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Feasibility study of using augmented reality in geotechnical site inspection

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Abstract

The construction industry is at the edge of digitalisation where several emergent technologies are being implemented. However, it is not possible to make a comparison with other sectors like the automotive or health ones. This is due to the construction's pain point, that is, its uniqueness of the construction site in every different situation.

Nonetheless, within the sphere of the construction industry, there are also divergences: whereas in the security and safety activities, innovative technologies have already been implemented and they are being developed, in the geotechnical ones, these are not applied yet. Some of these emergent technologies are Augmented Reality, and 3D printing, among others.

On the other hand, the concern about the huge frequency of landslides and their subsequent consequences, sometimes devastating, motivates the study of this research.

This Bachelor Thesis, hence, tries to aim at the AR application together with 3D printing in the geotechnical study field, more specifically in the on-site inspections in order to provide with a sample Augmented Reality *app* that enhances the routine visual inspections on site focusing on foreseeing landslides from happening because of the observation of specific indicators in the early stages of the movement.

Firstly, an exhaustive literature review regarding landslides, several geological indexes that characterize rock mass, embankment's inspections and emergent technologies in geotechnics is carried out.

Afterwards, the design of the *app* is designed and developed by means of different softwares used during the whole process. In the design, several requirements (*Key Performance Indicators, KPI)* are stablished in order to evaluate afterwards the proposed tool.

Following, the evaluation of the results according to the *KPIs* proposed in the design phase is performed in order to evaluate the *app*'s performance. Here, a scale model of an embankment is also created using 3D printing in order to evaluate the app.

At the end of this Thesis, the conclusions and several future research lines are explained.

Contents

Annex

List of Figures

List of Tables

Chapter 1. Introduction

1.1. Motivation

The science that investigates exhaustive and efficiently the interaction between the terrain and the construction site is geotechnics. This subject area always works hand in hand with geology in order to elaborate an adequate study. Moreover, thanks to the correct application of geotechnics is why safe and viable constructions can be carried on.

More specifically, one of the geotechnical study areas is the examination of natural elements located in the earth crust by means of geological principles so as to evaluate the soil or rock (sub-) surface for a future construction. This pre-construction process includes the study of physical, mechanical and chemical properties of the materials and the risk analysis of the location. Moreover, this aims to prevent future problems or even big disasters.

However, because of errors of a previous study or natural disasters, when a construction is already done, the foreseen failures cannot be avoided. Hence, they can derive to geotechnical problems such as landslides, rock falls, displacements, settlements, collapses, tipping... This is what leads to the second study area of geotechnics, which is the mitigation of risks and environmental impacts. Here, the geotechnical engineers are the responsible for study the situation and give solutions that may extend the lifespan of a construction. Therefore, some of the applications this field area encompasses are reinforcements, excavations and foundations. Nonetheless, to prevent and manage the risks, geotechnical inspections and studies still use traditional tools.

In spite of this, nowadays there is the new paradigm called “Industry 4.0”, more known as “Construction 4.0” in the construction industry. This term refers to the automation, monitoring, sensorisation, digitalisation... to improve production and distribution processes [7]. For the last three decades, however, some technologies have had a big impact in the construction industry [8]. These are the use of virtual reality (VR) and augmented reality (AR). They have been used for training and enhancement of safety purposes, such as the creation of VR or AR experiences to teach construction workers how to use a specific machinery, for visualisation purposes, such as the creation of virtual tours in VR or AR to give a client an idea of the product or for streamline collaborative purposes, to share documents with team members [9].
However, in the geotechnical environment, the first VR and AR application was released by Deep Excavation LLC in 2017 [8] and the results were very beneficial for the visualisation of the excavations and also for showing the solutions to anyone regardless

their engineering background. Moreover, VR and AR are used for geotechnical investigations and software developers for slope-stability analyses have started experimenting with these applications [8].
In the near future, hence, due to the innovation in technologies and tools in the construction industry, we can expect that the geotechnical practice will have radical changes.

Therefore, for all these innovations and expectations of the augmented reality, specifically, in the geotechnical inspections, this research focuses on the development of an augmented reality app as hands-on way to study its feasibility in geotechnical site inspection. If the early detection of unstable areas or the future forecast of the moment of breakage is identified, this tool could mitigate the future risks. Direct benefits can be already anticipated, for instance, the reduction of time devoted to on-site inspections.

1.2. Introduction

The more widespread geological event is landslides, as the World Health Organization (WHO) states [14]. These are characterised by the fast movement of masses (rock, soil or debris) down a slope and they can be triggered by different factors, such as: geological, morphological and human activities. Moreover, climate change also plays an important role in the occurrence of landslides.

Landslide can lead to huge devastating consequences causing big amounts of deaths, as well as the destruction of villages and communication routes, among others. *"Between 1998-2017, landslides affected an estimated 4.8 million people and caused more than 18.000 deaths"* [14]. This also leads to big expenses that affect differently to countries depending on their incomes.

In order to mitigate the impact of these events, on-site inspections and their monitoring is being implemented. However, it has been proven that the early detection of indicators of future landslides in the early stages of the movements, could prevent the disaster from happening or the risks could be mitigated. This is precisely why visual inspection are important. As Terzaghi (1950) stated, "*If a landslide comes as a surprise to the eyewitness, it would be more accurate to say that the observers failed to detect the phenomena with preceded the slide"* [16]. Hence, if the smallest movement was detected and measured at the earliest time, the hazard mitigation could be carried out early.

On the other hand, currently there are emergent technologies that are being developed and implemented in different industries. However, the construction sector is at the edge of digitalisation and these technologies are not as implemented as in the other industries. Augmented Reality, BIM, 3D printing, among others, are powerful technologies that are resulting very beneficial.

The importance and growing of these innovative technologies leads to the idea of study the implementation of this technologies in the construction industry, more specifically in the geotechnical field study and the landslide inspections by means of the creation of an Augmented Reality *app* that could provide advantages in the inspection of embankments and its routine use could allow the identification of indicators from early displacements of landslides.

1.3. Objectives

This research aims to create an augmented reality app for geotechnical applications by means of testing it in a 3D printed scale model, as a step-by-step procedure to explore the potential and a particular implementation route of AR technology in the geotechnical area.

In order to achieve this, specific objectives are defined:

- Understand how the emergent technologies such as BIM, digitalisation in a wider sense and mixed reality, are applied in geotechnics
- Study how rock embankments are inspected.
- Analyse the geotechnical engineer work in this area.
- Elaborate the embankment geometry with Rocscience – Slide3.
- Design and implement an augmented reality system for embankments inspections by using *Unity* and *Vuforia*.
- Validate the elaborated tool through a 3D scale model made with 3D printing

1.4. Methodology

The methodology for this investigation follows the 5 stages nominal process sequence described in the document *Design Science Research Methodology – DSRM* [1] [2] [3] [4]:

(1) Problem identification and motivation
(2) Objectives of a solution
(3) Design and development
(4) Demonstration
(5) Evaluation

In the first stage of the process a proper understanding of the current situation regarding landslide inspections on site and the use of augmented reality in the geotechnical environment wants to be achieved. To do so, a literature review is needed to obtain all this information. Afterwards, considering all the previous knowledge, the solution is defined as the creation of an augmented reality tool that will help geotechnical engineers carry out the in situ inspections. In the next stage, the design and development of the electronic device app is created. This third stage is the most time consuming one, due to the big amount of research that needs to be done and the several software that will be used in order to obtain the final result. Once this *app* is created, its evaluation is the next step to be done. It consists on the experimental design where the *app* is tested with a scale model created for this purpose. The last stage is the feasibility's evaluation in order to compare the current technologies applied in geotechnics and the designed app. As it can be seen in Figure 1, this is an iteration process where in order to improve the efficiency of the solution, once the evaluation is done, the process could finish or go back again to the second stage where the reconsideration of the aim of the solution is achieved or to the third stage and improve the design and development of the *app*.

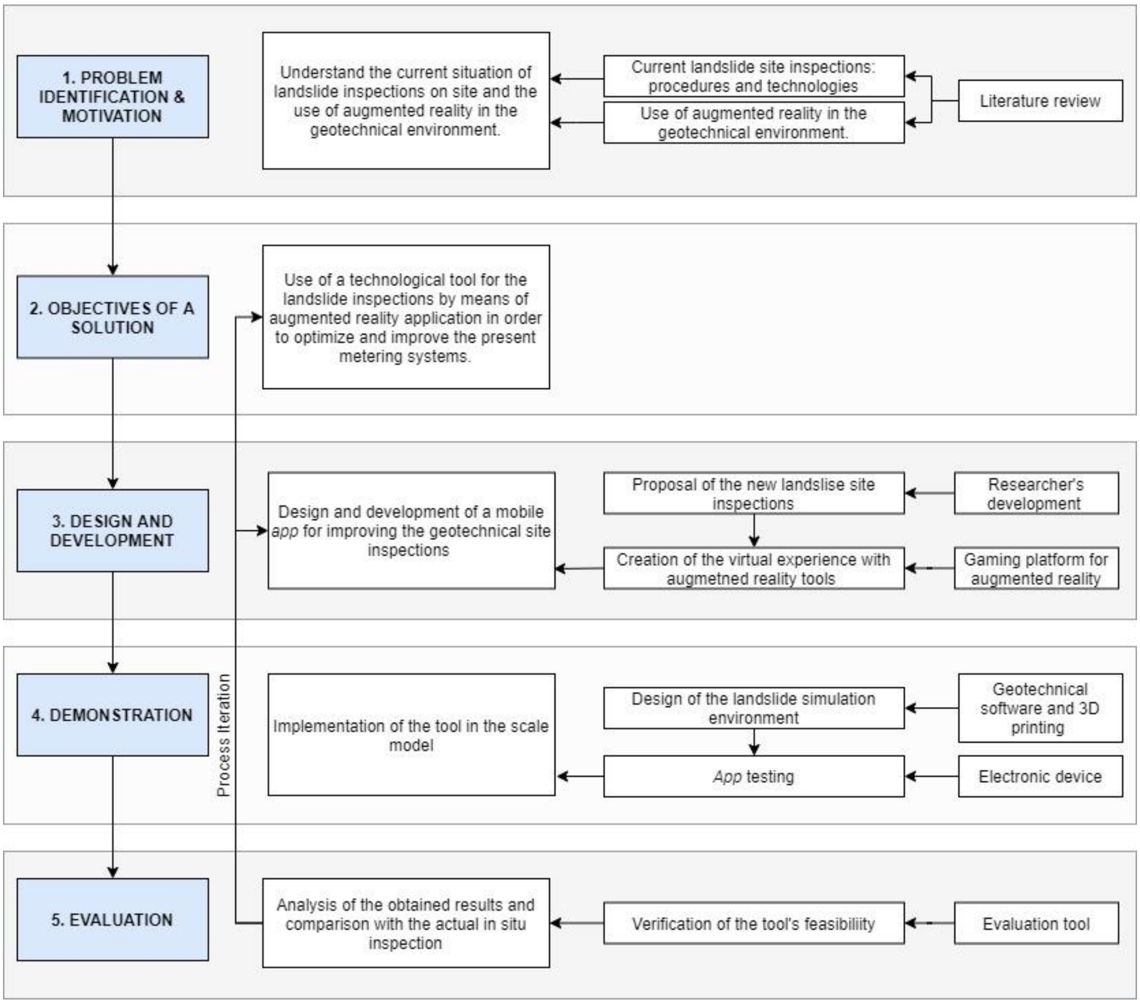


Figure 1 Methodology of the investigation.
Source: Own elaboration using draw.io.

