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Augmented Reality Application for Reducing Reconstruction Costs, Preventing Loss of Working Days and Improving Design Quality

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Abstract

The development of digital technologies in the construction sector, alongside the healthcare, industrial, and automotive sectors where technology has a wide range of applications, has created a significant transformation in building production processes and has enabled the widespread use of Building Information Modeling (BIM) and Augmented Reality (AR) applications in particular. In this study, a two-storey villa with an area of 300 m^2 was designed to demonstrate the application of technology adaptation in the construction sector. This designed project was adapted using an AR application as a result of Revit → 3ds Max → Unity → tablet APK, and new designs meeting the needs and expectations of three different customers were created. Subsequently, the resulting cost, time and quality items were evaluated. Taking the average of the three studies, the reconstruction cost is approximately 14% (16,237 USD) of the initial construction cost, and the average additional working days are approximately 18% (42 working days) of the total working days. This study, which aimed to eliminate or minimize reconstruction costs, working days and quality loss, sought to emphasize the importance of design quality, cost and working day loss based on the results obtained.

Keywords: augmented reality; cost; time; quality

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1. Introduction

Change and development have always been fundamental aspects of human history, and they are also the main drivers of progress in engineering and technology. In the 21st century, which is experiencing the fastest technological advances, many scientific fields are working to maximize the benefits of technology. While the medical sector leads the way, many other industries, such as construction, trade, communication, automotive, education, and defense, are also greatly benefiting from technological progress. The ability to make discoveries has grown so much that multiple innovations are occurring simultaneously across different fields, pushing technological progress into a new frontier.

Alongside globalization, advancements in science and technology have been fundamental factors in determining the necessary human resource profile for today's societies. Societies need people who are constantly developing themselves and who can learn throughout their lives [1].

When observing all the changes occurring in the fields of technology and science, the main goal for countries is to gain superiority over others and maximize their benefits. Countries with advancements in technology and science tend to focus on developments in areas such as industry and the economy, compared to other nations. Technology has a significant impact on competition between countries. As technology progresses and new applications emerge, nations that gain a significant advantage in terms of time and cost become economically stronger and remain among the few with influence in global governance.

Among the most critical factors contributing to the success of developed countries are their ability to maximize the benefits of technological development and change, as well as their quick adaptation and implementation. Processing, evaluating, and communicating the information obtained, as well as developing it for future work, are key to the success of these countries. Information technologies rely on a technological infrastructure, making it crucial that this infrastructure functions accurately and robustly. Otherwise, more complex problems will arise in the future. In line with developments in the technological field, applications such as digitalization, virtual reality, augmented reality, mixed reality, and extended reality have gained significant prominence in many sectors and are used effectively across various fields.

When evaluating the construction sector, the industry does not fully utilize technology, and the benefits gained from technology are limited compared to other sectors. The automotive, furniture, healthcare, and defense industries have rapidly adapted to technology, identified shortcomings over the years, and closely followed new technological developments, enabling them to make sector-specific advances. Some sectors have transitioned to artificial intelligence from existing technologies and have begun to integrate their developments with this technology.

With increased adoption of technology in the construction sector, achieving targets related to time, cost, and quality will become easier. As technology continues to be integrated, further advancements are expected in the industry. Since revisions made during the design phase occur early on, technology will play an active role throughout the entire process, from minimizing delays in licensing to addressing issues that affect quality, such as demolition and reconstruction, and reducing associated time and financial losses. Additionally, it will help ensure compliance with project specifications during the control phase, quickly identify and correct errors, and minimize both time and financial losses by using these technological tools not only during construction and implementation but also in the marketing phase. For example, customers can be easily reached from abroad for a complete residential building, and inquiries from customers can be minimized through these applications, allowing sales to close more quickly. The marketing approach will also facilitate customer decision-making, broadening the market share beyond just domestic buyers or foreign visitors, thereby enabling targets to be achieved more quickly. In public construction projects, remote inspections and controls can be conducted, enabling early intervention in issues and preventing payment delays.

Künüçen & Samur [2] noted in their study that digital development is accelerating day by day, and that the importance of digital reality has grown in tandem with digitalization. Digital reality environments are defined as the presentation of a visual experience to the user through a three-dimensional display screen, using copies of the artificial visuals of objects and spaces that exist or are designed.

Orhan & Karaman [3] state in their study that, with the development of information and communication technology, the boundaries of three-dimensional VR environments are increasingly expanding, and as a result, the lines between real and virtual concepts are gradually blurring and intersecting.

Virtual reality is at the forefront of environments created in the virtual world, and augmented reality is a technological application that builds upon virtual reality. Other reality applications have been developed after augmented reality.

Virtual reality (VR) is a computer simulation that enables users to interact in a three-dimensional environment that closely resembles reality through a specialized digital system equipped with sensors [4].

As shown in Figure 1, AR is defined as part of the mixed reality spectrum, which encompasses both real and virtual reality. Reality is added to virtual objects, and virtual environments, as well as augmented virtual environments, replace the physical environment with virtual objects. Augmented reality is a technology that enriches the real world by integrating digital objects into the physical environment. This enables virtual objects to be perceived as part of the physical environment [5].

