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# Augmented Reality Support for Self-Assembly of Metal Storage Boxes

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**Abstract.** Augmented Reality - AR - solutions are investigated and partially already used in the industrial sector for product and process visualization, assembly training, assistance systems in assembly and maintenance processes. This article presents the development and use of an AR app to assist in the self-assembly of a metal storage box. Currently the storage boxes are still delivered containing printed assembly and instruction manuals. The goal of this article is to show an approach and a solution to replace these with easily downloadable apps for handheld AR.

**Keywords:** augmented reality, handheld AR, self-assembly, assistance systems

## 1. Introduction

Since the presentation of the use of Augmented Reality (AR) as an assistance system for assembly processes by *T. Caudell* and *D. Mizell* in 1992, intensive research has been conducted on AR applications in assembly. *T. Caudell* et al. provided assembly instructions using AR to assemble wiring in aircrafts quickly and safely. Through AR glasses with optical-see-through displays workers could see hands free information while assembling ambidextrously [1]. In the meantime, AR hardware and software have been further developed and tested for use as an assembly assistance system. AR, like virtual reality (VR), is used in collaborative product development for design reviews [2]. VR and AR solutions are also used for designing mature assembly processes and for assembly training, AR is used for maintenance and repair assistance [3]. VR and AR are related; in VR, we are completely immersed in a synthetic world, where the boundaries of physical reality can be transcended. Gravity, time and physical laws no longer apply here. With AR we see the real world as we know it, and virtual content can be added. *P. Milgram* has vividly illustrated this in the reality-virtuality continuum [4].

For the application in this article, VR could only be used as an assembly - training environment, but the goal here is to support untrained people, they should be able to assemble immediately on the real object and get the individual assembly steps displayed. AR appears to be a target-oriented solution for this task.

As an assistance system, AR is often used for training for series assembly processes or for real processes with numerous variants. In this article customers are assisted in self-assembly of metal boxes with AR. In the case of bulky products such as furniture, these are often delivered to the customer as individual parts, packed in cardboard boxes. Assembly needs to be done by the customer himself. To ensure that this self-assembly can succeed without errors, assembly manuals are attached. Storage space boxes up to

4 m wide, 3 m high and 3 m deep are largely assembled outdoors with these instructions. Written instructions accompanied by pictures and drawings help customers to pick out the correct parts and compare them with the description. For simple positioning and joining processes such paperwork usually suffices. In the case of complex, superimposed joining processes such as hooking and partially swivelling, two-dimensional representations on pictures are sometimes insufficient or difficult to understand. If this assembly also takes place outdoors, where wind and rain could blow away the paper instructions or make them unreadable, other support systems are needed.

AR glasses would be good, but an ordinary customer usually doesn't have them at hand. Tablets would be possible, but the simplest AR hardware available are smartphones. As an anchor for a simple and feasible solution for self-assembly of a metal storage box, QR codes have been attached to the parts. Therefore, customers can easily download the required app to their smartphone, identify the correct parts in the correct order, and assemble them properly. The creation path of such an AR app and its use is presented here as well as tests with this app.

## 2. RELATED WORK

Whether AR is suitable for self-assembly or which hardware type should be considered *beforehand J. Blattgerste et al.* compared the AR glasses *Epson Moverio*, *Microsoft HoloLens* and *Smartphone* as AR handheld with conventional paper assembly instructions. *Lego* bricks with different colours and lengths were to be assembled following a certain pattern. With paper assembly instructions the tasks could be completed quickest showing the fewest errors and with the least mental strain. Using smartphones the tasks took longest, the results had many errors, and the cognitive load of the participants was the highest [5]. The comparison of smartphone mobile with smartphone on a tripod and spatial AR showed the shortest assembly times with spatial AR, the longest was assembled with smartphone on tripod, in between was the use of mobile smartphone. The error rate during assembly was also highest with mobile smartphone, and the mental workload was comparable for all technologies [6]. In both cases, smartphones did not perform particularly well. Although using hands free AR glasses, so called head mounted displays (HMD), has advantages they were not commercially successful. This could be due to the lack of appeal, too low availability, or too high costs. Handheld AR such as smartphones or tablets have become popular alternatives in the meantime. Good screen resolution and cameras with fast processors form an efficient, readily available system [7]. In the maintenance/repair of an industrial computer, the use of remote AR on smartphones was compared with paper instructions as a source of information. The repair took a similar amount of time with both systems, but the error rate was 75% lower with remote AR with smartphone, and here the intermediate verification of the work steps by the external expert was the decisive factor [8].