Chapter 2. Geotechnics: State of art

2.1. Geotechnics: Landslides

2.1.1. What is a landslide?

A big variety of definitions are given for the word *landslide* due to the many disciplines that are related with their study: ranging from geologist, engineers and other professionals are involved in it. The Glossary of Geology (Bates and Jackson, 1987) defined it as "…the downslope transport under gravitational influence of soil and rock material en masse"; Webster's 3rd International Dictionary describes it as "The usually rapid down slope movement of a mass of rock, earth or artificial fill on a slope"; and the International Geotechnical Societies' UNESCO Working Party suggested for use in the International Decade for Natural Disaster Reduction (1990-2000) the informal definition of landslide as "The movement of a mass of rock, earth or debris down a slope" [13]. Therefore, this is the worldwide definition and although landslides can occur on land and under water [15] this research focuses on landslides occurring on land.

Landslides affect worldwide regions and they can cause major hazards to their inhabitants and their properties that can derive to significant economic losses every year in addition to big amounts of deaths [10] [12]. For instance, in the United States, it can result in 25 to 50 deaths and 3.5$ billion in damage each year [14]. One of the costliest landslide in U.S history in April 1983: it destroyed the city of Thistle, Utah, and caused over 400$ million in damage. The landslide was triggered by heavy rain and rapidly melting snow leading to a total mass of earth of 305m wide, 61m thick and 1.6km long sliding to the Spanish Fork River and dammed it up (Figure 2). Nowadays, this city is still evacuated and only few buildings remain partially submerged along the old highway (Figure 3).

Figure 2 Thistle, 1983.
Source: *Utah State Archives and Records*

Figure 3 Thistle, 2020.
Source: utahsadventurefamily.com

Landslides can be initiated by different factors that causes them, such as rainfalls, seismic and volcanic activities, snowmelt, permafrost melting and deforestation, among others. Henceforth, the different classifications depending on the type of material and movement they follow (Varnes, 1978 and Hungr et al. 2014) and the particular mechanics of slope failure together with their main characteristics will be explained [12].

However, to understand the behaviour of a landslide, firstly, its parts need to be known. In Figure 4, the commonly used labels for the parts of a landslide are represented [12] (See Annex A.1 for the definitions of these words).

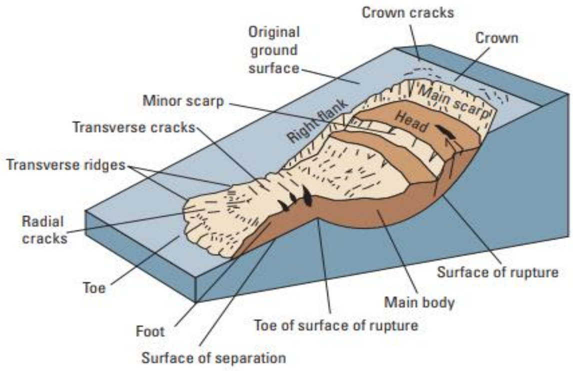


Figure 4 A simple illustration of a rotational landslide that has evolved into an earthflow.
Source: Varnes, 1978. [14][14]

2.1.2. Causes and effects of landslides

We may often think that landslides are mainly originated in mountain areas due to their vulnerability to them. These regions might be characterised by steep slopes and cliffs. However, landslides have been affecting many different regions worldwide that were not necessarily characterised by these features. Landslides can be caused by three main triggering mechanisms. These can be: geological, morphological and human activities [14] [16].

Geological causes are related to the characteristics of the earth or rock itself. Whether the material is in good conditions, its quality, its strength, its stiffness… [14] (see section 2.1.4 Geological indexes).

The second cause applies to the structure of the land [14] and it can be linked to natural occurrences, where the water and seismic and volcanic activities are the most significant ones. When the saturation by water of the ground occurs due to heavy rainfalls, snowmelt or changes in ground-water and surface-water levels, a landslide is prompt to happen due to the loss of stability on the slope [15]. Moreover, when a landslide occurs, it can cause flooding when sliding the material into waterway…and in the worst scenario, they can cause tsunamis when overtopping, for instance, a reservoir, like the Vaiont's disaster the 9th October 1963 (Italy), where 30million cubic meters of water flooded the Piave Valley below the dam [16] (See Figure 5).

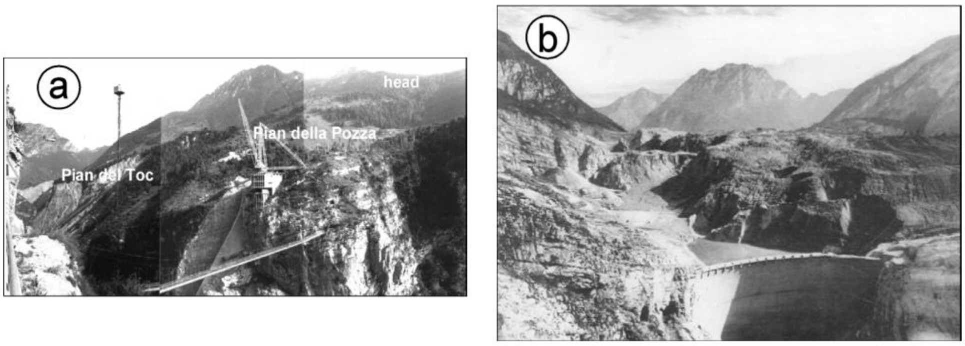


Figure 5 a) The northern slope of Monte Toc seen from the dam before the disaster.
Source: Semenza, 8-25-1959
b) The northern slope of Monte Toc seen from the dam on 10 October 1963.
Source: Zanfron, 1998

On the other hand, earthquakes can also increase the greater facility for a landslide to occur. Firstly, linked to the water effect, their shaking can allow rapid infiltrations. Next, there can also lead to liquefaction of sediments or dilation of soil materials. The latter mentioned activities, the volcanic ones, can lead to catastrophic disasters due to the sliding lava that can become an avalanche of earth material that destroy anything in its path [15].

Human activities destabilize the slope and increase the risk of a landslide [14]. The common activities are related to agriculture and construction. The former, includes activities such as irrigation, deforestation, water leakage [14], lawn watering, changing drainage patterns…[15] The latter refers to excavation [14], creation or drainage of reservoirs, leaking pipes… and the population expansion with the creation of new neighbourhoods, towns and cities [15]. This last aspect, already concerned Robert L. Schuster (1996) when he *listed "The factors causing this expected augmented activity"* [16] referring to the landslides activities on the 2nd Chapter of the BOOK *Landslides: Investigation and Mitigation* [16]. One of these three factors was "Increased urbanization and development in landslide-prone areas" and he stated that *"As a result of these population pressures, human activities have disturbed large volumes of geologic materials in housing development and in construction of industrial structures, transportation routes and facilities, mines and quarries, dams and reservoirs, and communications systems"* and *"All predictions are that worldwide slope distress due to urbanization and development will accelerate in the 21st century"* [16]. Indeed, he was true when he said that. Ask yourself: "How many situations of this type have we seen on the news?" Examples like the construction of a neighbourhood in Castries, Saint Lucia, Eastern Caribbean (2011) (See Figure 6) are very common to see nowadays.

Figure 6 Rainfall-triggered landslide in an informal community.
Source: Holcombe, 2011

Another aspect that concerns the society is climate change. Also Robert L. Schuster in 1996 explained his third factor he called *"Increased regional precipitation caused by changing climate patterns"* [16] and he did the following question referring to the greenhouse effect: *"Will it cause an overall increase in temperature and decrease in precipitation (…) or will it disrupt climate patterns, resulting in drought in some areas and increased precipitation in others (…)?"*[16]. Nowadays (2021), as NASA states *"Current climate models indicate that rising temperatures will intensify the Earth's water cycle (…). As a result, storm-affected areas are likely to experience increases in precipitation and increased risk of flooding, while areas located far away from storm tracts are likely to experience less precipitation and increased risk of drought."* [18]. Therefore, this aspect relates as well to the natural causes that trigger landslides.

Nevertheless, every cause has an effect, and whatever the factor that triggered the landslide was, the most commonly known effect of a landslide, as explained in the previous section, is the amount of deaths and economic losses it can cause.
The economic impacts caused by landslides has been summarized by Winter & Bromhead (2012) in three main categories [19]:

(1) Direct economic impacts: related to cleaning-up, repairing/replacing of lost/damaged infrastructure in the broadest sense and searching and rescuing.
(2) Direct consequential economic impacts: associated to the loss of utility due to the caused disruption to infrastructure.
(3) Indirect consequential economic impacts: correspond to the effect on economies that are based upon transport-dependent activities.

However, landslides also impact Earth's natural environment [21].