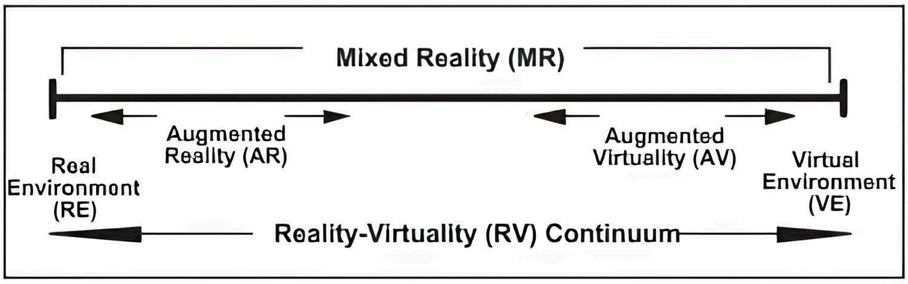


Figure 1. Milgram and Kishino's Reality–Virtuality Process/Plane.

If we were to define augmented reality, it would be the live or physical appearance that emerges when computer-generated sound, graphics, images, and GPS data enrich the environment and components within the real world.

The concept of AR was first introduced in 1992 by Thomas Preston Caudell, who conducted research at Boeing to develop applications for industrial use, specifically for visualizing specific assembly designs. AR is defined as a technology that enables real-time interaction between virtual objects and the real environment by integrating virtual objects into the real environment [6]. Initially developed for military pilots, AR technology is now utilized in various fields, including human and educational sciences, natural disaster and nuclear accident prevention, art, advertising and marketing, entertainment, health, and museology, as well as GPS and geotagging, engineering, and military and security applications [7].

Erbaş & Demirer [8], stated in their study that the widespread use of AR technology today is in wearable technologies, and in this direction, wearable technologies produced as jewelry as well as glasses, headgear, watches, helmets, t-shirts, and shoes have been developed, and some of them have been put into service. In addition to these, AR technology can be viewed with devices such as phones and tablets.

Dr. Faruk Arıcı and Assoc. Prof. Dr. Bayram Arıcı's book [9], Examples of Augmented Reality Applications and Material Design in Education, states that augmented reality (AR) is classified in two different ways based on image and location. Image-based AR uses special markers to overlay three-dimensional objects onto real-world images. This system mainly needs a camera and a marker label. When the camera detects the marker, the AR creates a three-dimensional virtual object that appears on the image. As the user moves the marker, the object also seems to move in the real environment. Location-based AR, on the other hand, relies on technologies such as GPS or wireless networks to determine the device's location and display information on the screen, unlike image-based systems.

AR and VR technology is applied across a wide range of fields, including medicine, the defense industry, automotive, tourism, cultural sectors such as museums, all types of education, marketing, retail food and beverages, transportation such as road, air, and sea, planning, management, entertainment sectors like gaming and cinema, and architecture and construction at every stage from device assembly to repair. Recently, AR has also been used in creating authenticity, restoration, and renovation projects for historical and cultural heritage structures, aiming to maximize conformity to the original design. Examining published articles, studies, papers, and conferences related to AR technology reveals that this technology is widely utilized across various sectors.

Demirezen [10], in a literature review on its applicability in the tourism sector, emphasized that every business in the tourism sector, such as museums, should adopt AR and VR technologies. The study noted that experienced individuals can be trained in the industry through tourism education, which can be effectively demonstrated in a virtual environment, resulting in efficient learning.

Aytekin et al. [11] found, in their study on the role of augmented reality technology in marketing, that AR technology is a striking, creative, and engaging marketing strategy, making it more appealing to companies. They also note that it will be used across all sectors where smart devices are present in the future. Additionally, they mention that it provides users with the opportunity to experience the physical environment and offers potential customers the chance to try out products or services before making a purchase. They discuss how it affects users' senses of sight, hearing, and touch, among other benefits. Furthermore, they explain the advantages it will bring to the retail sector. Regarding the disadvantages of AR technology, it was highlighted that the resolution of smart devices, the variability of operating systems used by different brands, the difficulty of adapting to the technology, and the possibility that consumers may become bored with similar AR applications—requiring companies to continually develop new ones—are concerns. Based on this study, it is noteworthy that this method can be applied in the construction sector to market real estate during both the construction phase and after completion. For example, thanks to AR technology, real estate can be marketed in a way that appeals to the visual senses of potential customers, both domestic and international.

In a literature review on the use of AR technology in education, it was observed that technology has begun to be adopted in most sectors and is becoming increasingly widespread, as it enables students to learn and understand in an engaging and enjoyable way. Çetinkaya & Akçay [12] state in their study that AR applications are increasingly common in education, with purposes including completing the curriculum, providing guidance, supporting promotion, as well as offering games, educational trips, and exercises. In the construction sector, studies have been conducted on how to reinforce electrical outlet installations using the AR + BIM system [13], how to support prototype applications for assembly tasks performed by steel workers [14], the use of VR and AR approaches in construction management education [15], the application of AR for education students [16], and understanding construction assemblies [17]. Models created by students were viewed in augmented reality (AR) using a mobile device (phone or tablet), and it was noted that this could help future generations understand the construction process by allowing them to examine and visualize construction details [18] interactively.

Among the areas where AR technology is effectively used are architecture and the construction industry. With AR applications, it is possible to visualize 3D models on 2D architectural plans, and the exterior and interior of the building to be constructed can be viewed [19]. Studies and developments in the use of AR applications in the construction industry have been increasing recently, and the growing adoption of this technology in the sector is making significant contributions. It will offer advantages in the future as it advances. For a new study to reach higher levels, it needs to be developed, implemented, and used across different aspects. For example, AR applications can be utilized throughout the entire project lifecycle, from initial stages through construction, control, completion, marketing, and beyond, providing significant benefits in the years to come, including renovation, maintenance, and repair. Additionally, this technology can also be applied in work safety, operational stages, and employee training.

