence, demonstrating that its implementation drives learning outcomes by transforming abstract concepts into realistic 3D visualizations (Alawyah et al., 2024). The media proves superior to conventional resources because it enables students to visualize precise structural-specifications in both 2D and 3D views, a critical requirement for industrial-readiness (Dewi et al., 2024; Hidayah et al., 2025). While other studies often focus on general machinery, this research is distinct in its emphasis on the intricate complexity of roof-construction elements for tenth-grade students. This targeted focus facilitates the

mastery of structural configurations by allowing students to explore details from various angles, thereby providing a more in-depth learning experience (Oktavia & Irfan, 2024; Ridho & Setyasto, 2024). Furthermore, the user-friendly, Android based application accommodates independent learning anytime and anywhere (Abdilah & Wulandari, 2024; Hafis et al., 2025). The study further implies that utilizing digital technology as a cognitive mediator helps teachers prepare innovative instruction (Sugihartini & Swisnandy, 2025), and strengthens students' technical competencies through student-centered exploration (Al Hanif & Santosa, 2022; Oksila et al., 2025). Ultimately, this Industry 4.0 based tool allows students to engage with realistic material while honing the technological literacy necessary for the challenges of Society 5.0 (Tuwoso et al., 2021; Trikotama et al., 2024).

Conclusion

The development of augmented reality learning media for roof construction elements has produced an instructional tool that meets the highest standards of quality. The research findings confirm that the media is very feasible, evidenced by a subject matter expert score of 4.63 and a media expert score of 4.71. Practicality assessments also reached the very practical category, with scores of 95.76 percent from teachers and 93.00 percent from students. Furthermore, the media is proven effective in improving student learning outcomes specifically for roof construction material, where the experimental group achieved a mean post-test score of 84.22 compared to the control group at 76.25. The independent sample *t*-test resulted in a significance value of 0.03, while the *N*-gain analysis reached 0.66 in the moderate category, proving that interactive 3D visualizations significantly enhance students conceptual mastery. Based on these results, students are encouraged to utilize this media to gain a deeper understanding of complex roof structural elements. Teachers are advised to implement this media as an innovative instructional alternative for the Fundamentals of Construction and Housing Engineering subject. While this study confirms the media effectiveness for roof construction elements, future researchers are advised to conduct trials on a more balanced sample size to address the statistical stability between experimental and control groups. Additionally, subsequent research should consider using a different design, such as large-scale group testing, to evaluate the long-term impact of augmented reality on other building construction materials.

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Author Contributions

Conceptualization and design of research work, data analysis and interpretation, H.W.A.; Implementation of field/laboratory experiments and data collection, H.W.A., N.S., and G.; Manuscript preparation, H.W.A., I.P.D., and N.S.

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Conflicts of Interest

The authors declare no conflict of interest.

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