Mainly, landslides are characterised by the falling material down the slope, as its definition specifically describes; hence, these falls can damage or create huge disasters in the closest areas where the phenomenon occurs. However, the level of damage will depend on the type of landslide, where the verticality of the slope, the velocity of the falling material and the failure mechanism need to be considered. This will be described herein in the next section 2.1.3 Types of landslides.

These downslope movements of masses can affect natural environment by means of modifying (1) the morphology of the continents (mountains and valley systems) and beneath the oceans due to seismic and volcanic activities; (2) the forests and grasslands destroyed by different factors that caused landslides such as rainfalls, hurricanes, earthquakes, and the consequent erosion of the surface; and (3) the native wildlife on the surface and in its rivers, lakes and seas as a result of the landslide deposits or, in the case of water ecosystems, the sediment washed into the streams 82 [21].

However, oddly enough, landslides can have positive effects in the medium-to-long term [16] [21]. Robert L. Schuster in 1996 stated that "*...they help to provide stable land that is suitable for agriculture and habitation*" [16] and in 2003, together with Lynn M. Highland, they established that *"landslides can actually benefit fish and wildlife habitats, either directly or by improving the habitat for organisms that the fish and wildlife rely on for food"* [21].
Nevertheless, this is a good point we try to obtain from a disaster (sometimes catastrophic). If the benefits obtained from landslides were astonishing, the human being would create artificial landslides in order to obtain the positive effects... Believe it or not, there are cases where landslides were purposely triggered to obtain benefits, in this cases, socio-economic ones. One example is a dam constructed on the Malaya Alma-Atinka River upstream from Alma-Ata in the Kazakh Republic of the former Soviet Union (Yesenow and Degovets 1982) between 1966-1967 *with landslides that were triggered by setting of large explosives charges in the valley walls* and then *shaped into a traditional check dam.* The benefit of this dam is the protection of Alma-Ata from debris flows [16].

2.1.3. Types of landslides

As explained in the previous section, there are different types of landslides or slope movements; therefore, they need to be classified. The most widely classification used is the one made by D. J. Varnes (1978) in the 2nd chapter of the report *Landslides. Analysis and Control* [22] [23]. However, some modifications have been made in Varnes' classification in order *to reflect recent advances in understanding of landslide phenomena and the materials and mechanisms involved* (Hungr et al. 2014) [24].

Nonetheless, because the most used and popular one is Varnes' classification, this section provides the complete explanation of this classification together with illustrations and tables that make the theory more comprehensible for the reader.

The slope movements' classification described in 1978 by D. J. Varnes is also a modification from a previous classification of landslides presented in Special Report 29 (Sharpe 1958), due to some *deficiencies* -as Varnes states- because the report was published in 1958. Varnes' classification uses the type of movement (instead of the term *landslide*) and type of material as the main criteria. In Table 1 [22], some of the resulting combinations of these two are shown and it is a shorten version of the whole classification of *Types of slope movement* (See Annex A.1).

<table>
<tr><th colspan="3" rowspan="3">TYPE OF MOVEMENT</th><th colspan="3">TYPE OF MATERIAL</th></tr>
<tr><th rowspan="2">BEDROCK</th><th colspan="2">ENGINEERING SOILS</th></tr>
<tr><th>Predominantly coarse</th><th>Predominantly fine</th></tr>
<tr><td colspan="3">FALLS</td><td>Rock fall</td><td>Debris fall</td><td>Earth fall</td></tr>
<tr><td colspan="3">TOPPLES</td><td>Rock topple</td><td>Debris topple</td><td>Earth topple</td></tr>
<tr><td rowspan="2">SLIDES</td><td>ROTATIONAL</td><td>FEW UNITS</td><td>Rock slump</td><td>Debris slump</td><td>Earth slump</td></tr>
<tr><td>TRANSLATIONAL</td><td>MANY UNITS</td><td>Rock block slide
Rock slide</td><td>Debris block side
Debris slide</td><td>Earth block side
Earth slide</td></tr>
<tr><td colspan="3">LATERAL SPREADS</td><td>Rock spread</td><td>Debris spread</td><td>Earth spread</td></tr>
<tr><td colspan="3" rowspan="2">FLOWS</td><td rowspan="2">Rock flow
(deep creep)</td><td>Debris flow</td><td>Earth flow</td></tr>
<tr><td colspan="2">(soil creep)</td></tr>
<tr><td colspan="3">COMPLEX</td><td colspan="3">Combination of two or more principal types of movement</td></tr>
</table>

Table 1 Abbreviated classification of slope movements.
Source: Varnes, 1978

However, Varnes stated that "*(…) the type of both movement and materials may vary from place to place or from time to time, (…); therefore, a rigid classification is neither practical nor desirable*" [22].

From Varnes' classification, the types of movements can be divided into: *falls*, *topples*, *slides*, *spreads* and *flows*. The sixth movement, *complex*, is a combination of two or more types of the previous movements mentioned before. Moreover, the types of material are divided into *rock* and *engineering soils* (which include *debris* and *earth*) [22].

Like the authors state in *The Varnes classification of landslide types, an update*, *"Ambiguities will always remain"* [24]. However, it can be concluded that the main type of movements are: *fall, topple, slide (rotational* and *translational), spread* and *flows.* In the following Table 2, a whole description of all of them is explained. It is based on the explanations made on *The Landslide Handbook – A Guide to Understanding Landslides* [14] and D.J. Varnes [22]; and for the purpose of this project, the description of the movement, their occurrence and predictability are explained.

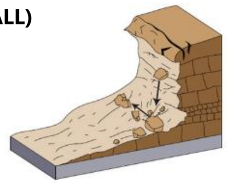
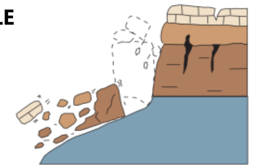
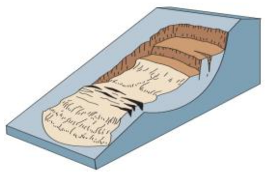
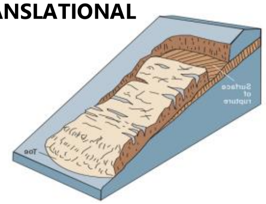
TYPE OF MOVEMENT		DESCRIPTION	OCCURENCE	PREDICTABILITY
FALL (ROCKFALL) 		Descending material by falling, bouncing, or rolling along a surface from a steep slope due to the detachment of soil or rock where little or no shear displacement has occurred.	Commonly on steep or vertical slopes. Also in coastal areas and along rocky banks of rivers and streams.	- Terrain with overhanging rock or fractured or joined rock along steep slopes. - Cut faces in gravel pits. - Mapping of hazardous rockfall areas. - Rock-bounce calculations and estimation methods for delineating the perimeter of rockfall zones.
TOPPLE 		Forward rotation of a mass of soil or rock around a point or axis below the centre of gravity of the displaced mass. Driven under the actions of gravity and forces exerted by adjacent units or by fluids in cracks.	Commonly in columnar-joined volcanic terrain, and along stream and river courses where there are steep banks.	- Monitoring of topple-prone areas by using tiltmeters.
SLIDE	**ROTATIONAL** 	Downslope movement of a soil or rock mass on a surface of rupture that is curve upward and the descending sliding movement is more or less rotational around a parallel axis to the contour of the slope. The material may move as a coherent mass along the rupture surface with little internal deformation whereas the head of the displaced mass may move vertically downslope and the upper surface may tilt	Mostly occurring on surface of rupture or on relatively thin zones of intense shear strain and in homogeneous materials (mainly in fill materials).	- Historical slides can be reactivated. - Consider good indicators of the initiation of failure like cracks at heads of the slopes.
	TRANSLATIONAL 	Outwards or downwards and outwards mass along a planar surface with little rotational movement or backward tilting. Unlike the rotational slides, they do not tend to restore the slide equilibrium, this slide may progress over distances if the surface of rupture is sufficiently inclined.	They commonly fail along geologic discontinuities (joints, bedding surfaces or the contact between rock and soil). However, they are found globally in all types of environments and conditions.	- Repetitive translational slides where they have already occurred. - In areas subject to frequent strong earth-quakes. - Consider good indicators of imminent failure like widening cracks at the head or toe of the slope.

Table 2 Description of the main type of movements.
Source: Own elaboration based on references [15] and [22].

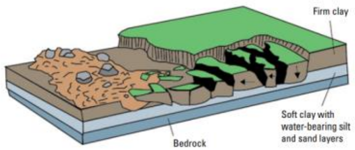
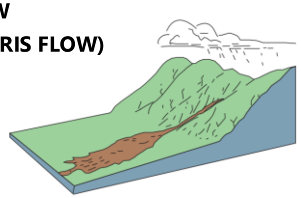
TYPE OF MOVEMENT	DESCRIPTION	OCCURENCE	PREDICTABILITY
SPREAD (LATERAL SPREAD) 	Lateral extension of the ground together with shear or tensile fractures.	They may result from liquefaction or flow (and extrusion) of the softer underlying material. On very gentle slopes or flat terrain, where a stronger upper later of rock or soil undergoes extension and moves above an underlying softer, weaker layer. Therefore, they commonly occur, where there are liquefiable soils and in areas where seismic activity is predominant.	- They can occur in areas that already had experienced previous problems. - Frequently in areas that have liquefiable soils and earthquake hazard. - They are related to susceptible marine clays.
FLOW (DEBRIS FLOW) 	Downslope of slurry formed by loose soil, rock and sometimes organic matter caused by a rapid mass movement. They can be very rapid and may occur without any warning.	Frequently in steep gullies and canyons, in slopes (or gullies) that have been denuded of vegetation or heavy rains have happened and in volcanic areas with weak soil.	- Mapping of potential debris-flow hazards. - Areas where heavy rains have happened. - Burned areas or deforestation.

Table 2 Description of the main type of movements.
Source: Own elaboration based on references [15] and [22].

2.1.4. Geological indexes

Landslides are a phenomenon that affect worldwide and can lead to major hazards. As explained in section 2.1.1 What is a landslide?, they can cause big amounts of deaths a year as well as great amounts of economic losses. Moreover, rockfall are the phenomenon that most affect civil engineering construction in mountainous areas, reason why this thesis focuses on them from here on.

When focusing on rockfall, it is important to highlight the examination of the rock mass in order to prevent or predict future landslides. Geomechanical classifications and rock mass and joint's deformability and resistance are some of the aspects that require further examination.