The role of AR technology in construction and architecture has been summarized in the literature under main headings, including scope, cost and financing, occupational safety, training, and site applications.

When examining the scope in industry and literature, as well as studies on construction application areas, Avşar [20] investigated the effects of Construction 4.0 components on digital real estate adoption by construction sector companies and the performance of companies using this application. Hajirasouli et al. [21] identified the thematic analysis and conceptual framework of AR application in design and construction. Schiavi et al. [22] conducted studies on examples of AR/VR technologies and BIM data flow in the architecture, engineering, and construction (AEC) sector. Oke & Arowoiya [23] emphasize the various application areas of augmented reality in the construction sector and their sources. Alaa [24] conducted studies on augmented and virtual reality and organized surveys among employees. The study's recommendation section states that these technological applications improve real-time project data, detect errors, enhance team collaboration, and improve construction safety standards. Albahbah et al. [25] conducted a comprehensive review of the application areas of AR and VR technologies in construction project management.

In studies on occupational safety, AR and VR were utilized to develop safety training for bridge construction. Potential hazards at construction sites were comprehensively investigated, and the technology was then employed to design the training scenario [26]. Research was conducted on hazard recognition in augmented reality and virtual environments in construction safety training and education [27]. Rahman et al. [28] conducted a study examining emerging technologies that aim to reduce ergonomic hazards in construction sites. As a result of the study, they identified current research trends in applying new technologies to occupational safety and health in the construction industry. Also, they suggested future research directions in this dynamic field. Kanangkaew et al. [29] developed a real-time fire evacuation system based on building information modeling and AR integration, while Chen & Xue [30] conducted studies on BIM-based augmented reality inspection and maintenance of fire safety equipment.

In a study on occupational safety, the aim is to train a newly hired heavy construction equipment operator using the developed ARTS augmented reality model, where the operator is trained in a virtual environment with real heavy construction equipment and a real construction site [31]. As new applications are developed, workers can be trained with real visuals, deficiencies and problematic situations can be identified, and potential adverse outcomes can be minimized.

Using AR technology in construction projects, users can access the information they need instantly on the construction site through a system set up with smart glasses, thereby avoiding unnecessary time and money spent on identifying faulty manufacturing or figuring out how to produce in accordance with the project. The developed system has been tested on brick-made walls, and it is expected to improve quality and significantly benefit the sector [32].

In a different study, immersive, multi-user AR effects were examined to support construction plan review meetings using 4D construction models. In this context, the study compares traditional screen-based 4D model reviews with AR-enabled head-mounted displays. Among the results, it was noted that AR can effectively support collaborative reviews of 4D construction plans and make a significant contribution to the field of construction planning. Additionally, participants generally preferred 4DMAR for collaborative activities. It was noted that AR could be a suitable environment for sharing resources in a collaborative setting [33].

AR technology has been used at various stages of construction on the site. Wu et al. [34] used it for iron binding, Li et al. [35] applied it to the urban gas pipeline network, Revolti et al. [36] utilized it in installing a regional heating system, Hidayat et al. [37] used it for road surface visualization, and Um et al. [38] employed it in pipe maintenance. Liu & Bai [39] used it for modeling, visualizing, and reinforcing post-earthquake conditions, Hasan et al. [40] created a visual representation of construction machinery, Fenais et al. [41] visualized underground infrastructure construction, Bloomquist et al. [42] installed wooden frame walls, Mitterberger et al. [43] managed the on-site installation of complex bricks, Ahn et al. [44] worked on construction panel production facilities, and Tzimas et al. [45] focused on machine tool installation.

In another study, a research tool called ACIPM was developed, incorporating core tools and techniques such as Review, Laser Scanning (LS), Unmanned Aerial Systems (UAS), Robots, Radio Frequency Identification (RFID), Augmented Reality (AR), Virtual Reality (VR), Computer Vision (CV), Deep Learning, and Building Information Modeling (BIM). Studies on progress tracking, quality control, facade inspection, scaffolding inspection, energy assessment, and usage permits in the construction field have been conducted, and the positive and limiting factors of future applications have been conveyed [46].

In a study, articles and theses related to AR were reviewed, and it was concluded that digital applications should be developed to reduce project costs, save time, and enhance safety and quality in construction work and for workers [21].

Most studies in construction and architecture show that technological advancements naturally integrate into this broad field. Developing technology specifically for this sector, expanding application areas, and quickly updating software will enhance efficiency in terms of cost, time, and quality.

2. Materials and Methods

The complexity of the construction industry is increasing daily. The need to carry out specialized and sequential construction processes at the right time, with minimal costs and consistent quality, makes the situation more challenging and riskier. As in all sectors, technology and digitalization are playing crucial roles in the construction industry, helping to eliminate or reduce errors in achieving objectives. Building Information Modeling (BIM) has recently become a key solution adopted by industry players for construction projects, and as these tools are used, new advancements are emerging in the industry.

Building Information Modeling (BIM) is a design and management tool used at every stage, both before and after, of the building construction. Each phase of construction is digitized, and digital roadmaps are created for projects. By digitally analyzing every stage of construction and manufacturing, engineers and workers can thoroughly review details, helping to identify potential or current errors. Technological tools encompass computer software, VR applications, AR applications, mixed reality, digitization, digital twins, and other related technologies. While these tools can help construction sector players perform their work more efficiently, they are not yet used globally, and even in most countries where they are employed, their adoption remains limited.