*A. Sanna* et al. used handheld devices to support AR-based maintenance instead of paper-based instructions. AR animations were shown on tablets to replace a hard drive on a netbook. Six testers performed the task with AR support, and the six other probands used paper-based instructions. The average time was only about 7% faster with AR, but the number of errors dropped to 1/3 of those measured with paper-based instructions [9]. In search of challenges, opportunities, and future trends in AR-based maintenance, F. Lamberti et al. described that AR is growing in routine car maintenance. Some car manufacturers provide their users with the owner's manual as an application for mobile devices. After capturing the engine with the device's camera, AR can provide animated instructions on how to, for example, locate the engine's coolant and fill it to the required level. They created a prototype application where images, animated 3D content and text are sent step-by-step to the technician. If needed, the technician can also ask the operator at the remote-control station. Using this kind of support, the operator can explain things or send text information. When an inefficient task description is identified, the operator can change the description or add 3D animations to update the AR scene in the application [10].

When comparing AR with paper-based maintenance for bus fleets, *D. Borro* et al. used tablet-based and wearable devices (*Microsoft HoloLens*). For both solutions, the goal was to improve the maintenance process based on review with task checklist. The prototypes are implemented in the company's facilities, with real users in an operational environment. In order to analyse the environment, to track the objects and users position, spatial mapping and object detection were used. *Unity 3D* and *Vuforia* libraries were used for image processing. In the workshop workflow with AR, the positions of the technician and the bus were first identified with tracking systems. Vehicle recognition was done with license plate identification and based on this; relevant maintenance tasks were provided in checklist form. The technician can see the open maintenance tasks, animated 3D or text descriptions are displayed if required. After completing the task, he confirms the checkbox with a digital tick. To compare the maintenance management systems, qualitative and quantitative key performance indicators (KPIs) have been defined. Effort in data management (time for planning work orders), effort in data processing (time for completing the documentation of work orders), Operator workload (subjective burden of methods on technicians) and the maintenance staff costs per vehicle are the KPIs that represent the main aspects of the maintenance management systems. As a result of the KPI analysis the use of a tablet as a mobile device is superior in all aspects. Only half of the effort in data management is needed in relation to paper-based solutions and ¼ in relation to use wearable devices. The time spent for data processing with a tablet is 30% lower compared to paper and like wearable devices. In addition, regarding operator's workload tablets have advantages. The very relevant costs for maintenance staff per vehicle are also lowest when using a tablet due to the reduced time required [11]. *F. Obermair* presented different types of assembly and suitable assistance systems, in particular AR, using *Android Studio* as the programming environment [12].

In a systematic literature review of the use of AR in maintenance, assembly, and training published over the past 20 years, *M. Gattullo* et al. presented the commonly used hardware and visualisation types for maintenance. Head-mounted displays (27%) were used similarly to handheld displays (27%) or desktop PCs (30%), while projection (5%) is less used. In AR for maintenance, the most used visual representation forms are text, 3D product models, and auxiliary models (such as arrows). Nowadays, most publications use head-worn displays and, as second hardware, handhelds for the examinations [13]. In industrial applications handhelds are preferred because of their availability and ease of use.

AR with handhelds is thus not the fastest technology, the advantage lies in good availability, and when used as remote AR also in lower susceptibility to errors. Good availability of smartphones or tablets is the main reason why this hardware is used for the solution described in this article.

# 3. DEVELOPMENT OF THE AR APP

To support the assembly of a storage box made of metal with a width of approximately 2 m, a height of 1 m and a depth of 1 m, a paper manual was previously included. To provide customers with animated assembly instructions on their smartphones, an AR app was developed in Unity3D based on existing CAD data for a metal storage box, with the animations generated in Blender. Thus, the required steps are:

- *CAD:* Save single objects as **.stl*
- *Blender*: Create animations, save as **.fbx*
- *Unity3D*: integrate marker image and **.fbx* file, create **.apk* file

We also created Apps in *Android Studio* (*Java script*), *Eclipse* (*Java*) or other software, the way presented here with *Unity3D* seemed to be the fastest and easiest.

## 3.1. AR Hardware / Software Function

QR codes and a marker image were attached to parts of the storage box. As soon as the AR app is started in a smartphone or tablet and it recognizes the QR code of the main sheet, the relevant, current animations are quickly downloaded from *Dropbox* and started. The camera also recognizes the marker image fixed on the main sheet, which serves as the basis for the position, scaling and rotation of the other parts. Animations of how the parts must be positioned and screwed on are displayed in the proper sequence, so that the assembly can be presented to the assembler in an animated step-by-step manner.