In this section of the chapter, a summary of the description of some index that characterise rock masses and slopes that were explained last year in Geological Engineering class are provided (see Table 3). Furthermore, it is important to highlight that these indexes are mostly based on visual checks that need to be carried out; fact that is important to consider for this thesis in order to justify afterwards the development of the augmented reality app.

Index	Definition	Parameters
Rock Quality Designation (RQD)	Indicates the percentage of "good" rock recovered from an interval of a borehole	Length of core pieces > 10 cm
		Core run length
		Volumetric joint count
Rock Mass Rating (RMR)	Geomechanical classification system for rocks	Strength of intact rock material
		Rock Quality Designation (RQD)
		Condition of discontinuities
		Groundwater conditions
		Orientation of discontinuities
Slope Mass Rating (SMR)	For the evaluation of rock slopes' stability.	F1, F2 and F3: adjustment factors related to joint orientation with respect to the slope orientation F4: adjustment factor that depends on the excavation method used
Rockfall Hazard Rating System (RHRS)	Index related to the assessment of risk exposition to rockfall.	Slope height
		Ditch effectiveness
		Average vehicle risk
		Decision sight distance
		Roadway width
		Structural condition
		Friction
		Difference in erosion rates

		Block size
		Volume of rockfall per event
		Climate and presence of water on slope
		Rockfall history
Rock mass quality (Q-system)	It values the rock mass quality.	Rock Quality Designation
		Joint set number
		Joint roughness number
		Joint alteration number
		Joint water reduction factor
		Stress Reduction Factor
Geological Strength Index (GSI)	Characterisation of rock masses on the basis of interlocking and joint alteration	Rock mass structure
		Surface conditions

Table 3 Summary of geological indexes
Source: Own elaboration

To conclude this section, as it can be seen in all these index calculations presented above, many visual inspections need to be into consideration, and due to the fact that these methods are susceptible to the person that conducts the examination, technologies should be implemented in this calculations in order to reduce the number of errors or be more precise with the results. (See Annex A.4 for more information about these indexes).

2.1.5. Inspection of landslides

Landslides occurrences can produce big amounts of material moving down the slope and can lead to big disasters. Although this amounts can be very variable, the material can always fall at high velocities. This, among the causes explained before, lead to the study of the embankments before they lead to future landslides in order to mitigate the risks.

One of the first steps in the inspection is the site investigation, where field observations need to be performed. Keaton and DeGraff (1996) stablished four procedures in the study of a landslides: (1)*pre-field investigation*, (2) *on-site engineering geological investigation*, (3) *surveys of the landslide site*, (4) *interpretation* by means of cross-sections, creation of formal landslide maps and conceptualization of geologic conditions. The second one, includes surface observations and characterisation of the subsurface. From this two, the former, together with geological mapping provides detailed and quantitative information of the slope movements and slip surfaces, position of piezometric surfaces, among others. The latter, respectively, provides information about the constructive properties related to material's strength, deformation or permeability [43].

"Features on the ground surface provide the key to understanding the details of landslide processes and causes" [38] (Schuster, 1996). This information is obtained by means of reconnaissance instrumentation that provides preliminary information related to the movement of landslides and the piezometric level. In Annex A.6 a table comparing several ground survey methods is provided.

However, after a long literature review, all researches conclude that the observation of instable areas along the years has proven that there are some indicators that could show a future landslide [37] and that although the regular performance of visual inspections is required [39], there are not stablished procedures for the inspection of embankments, except for the embankment dams. These need a specified visual inspection to be carried out (see Figure 7). However, these techniques are also useful for detecting changes in the slopes' uniformity of other embankments.

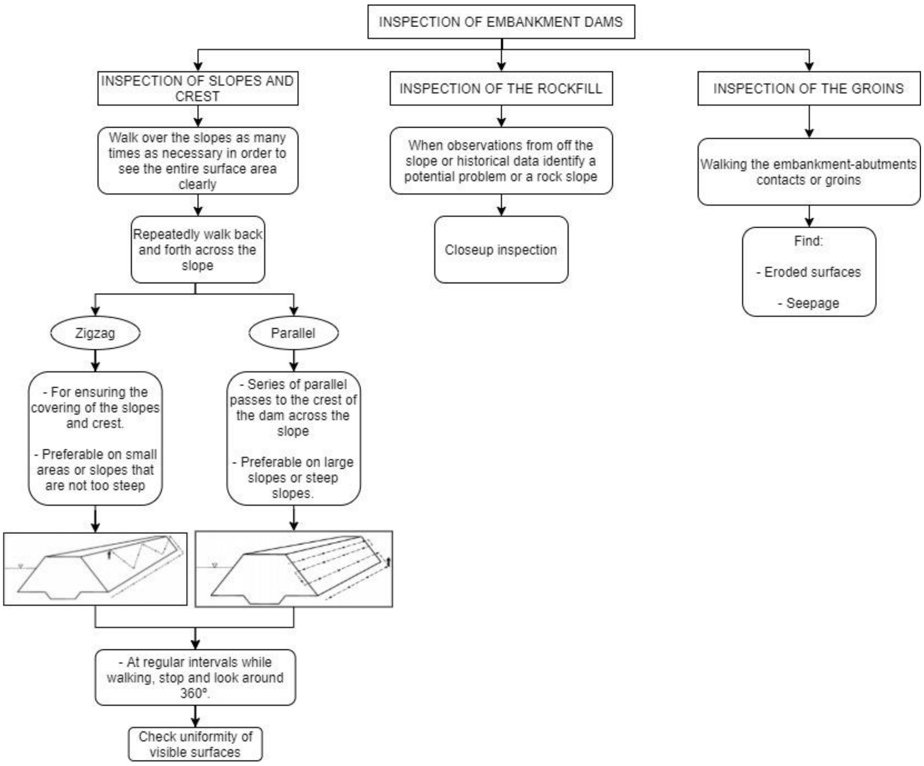


Figure 7 Embankment dams inspection techniques.
Source: Own elaboration based on reference [40][40]

The main objective of these inspections is the identification of deficiencies. These are defined as *"anomalies or conditions that affect or interfere with the proper safe operation of the dam"* [40]. And they are: (1) seepage, (2) cracking (transverse, longitudinal and desiccation), (3) instability, (4) sinkholes and (5) depressions. In order to identify them in the inspection, several aspects need to be looked for in every deficiency [40] (see Annex A.5).

Furthermore, other surveying techniques are the so-called remote sensing investigation techniques and are globally used because of its fast measurement of surface changes [42]. In this section the focus is on these: LiDAR [44], photogrammetry [43] [45] and Global Positioning System (GPS) [45] [46]. Moreover, the development of Unmanned Aerial Vehicles (UAV) (more commonly known as drones) in the last years, has improved the efficiency and quality of the collection of information [40]. Herein, they are explained in a summarised way in Table 4.

LiDAR (3D scanning or LASER scanning)

- It creates high-resolution digital elevation models (HRDEM) that are accurate and precise.
- Topography represented in 2.5D or 3D point clouds.
- LiDAR consists on *sending laser pulses that get back-scattered by various objects and record the returning signal.*
- Depending on the position of the sensor it can be Airbone Laser Scanning (ALS) or Terrestrial Laser Scanning (TLS).
- Within maximum distances of 800-1000m, it has an accuracy of ±5cm and its resolution determines the level of detail of the point clouds.
- In landslides investigations, LiDAR can be used for:
  - Detection and characterisation of mass movements
    - ALS allows the identification of scarps and displaced material of a landslide. This does not replace field investigation.
    - TLS allows the interpretation of landslide mechanism, the delineation of limits and estimation of volumes.
    - ALD and TLS have improved the characterization process in rock slopes due to the fact that rock instabilities are mainly controlled by structures that are locally planar.
  - Hazard assessment, susceptibility mapping and modelling
    - ALS-DEM provides a detailed delimitation on the topographical surface of the landslides which is used to infer the failure surface in 3D.
    - TLS is not mainly used for hazard assessment although it can improve the modelling.
    - Hazard assessment might require the modelling of trajectories and propagation
  - Monitoring
    - The use of HRDEM are required for monitoring techniques and the results are vectors between points or distances between data sets.
    - Easier to perform in rock slopes due to the easy consideration of the material as a rigid body that facilitates the identification and decomposition of the slope movements.

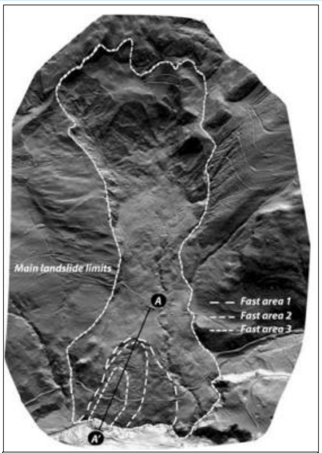


Figure 8 3D View of the shaded relief of the main landslide extent obtained with ALS. La Frasse, Switzerland.
Source: Reference [44]

Advantages:

- ➢ Easy set up and portability.
- ➢ High resolution.

➢ Fast acquisition of data and real 3D information.

PHOTOGRAMMETRY

- Allows the determination of 3D motion vectors
- The images are obtained by satellites, aircraft, helicopters, UAV, digital cameras, scanners…
- Allows the creation of 2D and 3D digital elevation models.

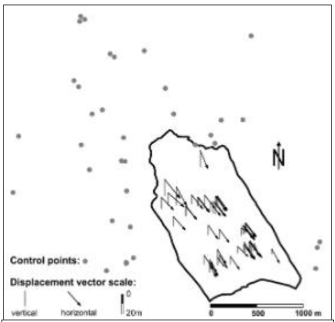


Figure 9 Displacement vectors derived from photogrammetric measurements (period 1962-1996). Gradenbach area, Austria.
Source: Reference [45]

Advantages:

➢ Reduced time of fieldwork.

➢ High accuracy.

Global Positioning System (GPS)

- Together with GIS and remote sensing, GPS can be used to produce hazard layers.
- It can be installed on the surface of the embankment and remotelly controlled.
- The ground displacement is obtained by means of the study of the change in the coordinates.
- Provides differential position information with precisions from 2mm to 2cm (it can be affected by vegetation and topography).