AR technology plays a vital role in the construction industry due to its three-dimensional visuals and seamless integration into the real world. In recent years, the combination of BIM and AR technologies in construction has provided significant benefits, including enhanced site organization, improved communication among workers, improved coordination, streamlined manufacturing controls, and ensured precision in work safety measures and training. It has positively impacted cost, time, and quality by supporting project management processes. Additionally, it actively contributes to post-construction activities, simplifying complex issues such as marketing, maintenance planning, and building documentation.

This study focused on the AR application, utilizing it for visualization during the design phase before constructing a villa project. A project visualization was created, and any parts requiring revision or identification were redesigned and visualized again in the final version. Once the final version is approved, the project can advance to licensing and construction. Applying this approach to construction projects can help prevent changes during or after construction, avoiding issues such as increased costs, project delays, and the need for demolition or rebuilding. This study aims to show that this technology can be applied from the early stages of a construction project and that modifications affecting cost, time, and quality can be quickly and easily identified through visual perception.

Augmented Reality Application

At the beginning of the study, a literature review was conducted to identify areas where AR applications are utilized in construction and other sectors. In particular, the research expanded to define the scope of this technology's use in the construction industry and potential areas for development. The study examined the benefits of employing technology at the early stage of a construction project. Developments in technology were tested on a villa project and visualized in an AR environment. Possible modifications within the project's scope were identified through visualization, and revisions were made based on these findings. The visualizations were then repeated to achieve the result.

Within the scope of the study, all structural details, including columns, beams, floors, walls, stairs, doors, and windows, which were prepared as drafts and included in the preliminary architectural project, were transferred to the Revit program. Autodesk Revit is a Building Information Modeling (BIM) that operates through three-dimensional (3D) object-based models. This software enhances collaboration and information flow among all disciplines involved in various stages and tasks of the project, including architects, engineers, and contractors. Revit supports coordination among stakeholders by providing access to vital project information and reports through a central platform.

The 3DS Max programme is typically used for technical three-dimensional design, modeling, and animation. In this study, it was used to color the three-dimensional visualization obtained during the transition between programmes.

Unity offers powerful tools for creating rich, immersive augmented reality (AR) experiences that interact intelligently with the real world. With the Unity platform, you can develop games, design 3D levels, and program using the C# language. This platform was also used to enhance 3D visualization in the study.

For the AR visualization of the project, as shown in Figure 2, a literature review was first conducted. The 3D image of the project was created in Revit, and then the visual was colored in 3DS Max. A QR code was generated for the project visuals. A colored visualization was embedded into the QR code using Unity, and the visualization was converted into an APK file for tablets created through Unity. The exact process was then repeated for the modified parts where changes were detected, completing the project. This work helped determine the contributions of the differences between the initial and modified projects in terms of cost, time, and quality. Figure 3 lists the programs used for the work.

The study was conducted on a two-storey villa project covering 300 square meters. During the design phase, a three-dimensional visualization of the project was created, as shown in Figure 4. Since the output from Revit is transferred to the Unity program in black and white (Figure 5), the colored image in 3DS Max, transferred to Unity, is shown in Figure 6.

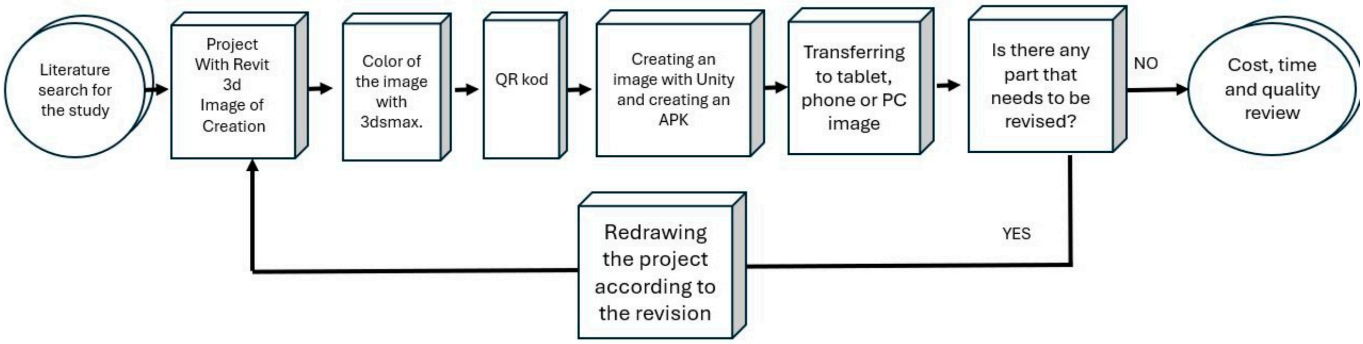


Figure 2. Flow chart of the study.

Figure 3. Programs used in the study.

Figure 4. Three-dimensional image created in Revit program.

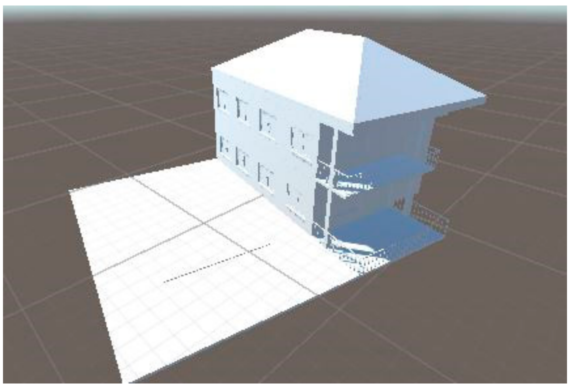


Figure 5. Image transferred from Revit program to Unity program.