In Figure 1, the left image shows the user pointing a tablet or smartphone at the main sheet with QR code and marker image. The camera in the tablet downloads the correct animations from *Dropbox* based on the QR code and places them on the correct position, size and rotation based on the recognized marker image. For the user it looks like the virtual part is mounted on the existing real part as well as attached with screws. In the right image of this illustration the result of this AR solution can be seen. On the bottom is the white main sheet and above it the prepared first side part. On the tablet the white main sheet with marker image and QR code is visible, as well as the virtual side part colored yellow here, which was positioned in an animated manner. The screws to be used are then displayed in 3D and positioned virtually one after the other. The assembler now knows where and how to mount this metal sheet.

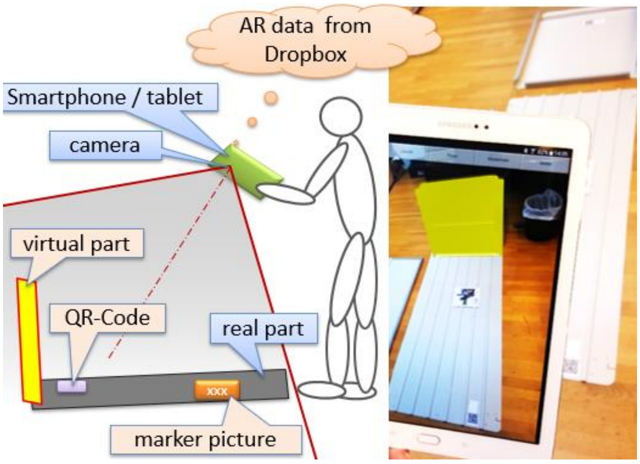

Fig. 1. AR function – l: principle, r: resulting view cf.[12].

## 3.2. Use of Existing CAD Data

The CAD data of the storage box (Figure 2) available in the production company were used as a basis, thus eliminating the need for time-consuming reconstruction. In order to be able to process these data with the subsequent software *Blender, *.stl* was chosen as the neutral storage format, other formats such as **.obj* can also be used. With the format **.obj* color information from the CAD is taken over, with **.stl* everything is in gray, colors can be attached here afterwards in *Blender*. Parts that are to be moved to each other must each be saved as a single **.stl* file, otherwise the storage box is a part that cannot be broken down into individual parts. If only the opening of the lid is to be animated, it is sufficient to save the box and the lid in separate **.stl* files. In our case, each individual part is to be moved and mounted, so each part must be saved individually in a **.stl* file.

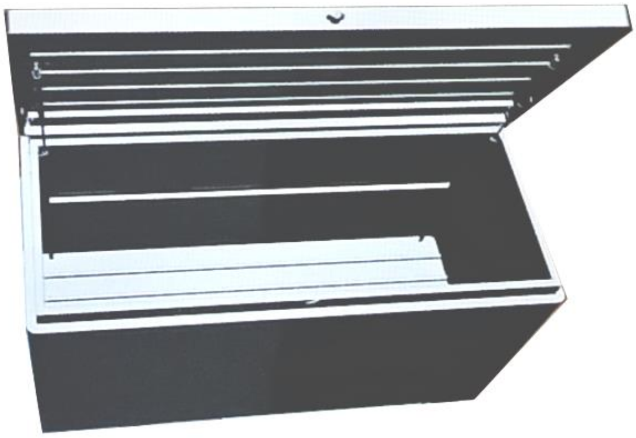
Fig. 2. CAD data of a storage box (2 x 1 x 1 m).

## 3.3. Blender for Animations

Animations can be created and transferred from CAD to *Unity3D*. For the storage box the freeware *Blender* was chosen because it can be used to quickly create good animations. After importing the **.stl* files the position and orientation in space as well as the scaling can be defined or changed. A kind of movie is created by defining a start and end position, the movements in between are generated automatically. This way, an understandable animation in 3D can be created step by step. In Figure 3, the animation of the assembly of a pulley and a parallel key on a shaft is created. Taking existing *CAD* data this can result in big file sizes of more than 100 MB for machines or vehicles, which makes it difficult to receive a smooth presentation on smartphones. Here, the surface model can be re-meshed in Blender and with larger distances. The image resolution of the machines or parts is reduced and to display them on smartphones it is usually quite sufficient. Created animations are saved in the **.fbx* format to be applicable for the software *Unity3D.*