Advantages:

➢ Its measurements hace higher accuracy than the ones obtained by optical surveying.

➢ No line-of-sight obsevations between the stations.

DRONES (Unmanned Aerial Vehicles, UAV)

- Drones allow the collection of:
    - Good quality orthophotos
    - 3D point cloud
    - 3D textured mesh
    - Elevation model of the terrain in raster format.

- Together with digital photogrammetry, drones allow us the collection of cartographic, geometric and graphic products, such as: contour lines, ground profiles, slope maps… In addition to the characterisation of slope movements and collection of 3D models after their occurrence.

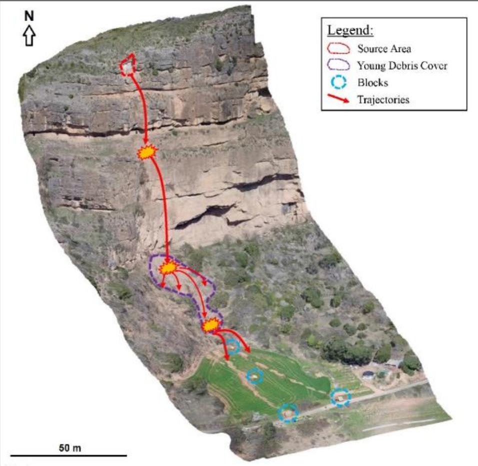


Figure 10 3D model of a landslide in the municipaliti of Gurp, La Conca de Tremp (Catalonia)
Source: Reference [40]

- The 3D models, together with the orthophotos and elevation models allow the accurate measurement, for instance, of maximum extent of the material, slopes or areas, as well as the distance between 2 points or angles.

Advantages:

- ➢ They can fly very close to the ground. Hence, a good resolution is achieved.
- ➢ They contain a satellite positioning system that allow them perform programmed routes and tasks.
- ➢ 3D models improve the scenario interpretation.
- ➢ Unlike digital elevation models (DEM), 3D cloud points obtained with drones allow very accurate ground profiles, which are the basic and needed description in the stability analysis and evolution of a slope.
- ➢ Improves the security and efficiency in the on-site works and the quality of the information obtained.

Table 4 Summary of some remote sensing investigation techniques used for landslides.
Source: Own elaboration based on references [40] [43] [44] [45] [46]

Nonetheless, because of the wide variety of landslides, field conditions, ongoing technological development of monitoring sensors, etc. a standard solution for monitoring cannot be adopted [43].

To finish this chapter, it is important to highlight the use of Finite Element Methods (FEM) in the study of landslides. On the one hand, it helps in the assessment of slope stability analysis, where the computation of the safety factor (mainly by the shear strength reduction technique) is performed. Hence, FEM methods are used in the determination of the correct position of the measuring instruments [47].

2.2 Emergent technologies used in geotechnical inspections

The current technology revolution era we are living in is affecting all the industries. However, not at the same level. This are the called *Emergent technologies* and in geotechnical inspections, the adaptation to them seems more difficult that other industries. That is why this section focuses on these emergent technologies that are improving the industry and how they are implemented in the geotechnical study area.

2.2.1. Virtual and Augmented Reality

Virtual Reality is the combination of objects and scenes that have been created digitally in order to create a three-dimensional virtual environment and make the users have a realistic feeling of different surrounding than the real one allowing them to interact with it [49]. It has several applications in different areas, in addition to gaming that it would be the most famous, such as for educational purposes (driving licence, construction workers, healthcare…), in architecture, tourism, gambling, sports, art and design…[52] (See Figure 11). It allows the possibility of visualising the virtual environment without the necessity of, for instance, being in risk, having to travel or use other expensive resources.

Figure 11 Surgical training and assessment tool with *Osso VR.*
Source: Reference [52]

On the other hand, although Augmented Reality also works with virtual models, it does it in the real environment simultaneously. As its name indicates, it *augments* a virtual object at the same time that superimposes it over the real world. These virtual models include information that has been created by a computer previously in order to understand their interaction with the real world [49][50]. Its uses are mainly focused in the manufacturing industry (see Figure 12) [51] although a considerable amount of studies have been focused on architecture, construction and engineering [52]. For the purpose of this thesis, the emphasis is done in AR technology.

Figure 12 AR mobile device.
Source: Reference [51]

If the focus is put in the construction industry, several Augmented Reality applications have already been developed, although, as Jorge stated in his Bachelor Thesis (2019), the

Augmented Reality investment in this industry is lower. However, these applications prove the extraction of information and easiness of visualisation of complex elements [1]. An example could be the visibility of subsurface utilities (Figure 13) or air passages of a building (Figure 14).

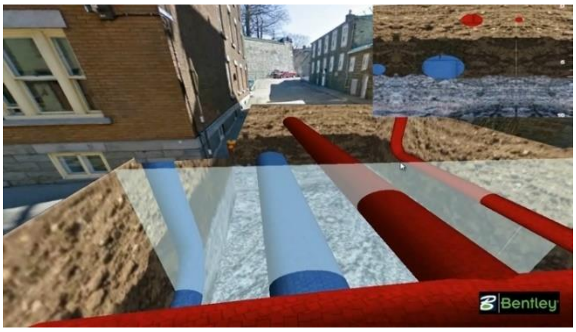


Figure 13 Vertical slicing tool performed in a street in order to see the subsurface utilities.
Source: BentleyCommunities

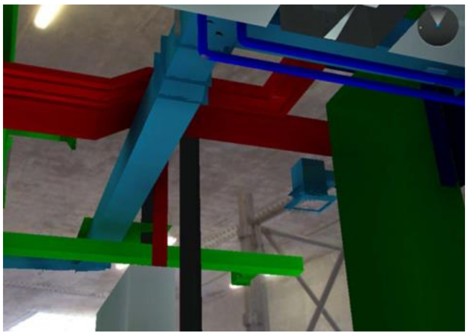


Figure 14 Augmented Reality imaging in situ.
Source: Institution of Civil Engineers (ICE)

Many applications are destined to infrastructure purposes. However, the use of Augmented reality in geotechnics, is still in the early stages of development. The study in the "*Implementation of augmented reality for segment displacement inspection during tunnelling construction"* [52] stated form the results obtained that *"AR has shown to be a potentially useful visualization tool for the AEC industry"*, which should motivate researchers to develop more AR tools. In this study, the evaluation of the AR benefits were studied, concluding that the system met the required accuracy and precision to perform the inspection.

This leads to the encouragement of designing new Augmented Reality tools, not only in all industries, but also in the geotechnical study field.

2.2.1. BIM

Building Information Modelling (BIM) is the new paradigm in the construction process that aims to work in a common model (central model), in which all the stakeholders involved in its creation can communicate and interact together simultaneously. This central model organises information regarding the budget, structures, architecture... During the construction project lifecycle, multiple aspects, dimension of the project and a lot of information need to be managed. In the current situation, therefore, two aspects need to be highlighted, and these are: (1) the misinterpretation of information, in addition to (2) the interoperability problems, that is, the compatibility between the data structure and data template between the shared files. This is due to the one-to-one model communication, instead of the one-to-model that BIM suggests.

BIM works based on parametric modelling, where the geometry's shapes are defined in terms of mathematical equations, relations or constraints that generate them in terms of a series of parameters. Moreover, the representations are three-dimensional and the import of drawings where the model can be build can be imported [49].

This new methodology stablishes 7 dimensions that are [5][6] (Figure 15):

(1) 3D: three-dimensional modelling
(2) 4D: scheduling
(3) 5D: budgeting
(4) 6D: sustainability
(5) 7D: maintenance
(6) 8D: security

Figure 15 BIM dimensions.
Source: G.Bosurgi et al. (2019)

However, BIM does not take into consideration the geotechnics dimension in any of the four phases of the construction process (Design – Build – Operate - Maintain), although it focuses in the whole lifecycle of the project. Because BIM is Object-Oriented, meaning, that it tries to describe the objects trough representing classes and the relationships between them; it can be used in the elaboration of structural, architectural or MEP (mechanical, electrical and plumbing) models. These type of models can be created by the combination of this objects that are already defined. On the contrary, if we focus on geotechnics, every construction site, every terrain, every embankment… is unique. Hence, this is the geotechnic's (and construction's) pain point. Because of its uniqueness, the objects cannot be designed. Marta Fernández (2020) on his final Master Thesis, already commented this and made an exhaustive research on the *"Implementation of geotechnics in building constructions using BIM tools"* [6]. She proposed a methodology in which geological models and survey results can be imported to a BIM platform.
This is an important progress because like this, the cooperation between all the stakeholders involved in the central model of the construction, could be up-to-date at real time and they could interact together while observing the terrain interactions with the building.

Chapter 3. Design of an Augmented Reality based system for in-situ Geotechnical inspection

Once landslides and their inspections have been analysed, the design of the augmented reality tool for the inspection of landslides is explained in this chapter, which includes:

- The justification of the application
- The stablished requirements for its functioning
- The proposed tool for the geotechnical inspection

3.1. Justification of the proposal

The superficial field studies on the embankments are the first steps in the study of their stability [54]. This might provide with the observation of indicators that could lead to landslides in the future. These are the internal parameters such as the morphology of the embankment or mechanical characteristics of the rock [37]. However, there is a lack of routine standardisations on how embankments are investigated.

This *app* aims to facilitate the inspections on site by means of an enriched visual inspection technology in order to make them routine so that future disasters and fatalities could be avoided.

With this, the tool has the objective of improving the on-site inspections by means of Augmented Reality, so that all the equipment needed to carry on site is not needed and the inspector has all the tools in one device. Taking into consideration the embankment dams this equipment is: notebook and drawings, ruler or tape measure, camera and as-built drawings [55]. However, there are other geological tools like the Freiberger compass that enables the measurement of the orientation of geological structures. In this app, the tape measure and camera are the ones chosen, whereas is also opening the door for future improvements based on computer vision combined with Algorithms to identify and classify geotechnical elements.

Another issue that this *app* tries to avoid is the subjectivity of the assessment in the inspection. Although the Image Targets are placed by the inspector the measurements are more precise when they are performed by the device.