The final image created in 3DS Max was imported into Unity using a barcode trigger, and an APK was generated. The final image was then reviewed on a tablet in both office and physical environments. The areas of the image that needed modification (such as the balcony, exterior door, balcony door, and interior staircase) were adjusted in the project, and the exact steps were repeated to prepare the three-dimensional image for display using AR technology. The final project was the result of these modifications. The images in Figure 7 are AR-generated images and represent the first project images produced. The images in Figure 8 are AR images created in response to revision requests from three different customers.

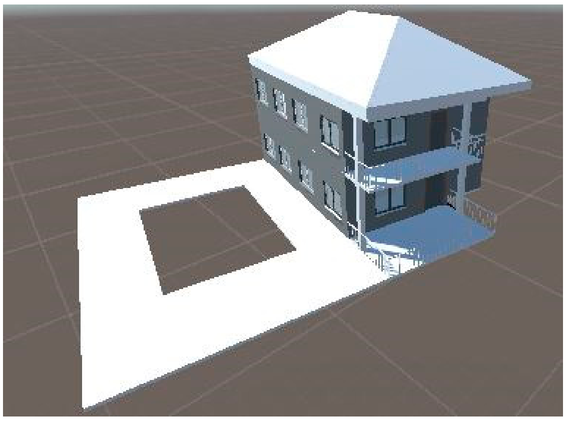


Figure 6. Image created in 3DSmax program and transferred to Unity program.

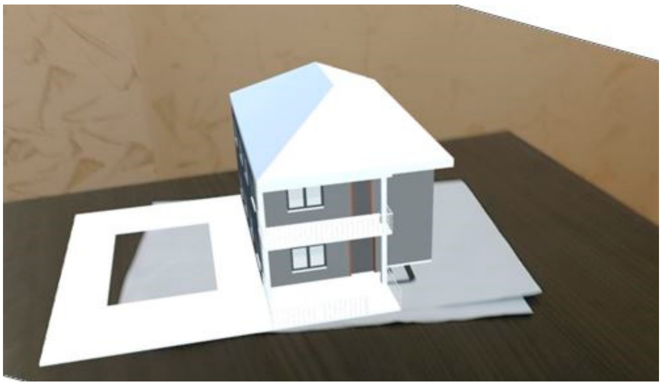
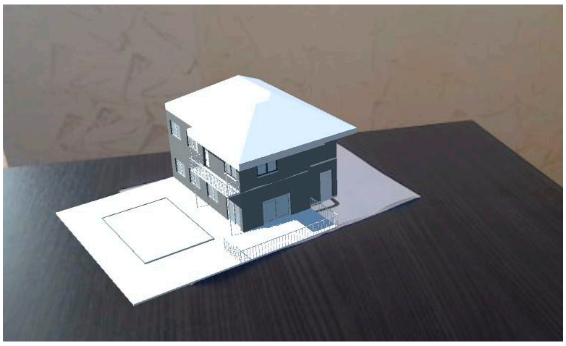


Figure 7. The first AR image obtained in the study.

The work was categorized based on requests from three different customers. Costs were calculated according to this categorization. Additionally, efforts were made to estimate the loss of working days due to the work. One of the key aspects of the study was to identify which stages directly impacted quality. In all three projects, items such as renovation projects and renovation permits—potentially causing significant cost and time losses—were affected. Customers were asked to evaluate their extensive requests and preferences regarding the positioning of windows, exterior doors, and garden terraces based on the views from the rooms, balconies, and facades included in the project. Revised projects were created accordingly. Furthermore, for the first customer, extensive reconstruction tasks were identified, including slab replacement, wall demolition, relocation, rough plastering, fine plastering, painting, door and window relocation, balcony relocation, removal and installation of railings, roof rework, and internal stairs and external doors. For the second customer, no changes were made to the internal staircase or external door; however, similar reconstruction activities to those in the first project were noted. In the third customer's project, the external door and internal staircase locations were altered, and there was a request to omit roof construction, leaving it as a terrace. Table 1 outlines the work to be performed. When assessing quality, the most important criterion considered was the items that would be affected by the demolition work to be carried out after construction was completed. As demolition and reconstruction would affect quality, changes to be made to slabs, walls, roofs, staircases, doors and window installations were identified as areas that would negatively impact quality.



(**a**)

(**b**)

(**c**)

Figure 8. AR images obtained in the study; (**a**) First According to customer requests; (**b**) Second According to customer requests; (**c**) Third According to customer requests.

Table 1. List of changes identified in the studies. ("+" Indicates the items that have made changes.)

	First Study	Second Study	Third Study
Projects	+	+	+
License	+	+	+
1st Floor + 2nd Floor Deck	+	+	
Internal Staircase	+		+
Wall	+	+	+
Roof	+	+	
Other (Exterior door, railing, window, etc.)	+	+	+

3. Results and Discussions

Since the work was performed during the project planning stage, revisions were made digitally only. As the project has not yet been licensed, there have been no legal issues, and no changes have been made to the building permit, architectural plan, structural plan, electrical plan, mechanical plan, etc. Additionally, activities such as demolition, casting, and reconstruction have been prevented at the construction site. Negative situations that could directly impact the project's timeline, cost, and quality have been avoided.