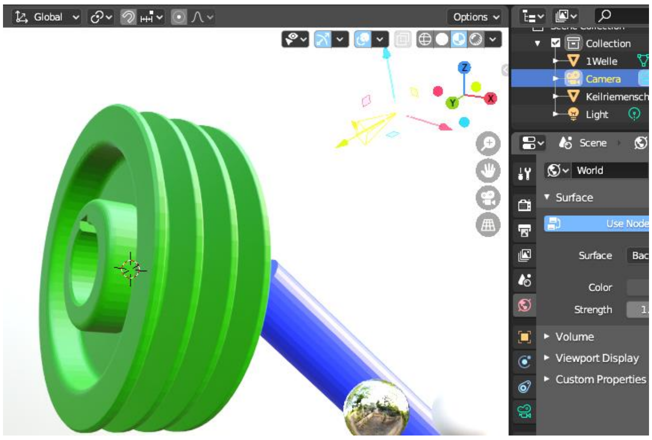


Fig. 3. Creation of animations in Blender.

## 3.4. App Generation in Unity3D

The user interface in *Unity3D* consists of a menu bar, the Project area, which serves as a data store, a *Hirachy* area and the *Inspector* area (Figure 4). The **.fbx* file and other data that may be required for this project are stored in the Project data store. As long as these data are stored in the folder Project, they are not active. Everything stored under *Hirachy* is used in the current project and is displayed under Display. This can be an AR camera, lights, marker images or animations from *Blender* in **.fbx* format. In the *Inspector* section, individual integrated items such as an AR camera can be activated and tuned by changing parameters or setting check marks. For more complex applications parts of the AR solution must be written in programming code.

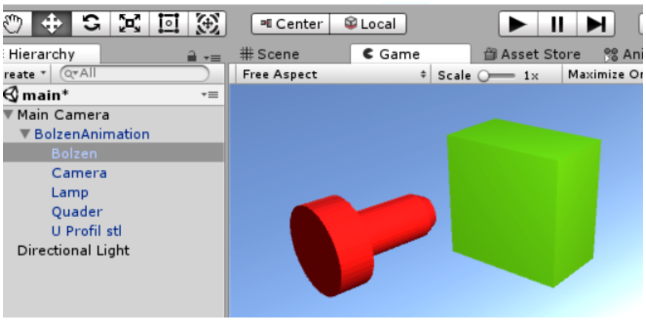


Fig. 4. Main view in Unity3D.

When creating an app, first select the operating system type the app should be run on, by ticking *Android*, *iOS, Microsoft* or others. *Unity3D* is mainly used to develop games. For an AR app, an AR camera and the tracking system *Vuforia*, which is integrated in *Unity3D*, must also be selected. After selecting, integrating and positioning the desired marker image under *Hirachy*, the animation or animations prepared in *Blender* are integrated. Each marker, object or animation integration can be immediately visualized and viewed under *Display* (Figure 5).

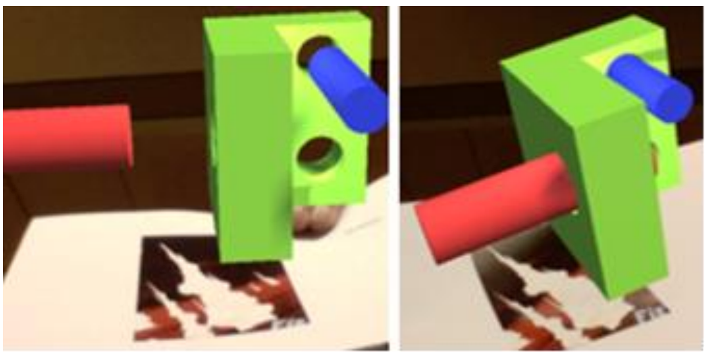

Fig. 5. Visualization of a bolt assembly, which is connected to a marker image, l: before, r: after the assembly

Animations can be started step by step by creating individual "states" for individual animations (Figure 6). Again, most tasks can be connected by clicking and dragging and dropping.

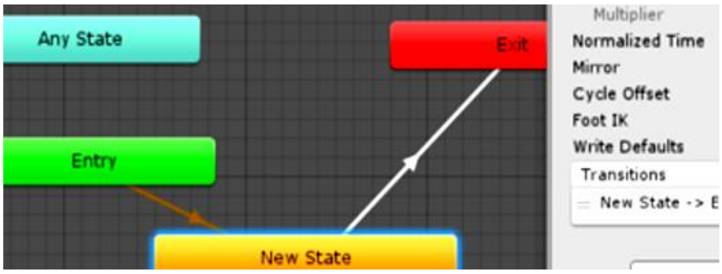


Fig. 6. Start animations step by step.