With all of these, the *app* tries to bring an innovative approach in the geotechnical and geological study fields in order to keep up with the digitalisation era we are currently living.

3.2. Design requirements

In order to design the augmented reality tool, several requirements are considered in order to achieve the best performance of the *app.* It aims to be a simple application with a clear distribution of the buttons and their respective functions so that every inspector can use it independent on their skills.
Moreover, to see its effectiveness, the so-called Key Performance Indicators (KPI) are used. They demonstrate if the *app*, in this particular case, is working properly or if it is progressing adequately. They can be used to identify poor performances and the improvement potential [67].

In the design of this *app,* several KPI have been considered (see Table 5), although only the ones that could be easily valued are showed in Table 5. Moreover, it is important to highlight the importance of *performance improvements* and *reduction of usage* KPIs because they are the responsible for making people adopt new technologies that provide better benefits that the ones already existing [69].

Key Performance Indicators – AR *App*		**Objective Value**
Quantifiers	Weight *app*	50 MB
	Precision	5 m
	Usability	40 taps
Qualifiers	Hardware	Mobile / Tablet / Computer
	Software	Unity, Vuforia / ARCore, ARKit, Slide3
	Operating System	Android / iOS / Windows

Table 5 Key Performance Indicators for the proposed AR *app.*
Source: Own elaboration based on reference [64]

Firstly, according to augmented reality *apps* for the phone, such as the widely known game *Pokémon GO*, which weight is approximately 51 MB, it has been decided to be 50MB for the creation of the *app.*

On the other hand, the *precision* can be defined in lots of ways. However, due to this fact, in this case it is defined as the distance from which the phone can track the Image Target and augment the virtual model on the screen and its objective value is 5m.

Moreover, the *usability*, like the *precision* indicator, can be valued in several ways. In this case it is measured by the number of taps the user has to do on the screen since the inspection starts until the app closes. It is thought to be 40 taps although depending on the inspection and the inspector this could vary a lot. Hence, this number tries to take this into consideration.

Related to the hardware, this *app* would be used for tablets and mobiles, and its design has to be done in a computer (laptop).

In relation to the software, the videogames platform where the *app* is created is *Unity* and the augmented reality *SDK* responsible for augmenting the content is *Vuforia* (if Image Targets are being used) or *ARCore.* In addition to that, the software responsible for the modification or creation of the geometry is *Slide3,* from *Rocscience.*

To finish, the objective operating systems where the *app* could be downloaded could be *Android, iOS* and *Windows*, that are the most widely used in the previous objective hardwares.

3.3. Proposed tool of augmented reality

The final proposed tool for the on-site inspection consists in a series of steps the inspector needs to follow. The *app* is a combination of scenes that interact between them by means of buttons the inspector needs to tap. Moreover, there are input fields the user needs to complete.

Firstly, the user faces an introductory scene where the welcome is given and there are two possibilities: (1) start the inspection or (2) read the instructions. In the former, the user will start with the next step. On the contrary, if the user choses to read the instructions, a new scene appears with some information regarding the functioning of the *app* and afterwards, the inspection starts in the same scene as if the user had chosen the first option.
Once the experience starts, the inspector needs to fill in the information related to the name, location and current situation. Here, if the user still has questions, he/she can press the *"Back"* button and go to the previous scene where the *"Instructions"* button is available. After completing the first information, the user needs to start with the inspection itself. There, there are several options: (1) go to the next scene and add inspection information, (2) activate or deactivate the visibility of the virtual model, (3) measure lengths and (4) take a screenshot; in addition to the options of going back to the previous scene or check the instructions, as well. The first and third possibilities lead to a new scene, whereas the second and fourth happen in the same one.

In the first one, the inspector needs to fill in information related to the embankment. However, in case the user needs to go back to the previous scene, there is also the *"Back"* button. Furthermore, there are 3 more buttons: (1) allows to save the written information in the input fields in case the user changes the scene, (2) it sends the information to the Excel Form from Google, where all the results are stored and (3) it ends the inspection leading the user to the last scene where a summary of where the screenshots and Excel Form can be found.
In the third one, it is possible to measure lengths by means of the use of two Image Targets.

As it can be seen, the inspection consists in an iterative method in which there is always the possibility to go back to previous scenes and, therefore, perform previous actions.

This inspection finishes when the inspector considers there is no more information to add.

The workflow of the inspection is represented in the next Figure 16.

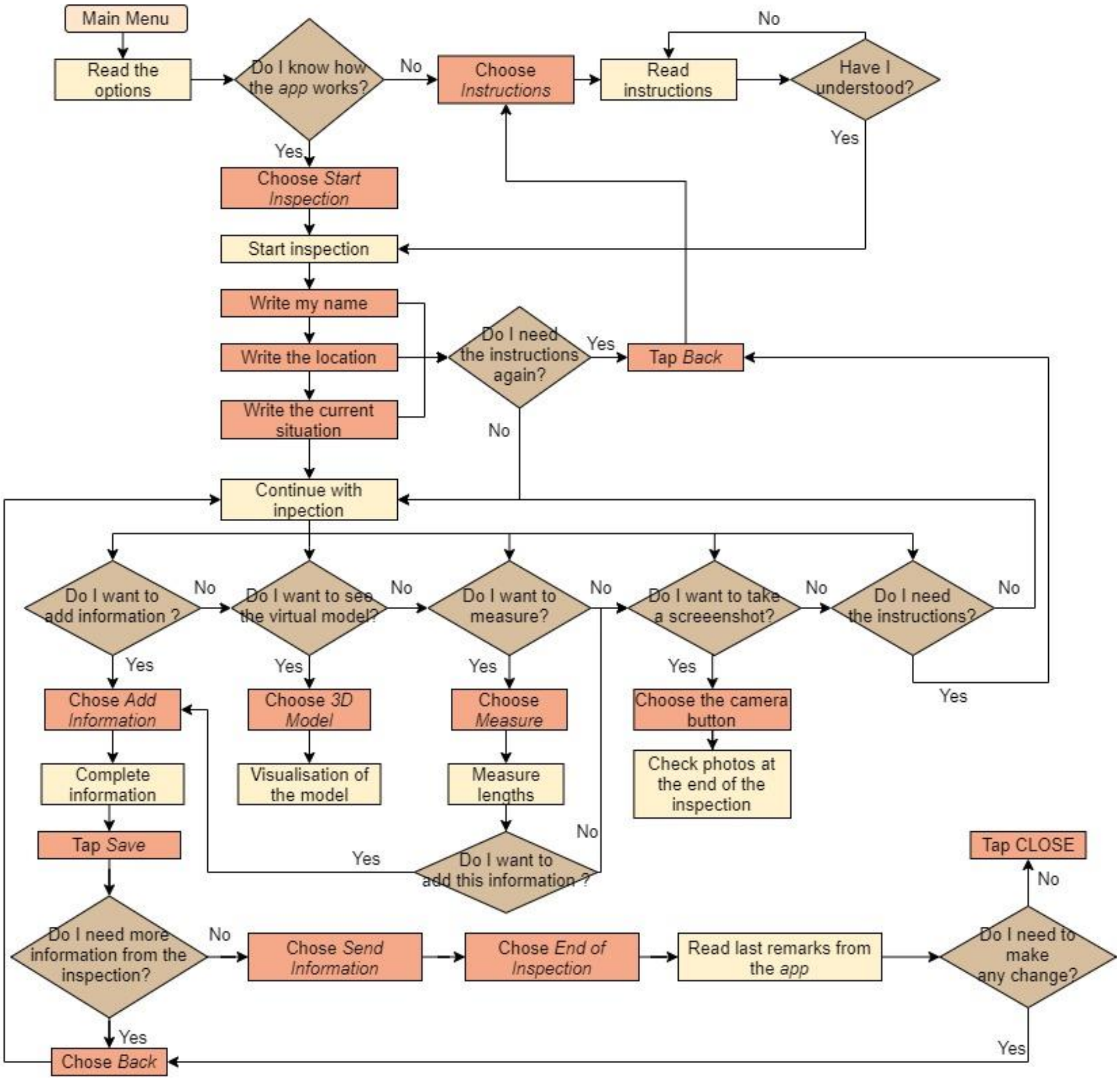


Figure 16 Workflow of the activities to be carried on in the *app*.
Source: Own elaboration using draw.io.

Chapter 4. Development of an Augmented Reality based system for in-situ Geotechnical inspection

The development of the application is based on the previous chapter about its design and the analysed information related to landslides and their inspections. In this chapter, all the softwares used in order to develop the *app* are taken into account, in addition to the process of creation of the *app* itself.
Chapter 4, hence, explains, firstly, the detailed steps that have been followed in the creation of the complete *app*. Afterwards, the exhaustive explanation of the creation of the *app* in Unity, including the creation of scenes and the programming of the *app*'s functions, is provided.

4.1. Development of the tool

In order to develop the augmented reality *app*, different steps needed to be followed. In this section, a description of the interaction between the several platforms used for this development (see Figure 17) and the specific workflow followed (see Figure 18) are described.

To start with the creation of the *app*, firstly, the information related to the geometry is needed in order to create or modify the correct embankment that needs to be inspected. In this thesis, this is done with *Slide3* program from *Rocscience.* However, as a future improvement of the Augmented Reality solution, the geometry could be made during the execution time. Then, the model is imported into the game development software *Unity,* where the whole *app* is created by means of the combination of scenes and the *Software Development Kit (SDK)* for creating augmented reality *apps*, *Vuforia.* Moreover, the proper functioning of the app and buttons, as well as the creation of the final form are possible due to the creation of C# scripts generated in *Microsoft Visual Studio*.