The potential cost loss if the reconstructions mentioned above were performed after the construction was completed is shown in Table 2. As shown in Table 1, for the project with a total initial construction cost of 113,819 USD, the expenses needed to bring items such as the permit, 1st and 2nd floor slabs, internal staircase, walls, roof, external doors, railings, and windows up to date with the renovation project have been identified. An additional cost of $20,000 in the first study, $17,583 in the second study, and $11,128 in the third study can be avoided. All calculations were made with the assistance of an architect and a civil engineer, and current cost values were based on the areas involved in the reconstruction.

Table 2. Cost table.

	Construction Cost (USD)	Rework Cost-1 (USD)	Rework Cost-2 (USD)	Rework Cost-3 (USD)
Projects	15,692	5405	5405	5405
License	270	270	270	270
1st Floor + 2nd Floor Deck	40,211	2703	2805	
Internal Staircase	8108	2703		2703
Wall	27,051	4054	4150	1500
Roof	6676	2703	2703	250
Other (Exterior door, railing, window, etc.)	15,811	2162	2250	1000
Total	113,819	20,000	17,583	11,128
		18%	15%	10%

Table 3 shows the workday losses resulting from reconstructions and highlights the factors that impact construction quality. The project, estimated to take 235 working days for the initial phase, is expected to lose 50 working days during the first reconstruction, 45 days during the second, and 32 days during the third, according to the requirements. Additionally, demolition and reconstruction work resulting from changes in locations, such as slabs, walls, roof renovations, internal stairs, doors, railings, windows, and other elements, may negatively affect the project's quality. Decisions made at the start of the project will also address these factors that directly influence quality.

Table 3. Time and quality loss table.

	Construction Time (Working Days)	Loss of Time-1 (Working Days)	Loss of Time-2 (Working Days)	Loss of Time-3 (Working Days)	Work That Negatively Affects Quality
Projects	50	10	10	10	
License	20	10	10	10	
1st Floor + 2nd Floor Deck	50	10	10		+
Internal Staircase	10	5		5	+
Wall	50	5	5	3	+
Roof	30	5	5	2	+
Other (Exterior door, railing, window, etc.)	25	5	5	2	+
Total	235	50	45	32	
		21%	19%	14%	

Table 2 shows that the first study accounts for 18% of the total cost, the second study accounts for 15%, and the third study accounts for around 10%. Table 3 indicates that, in terms of working days, the losses in working days represent 21%, 19%, and 14% of the total working days, respectively. The Construction and Installation Unit Prices announced by the Ministry of Environment, Urbanisation and Climate Change, the 2025 approximate unit costs for structures to be used in calculating Architecture and Engineering Service Fees, and the 2025 current market research have been taken as the basis for costs.

In the cost calculation for rework costs, unit prices have been taken into account for all labor, materials, etc. When examining the first customer, the costs for relocating the balconies for the first and second floor slabs are approximately 2703 USD (20 m^2 × 135 USD). The costs for dismantling the staircase, installing it in its new location, and installing it in the new space created for the change in the location of the internal staircase are taken into account at 2703 USD. For changes to be made to the walls, rework costs of 4054 USD are taken into account, considering the change in the location of the doors and windows due to the change in the location of the balconies (35 m^2 × 116 USD), new costs arising from changes to the roof structure due to alterations to the lower floor slabs amounting to 2703 USD, and a total rework cost of 2162 USD for the relocation of external doors, railings and windows. The second customer also has costs of approximately 2805 USD (20.8 m^2 × 135 USD) for the relocation of balconies on the first and second floor slabs. Considering the changes to be made on the walls and the relocation of doors and windows due to the relocation of balconies, the rework costs are 4150 USD (35.8 m^2 × 116 USD), and the new cost arising from the shape of the roof due to changes to be made to the slabs on the lower floors of the roof is 2703 USD. It has been determined that a total rework cost of 2250 USD will be incurred for the relocation of the external door, railings, and windows. The third customer also has rework costs of 2703 USD for the removal of the internal staircase, its installation in the new location, and the costs of installing it in the new space created, taking into account the change in the location of the staircase. For the changes to be made to the walls, rework costs of 1500 USD (12.9 m^2 × 116 USD), and 1000 USD for rework costs associated with relocating the external door.

The lost working days were calculated taking into account the nature of the work to be performed in the rework and all the steps required for the rework. It was also taken into account that in interdependent tasks, completion of the other task would be awaited, which would cause time loss on the critical path. Due to the rework, the critical activities were extended, and the resulting loss of days was determined by considering how many workers would be required to complete the work and at what speed. The daily labor capacity is based on 8 h per day, with 2 workers employed for the work. The calculation takes into account demolition times, formwork, steel reinforcement, concrete pouring and epoxy work for changes made to slabs, as well as detailed work such as dismantling, demolition, rebuilding walls, rough plastering, fine plastering and painting for window and door location changes.

Figure 9 illustrates the cost loss relative to the initial construction cost, and Figure 10 shows the loss of working days. In Figure 11, the average of the cost and time losses in the study is taken and the details are given item by item on the basis of the work performed.

As a result of the study, the initial cost, reconstruction cost, initial construction period, and reconstruction period were calculated. With the application, the initial construction cost, which was 113,819 USD and 235 working days, resulted in a reconstruction cost of approximately 20,000 USD and a loss of 50 working days in the first study; a reconstruction cost of approximately 17,583 USD and 45 working days lost in the second study; and approximately 11,128 USD in reconstruction costs and 32 working days lost in the third study. When averaging the three studies, the reconstruction cost is approximately 14% (16,237 USD) of the initial construction cost. The average additional workdays lost amount to roughly 18% (42 workdays) of the total workdays. Additionally, indirect losses such as electricity, water, daily wages for workers, accommodation, basic living necessities, and vehicle rentals required for the construction site would be avoided due to the additional workdays lost. Furthermore, all renovations directly affect construction quality, such as slabs, doors, windows, walls, flooring, railings, stairs, and roofs, will either not occur or will be kept to a minimum.