The query of QR codes and data retrieval from Dropbox based on them are implemented. The next step is the creation of the app, under *File-Build-Settings Build* is selected, a **.apk* file is created, which can immediately be sent to a smartphone, installed there, and started. The app is ready for use.

## 4. ASSEMBLY TESTS

The app installed in the AR handheld is opened, it is held towards the floor plate with marker and QR code. The correct and current animations are loaded from the *Dropbox* and visualized. Figure 7 on the left shows the starting position for the first step of the assembly of the right panel with the screws required, whereby the screws are scaled larger by a factor of 20 to be able to distinguish them easily.

Fig. 7. 2nd step: assembly of the back wall – l: initial r. final state cf. [12].

Here the real right panel is prepared on the right from the base plate as presented in the animation. A marker image is only attached to the base plate, a QR code is attached to each part to be mounted for identification and activation of the animation. The animation can be started and shows the untwisting and positioning of the right panel as well as the insertion of the screws. Figure 7 on the right shows the screwed right panel both, in the animation and on the real component.

For the third assembly step Figure 8 again shows the starting position. The virtual left side panel must be placed on the floor, as displayed on the AR handheld, and the required screws, washers and nuts are clearly visible in enlarged form. After tapping on the AR handheld, the assembly animation is started. The left side panel is turned up, positioned, and fastened with screws.

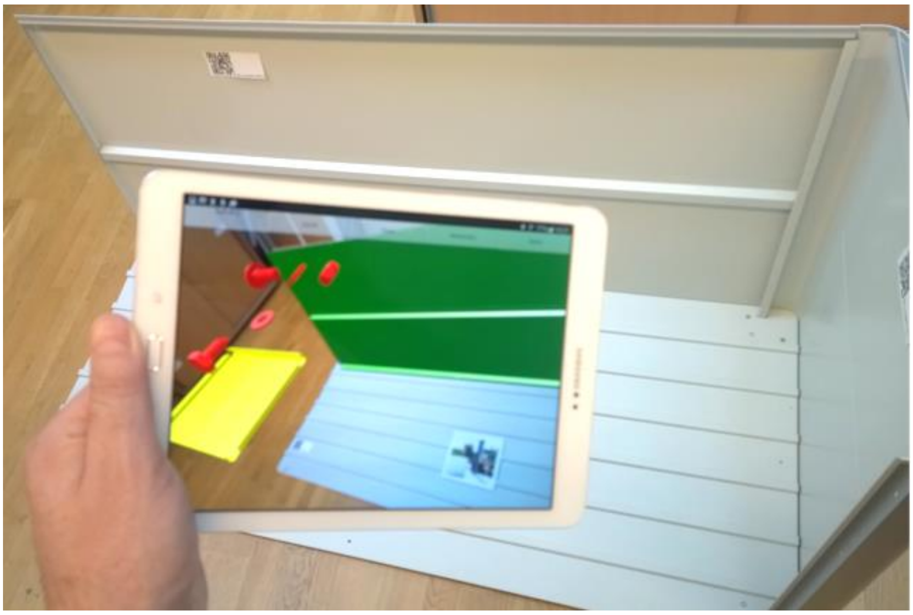

Fig. 8. 3rd step: assembly of the left wall – initial state cf. [12].

After animation and real assembly of the remaining parts, the box is ready for use. The assembly test, supported by the AR app on the handheld, worked well, each step was easy to understand for the test assemblers. Compared to the paper-based instructions, it was easier to find the right step, and due to the animations above the real base plate, it was clear where and how to place, assemble the next plate or screw [12].

## 5. RESULTS / SUMMARY

Traditionally, a self-assembly metal box includes a printed assembly manual. To support the customers of such a box even better during assembly, as well as from the point of view of sustainability, the paper instructions required only during assembly could be replaced by an app. Existing *CAD* data is used as the basis and stored in a neutral format. Animations are created in the software Blender, and the app is created in *Unity3D*. Through the step-by-step assembly steps presented in the app, even unexperienced customers can easily assemble the storage box. The extent to which assembly with the app is easier, faster, or more error-free compared to paper instructions, as well as the degree of their acceptance by customers are open to further research.

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