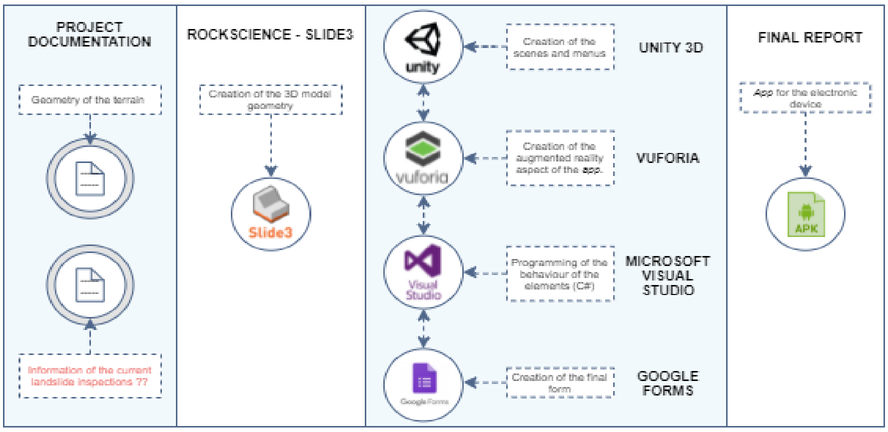


Figure 17 Tool flow for the creation of the virtual experience.
Source: Own elaboration using draw.io.

More specifically, in order to start the process, firstly, the geometry file is needed and hence, the adequate modifications need to be done. This file is imported to *Unity*, so that the embankment can be seen in the program (and, consequently, in the *app*). This sequence of steps focused on the creation of the *.apk* continues with the development of the *app* itself in *Unity*, where the *Software Development Kit* (SDK) for creating augmented reality *apps, Vuforia*, is needed. After the *app* is created, it is time to verify it. If it performs as it was thought to, then this branch is finished and, therefore, the whole workflow is concluded. Otherwise, if the *app* still does not work as we would like, more modifications need to be done until it performs perfectly. When it does, the steps are finished and the design of the app is finished.

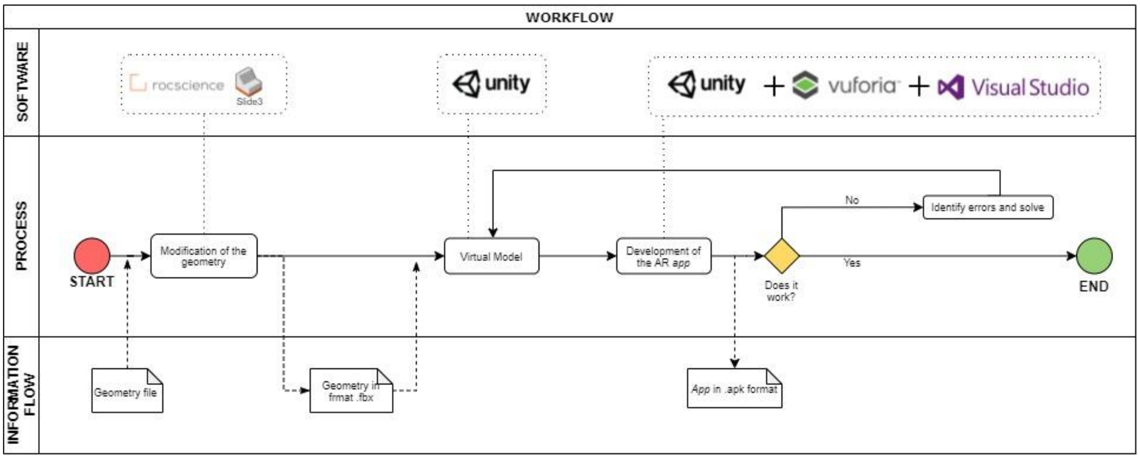


Figure 18 Workflow of the development of the *app*.
Source: Own elaboration using draw.io.

4.2. Creation of the project in Unity

This sections provides the exhaustive description of the development of the project in *Unity*. It is important to highlight that this is a sample *app* that introduced me in the augmented reality *world* and let me obtain the knowledge in order to create an *app*. It tries to encourage the use of augmented reality in geotechnics and justifies its implementation in geotechnical inspections. Therefore, it includes some functions that after the literature review were thought they would be helpful on-site.

The development of the *app* is done with Unity, *"the world's leading platform for creating and operating interactive, real-time 3D content"*, as its website indicates [56]. Moreover, by using *Unity*, virtual reality and augmented reality *apps* can be developed. In this case, the 2019.4.17f1 version of *Unity* for Windows is used. Furthermore, the augmented reality platform *Vuforia* is chosen. It is *"the most widely used platform for AR development, with support for leading phones, tablets, and eyewear"* [57] and it is a *"software development kit (SDK) for creating augmented reality apps" [58]* that uses Image Targets that it can firstly detect and, afterwards, track the image and augment the content. The tracking is possible due to the comparison of *"extracted natural features from the camera image"* against the known target included in a database [59].

In order to create the project, firstly, the program needs to be opened by means of *UnityHub,* previously installed on the computer. This is a management tool that allows managing all the *Unity* projects and installations [60]. In order to create the new project, hence, in the *Projects* window, the *New* button is selected and the version is chosen (in this case 2019.4.17f1). Now, the type of project that is going to be created is selected by specifying *Template3D*, the name of the project (*"TFG"*) and the location where it is going to be stored. All this firsts settings are shown in Figure 19.

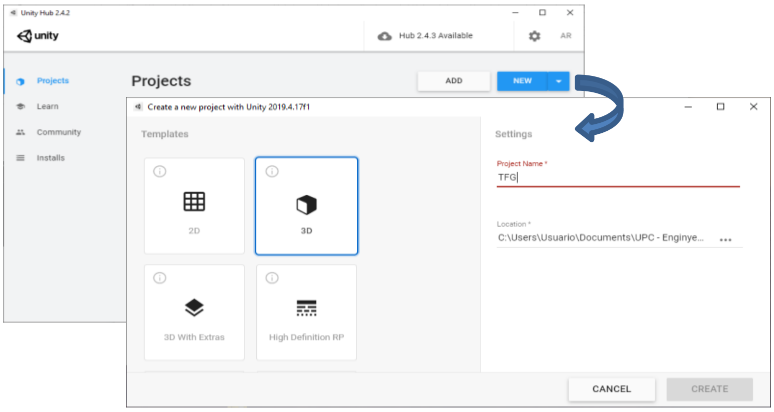


Figure 19 GitHub's window for the creation of a new project in Unity.
Source: GitHub

Now that *Unity* is opened, the next step is to add *Vuforia Engine* to the project. In order to do so, this package is downloaded from *Vuforia Engine Developer Portal* [61] and added to the project by means of the *Package Manager* from *Unity.* In this case it is the version 9.8.5. See next Figure 20:

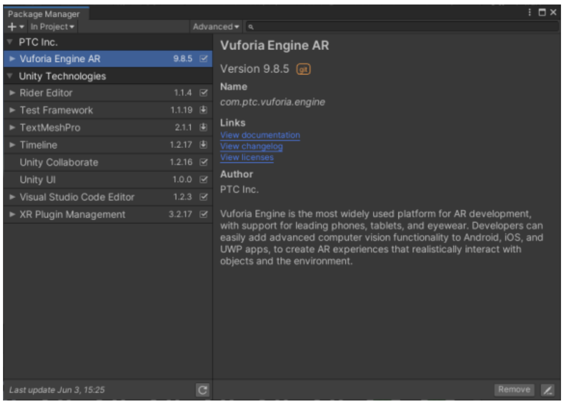


Figure 20 *Package Manager* from *Unity* with *Vuforia Engine* package added.
Source: Unity

Once this installation is done, the *Vuforia Engine* is already added to the *GameObject* tab of the program and all its features can be used.

In order to create the Image Target for this project, first, an account needs to be created in the *Vuforia Developer Portal.* Afterwards, a *License Key* needs to be created in the *Developer Portal* following the next steps: *Develop > License Manager > Get Development Key > Add a free Development License Key.* In Figure 21 it can be seen the one created for this project called *AR Vuforia.* Aftwerwards, the *License Key* is copied and pasted in the *Vuforia* Configuration *App License Key* Figure 22.

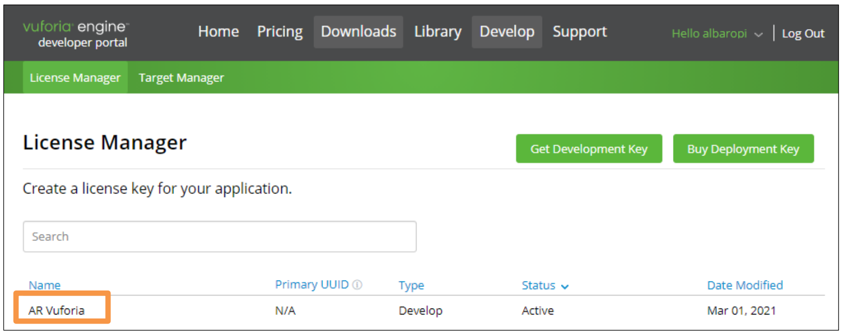


Figure 21 License Key created called *AR Vuforia.*
Source: Vuforia Developer Portal

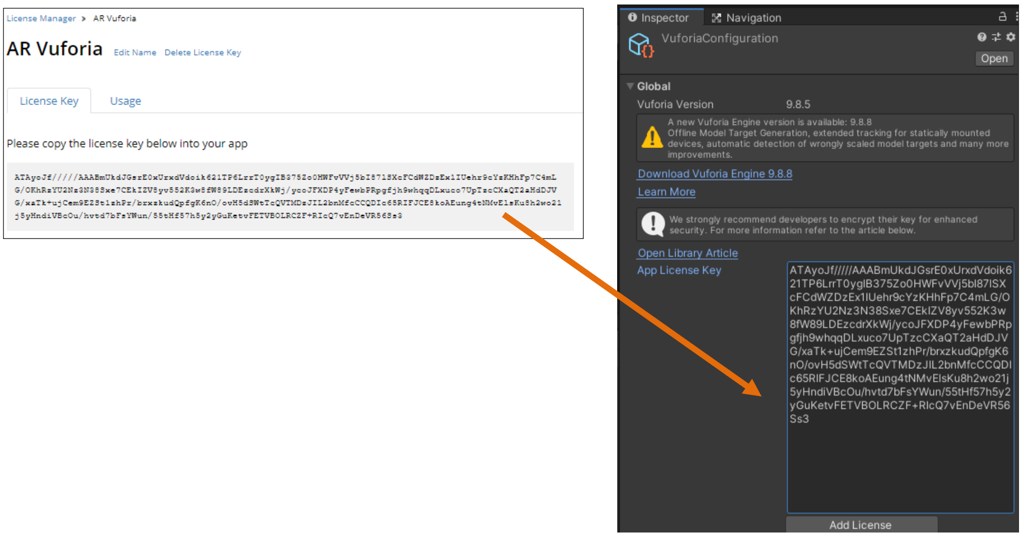


Figure 22 License Key *AR Vuforia* and *Vuforia* configuration in *Unity.*
Source: Vuforia Developer Portal and Unity

The creation of the Image Target continues in the *Vuforia Developer Portal > Target Manager > Add Database.* Here, a name is given *("AR")* and the type *Device* is selected (see Figure 23). Next, the database is clicked > *Add Target > Single Image > Choose the file > write the width (in meters) > give it a name.*

In this *app,* three Image Targets are chosen:

(1) *"marcador_upcc":* Logo of Universitat Politècnica de Catalunya, UPC. It has some patterns that make its detection easier. Its dimensions are: 10 cm x 14 cm (see Figure 24). It will augment the embankment's geology.