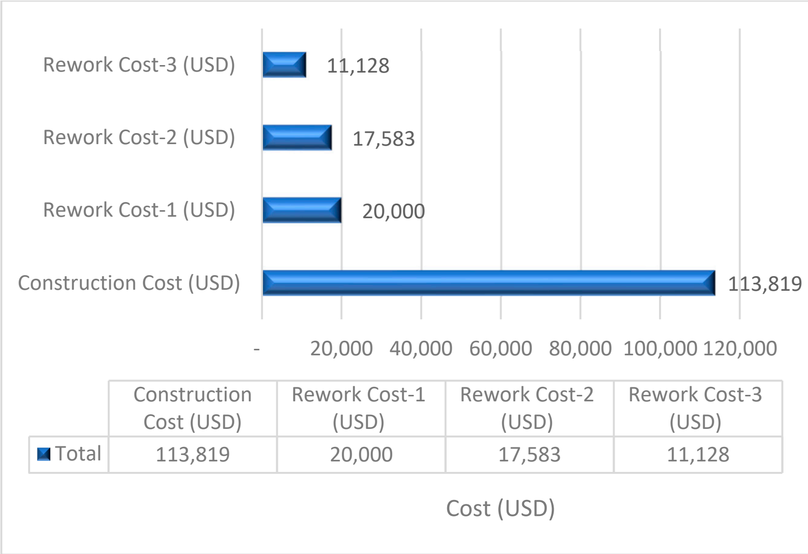


Figure 9. Build Cost and Rebuild Cost Chart.

Figure 10. Graph of the normal construction time of the construction and the time to be spent on reconstruction.

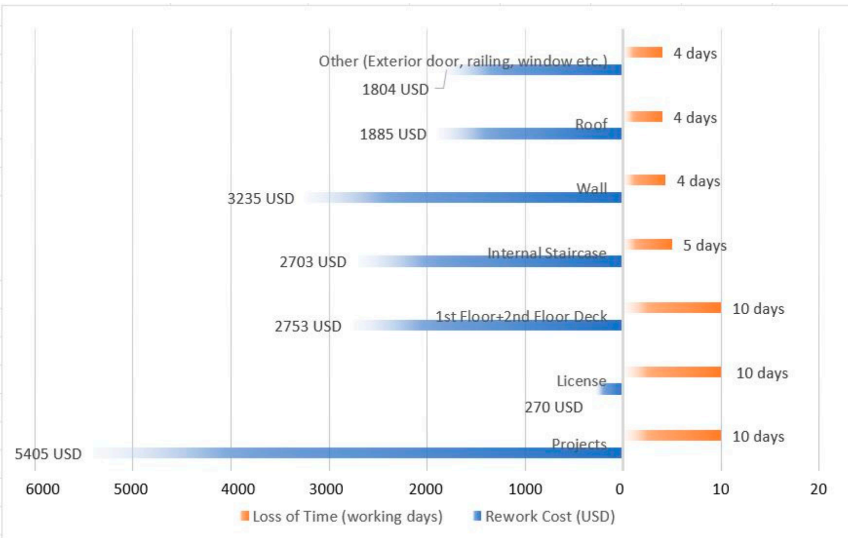


Figure 11. Graph of combined.

4. Conclusions

Our world is becoming increasingly dependent on technology, and as a result, our lives are becoming more computer-centric. This transformation is happening rapidly, with new technological applications emerging or new versions of existing technologies entering the market even as the adaptation process continues. In this ongoing cycle of innovation, numerous advancements are being made available to humanity through development and change. To influence technological progress, create and develop our own applications, and establish a presence in the industry, it is essential to adapt quickly, integrate applications into the sector promptly, use the experience gained to lay the groundwork for innovations, and ensure that development remains continuous for future generations.

One of the most promising applications of technological advancements is AR. This application, which caters to the needs of all sectors, effectively maximizes the use of technology. The construction sector lags others in digitalization, usage, and prevalence. It also does not reach the desired level in our country. When research and studies on AR and other technological developments in the sector, along with the benefits they can bring, are examined, they are likely to have a very positive impact. Augmented reality technology is constantly evolving and transforming, and its widespread adoption in construction can lead to more effective and efficient project management, driving a significant transformation in the sector. Additionally, integrating innovative technologies such as mixed reality (MR) will speed up digitalization in construction, fostering sustainable and efficient solutions.

The construction industry is one of the sectors that must quickly adapt to technological advancements because of its economic importance, labor capacity, and the need to meet the housing and basic needs of the world’s population. The development of digital technologies has significantly transformed building production processes, promoting the widespread use of Building Information Modeling (BIM) and Augmented Reality (AR) applications. AR applications can operate in conjunction with BIM software and complement each other. Integrating BIM and AR technologies into construction processes allows these processes to be more controlled, systematic, and efficient.

This study was conducted for a two-storey villa project, which is still in the initial design phase. The study examined the contribution of AR applications to the project during the design phase. According to the results obtained, it was observed that AR applications directly impact the optimal timing, minimal costs, and high quality needed for the project to achieve its goals. The benefits of this application were evident in this project, which is less complex than other large-scale projects, where issues can be resolved using simpler methods. In complex projects with high investment costs, where mistakes or changes are hard to reverse, using AR will offer significant benefits to investors and the national economy. As a result of the study, the initial cost, reconstruction cost, initial construction period, and reconstruction period were calculated. During the design phase, it was seen that it helped to determine the location of the balcony, room, window and door layout within legal limits. It was observed that the highest losses in terms of cost and time were in demolition and reconstruction items.

It was stated that it is easier to find three-dimensional visuals and adapt them to the real environment with AR, except for the fact that the people applied within the scope of the study do not have technical knowledge on a normal project or the determinations made by the project implementers in line with the explanations.

With the AR study, with the prior determination of the modifications to be made at the beginning of the project, as in this study, before the legal processes begin,

- It can directly affect cost, time and quality.
- It will ensure that many decisions are made at an early stage, such as the sustainability rate of the building and the maximum use of the energy savings to be obtained from the building.
- In addition to clear targets such as cost, quality and time, other factors that will negatively affect sustainability such as paper waste and energy loss will also be prevented.

This study will be more applicable to large-scale projects, and the benefits provided according to the size of the projects may be more extensive. In a project such as a hotel, where there are more varied structural elements, the clearer view of the landscape will enable more efficient assessments of the location of the rooms in terms of use and will allow for clearer decisions to be made during the design phase regarding the location of items such as balconies, bathrooms and furnishings within the rooms. In projects such as hospitals, visuals created during the design phase can facilitate the identification of details that would be costly to rework later, such as the location of installations and the layout of rooms. In large projects, it is likely that the computer, tablet, or other device used for implementation will need to have advanced technical specifications, such as a sophisticated operating system and RAM.

Considering the stages of a construction project, AR applications can be used from the initial idea phase, through construction, control, completion, and even in subsequent marketing, maintenance, renovation, and demolition processes.

In a project divided into independent sections, later changes can cause issues such as ownership disputes, lead to legal action, and result in interruptions, severe damage, and delays. Visualizing the changes at the project's outset with AR and obtaining approval from all stakeholders will help prevent these adverse outcomes.

When considering the implementation phase, the visualization provided by AR will help with timely and precise material selection. In building complex structures, AR glasses will assist workers during the construction process and help ensure it is completed efficiently. It will enhance coordination among different units such as architecture, statics, installations, mechanics, and electricity, which is a key issue in construction projects, and prevent errors in manufacturing.

During the control phase, it enables comparison of the physical structure and the project in a visual environment, allowing for the timely detection of parts that do not match the project, preventing problems from escalating and ensuring compliance. Additionally, if there are deviations from the work plan, it provides opportunities for early intervention through options such as double shifts or additional teams, ensuring the work is completed on time. After completing the project, visual inspections can verify compliance with maintenance, repair, and renovation requirements of the structure. During the marketing phase, the AR application will offer instant visual capabilities to both domestic and international customers, and property marketing will not be limited to a customer portfolio that can physically view the property. The market share will expand internationally and domestically, the marketing period will decrease, and sales figures can be maximized in a short time. AR-based training provided to workers will help prevent accidents by ensuring workers' health and safety. Additionally, it will significantly facilitate training for users of heavy and dangerous machinery. It will prevent time loss and waste related to documents and procedures. For instance, if changes are made to a printed project for review, there will be no need to reprint the project multiple times for all project groups, thus eliminating both printing costs and paper waste. AR technology will play a crucial role in the future of construction management. Its integration into the construction industry will save time, costs, and energy, enhance quality, and protect worker health, ultimately maximizing efficiency. In this study, the work developed on a computer was visualized on a tablet. The work can also be conducted by transferring the generated APK output to glasses.

When AR is examined in the context of engineering education, it is seen to have a very wide scope, and it is believed that students' comprehension skills can be enhanced through visualizations. AR applications in engineering education are among the innovative technologies that support learning by making theoretical information more interactive through visualization. AR helps improve understanding of complex engineering concepts while allowing students to acquire practical skills and develop more effective solutions to real-world engineering problems.

Some reasons for the limited adoption of AR technology include high initial investment and maintenance costs for digitalization, low employee education levels, insufficient training on AR products in our country, resistance to innovation among employees, inability to achieve full integration due to numerous subcontractors, technical and hardware issues, poor user experience, and a lack of coordination resulting from limited use across all departments.

All these studies demonstrate that technology and digitalization are crucial for the construction sector. Although the construction industry lags other sectors, it will inevitably adopt concepts such as technology and digitalization more broadly in the future. In fact, more advanced AR technology will require the development of mixed reality (MR) and extended reality (XR) applications. The widespread use of technology in construction projects, covering not only architecture and structural analysis but also electrical and mechanical systems, can significantly improve efficiency and sustainability. In challenging situations, such as earthquakes, using AR to visually represent the pre-constructed structure can yield positive results. The techniques used in reinforcement projects can also accelerate the construction process. To leave a more livable world for future generations in this evolving environment, the active integration of sustainability—a critically important and necessary concept—must accompany technological advancements. It is expected that future projects will require the integration of technology and sustainability, with ongoing innovations leading to new applications.

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Abbreviations

The following abbreviations are used in this manuscript:

AR	Augmented Reality
VR	Virtual Reality
XR	Extended Reality
MR	Mixed Reality
QR	Quick response
APK	Android Package Kit
BIM	Building Information Modeling

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