(2) *"StartPoint":* It has the letters S.P. and an arrow in order to make the patterns' detection easier. It dimensions are: 20.5 cm x 8 cm (see Figure 24). It will augment a little cube that will indicate the beginning of the measure.

(3) *"EndPoint":* It has the letters E.P. and an arrow in order to make the patterns' detection easier. It dimensions are: 20.5 cm x 8 cm (see Figure 24). It will augment a little cube that will indicate the end of the measure.

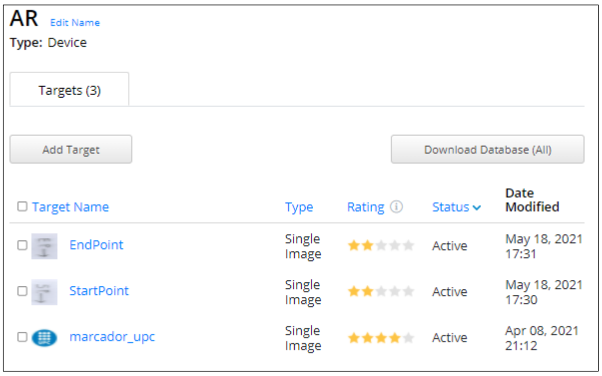


Figure 23 *Data Base "AR"* with the three Image Targets created.
Source: Vuforia Developer Portal

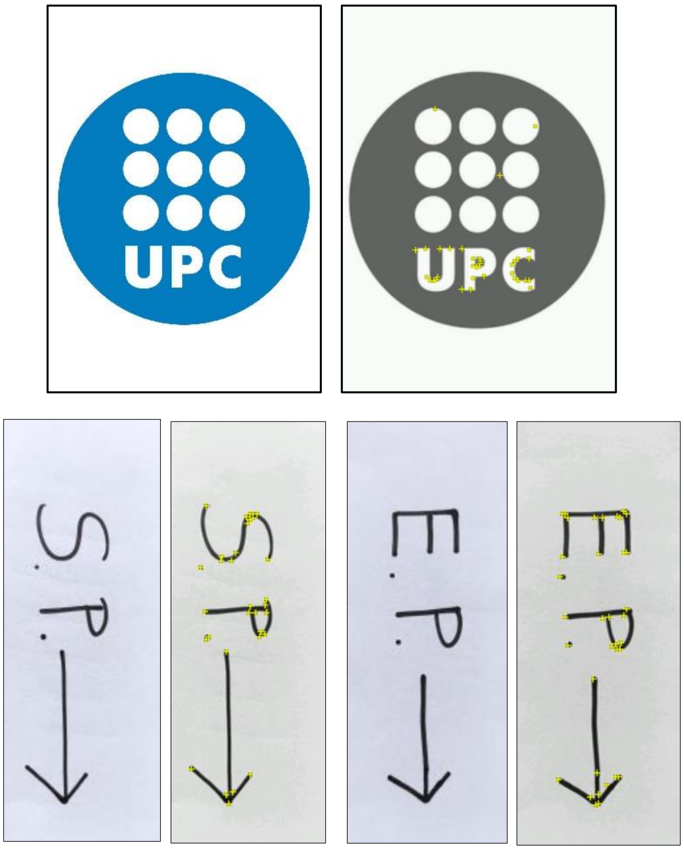


Figure 24 Original Image Targets used for the *app (left) and patterns detected by Vuforia (right).*
Source: Own elaboration and Vuforia

Moreover, in order to understand the whole following process, it is important to highlight that it is only in this particular research project that the *app* is thought to be used in

Android devices. Furthermore, the importance of checking the version numbers and compatibilities between the packages of the several softwares used need to be emphasised because this can easily change with the time, in only some month, or even in some weeks depending on the device being used.

The *app*'s environment is achieved with the help of *Unity Manual* online [62], which indicates the following steps:

(1) Install *Android Build Support* and the *Android SDK & NDK* tools: This is made using *UnityHub*, where in the *Unity Editor*, in the *Unity* version that is already installed from before, some *Modules* can be added. In Figure 25 this can be seen:

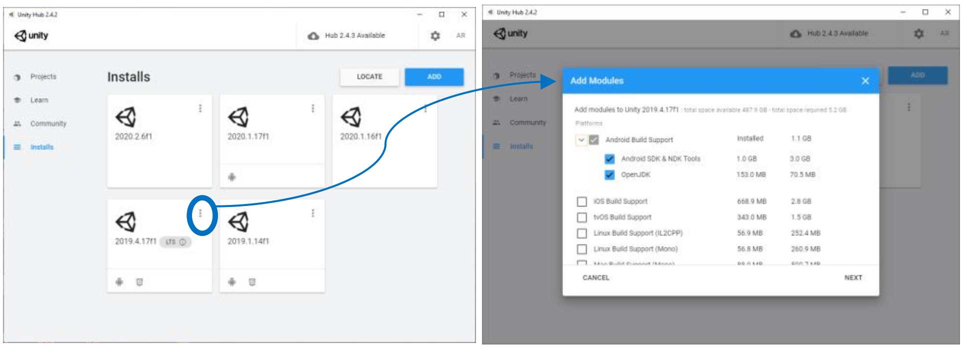


Figure 25 Installation of *Android Build Support* and the *SDK & NDK* tools.
Source: UnityHub

(2) Enable USB debugging on the device: To do so, the *Developer* option in my phone is enabled (*Settings* > *About phone* > Tap 3 times: *Build number*).

(3) Customize the *Android SDK & NDK Tools and OpenJDK* installation: In *Unity: Edit* > *Preferences* > *External Tools* the directory paths of the *SDK* and *NDK* can be found. Although these paths are automatically created, sometimes they need to be reallocated (Figure 26), as it is explained in the next steps:

(4) Change the *OpenJDK* path: Its box needs to be unmarked and install the new *JDK* downloaded from www.oracle.com according to the type of operating system using.

(5) Change the *Android SDK Tools* path: In this case, the *SDK* path was obtained from *Android Studio* program (Figure 27).

(6) Change the *Android NDK* path: This has not been changed because the location automatically placed works.

(7) Updating the *Android SDK Target API*: Because Unity Hub already installs its latest version required by *Google Play*, it is stablished as *Automatic (highest installed)* (see Figure 28).

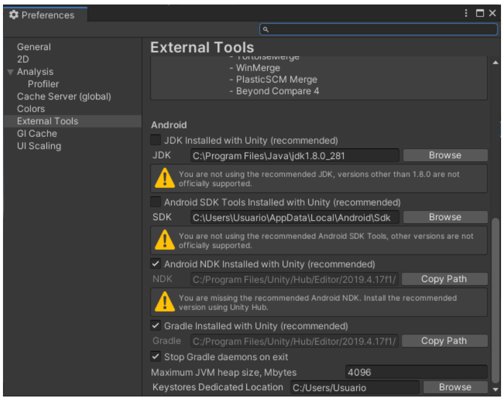


Figure 26 Final directory paths in *External Tools.*
Source: Unity

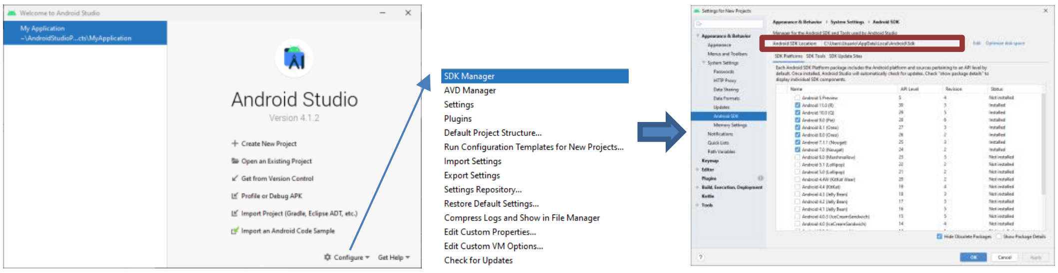


Figure 27 Obtention of the *SDK* path.
Source: Android Studio

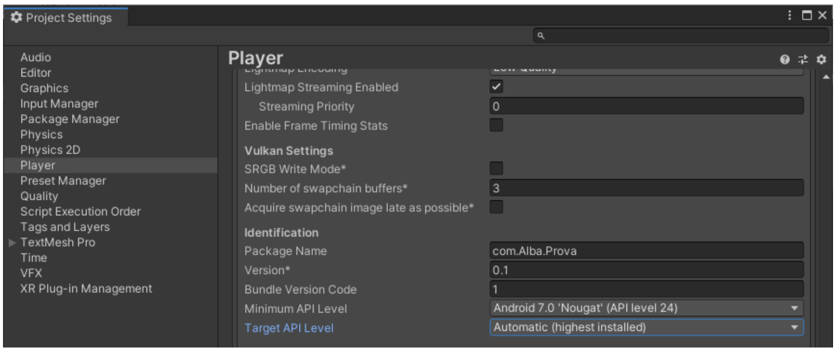


Figure 28 *Target API Level* set as *Automatic.*
Source: Unity

4.3. Creation of scenes

This augmented reality *app* consists on different scenes the user will face while carrying on the field inspection. All these scenes have been created in a new folder called *Scenes.* It is located inside the *Project* window, in folder *Assets* (see Figure 29):

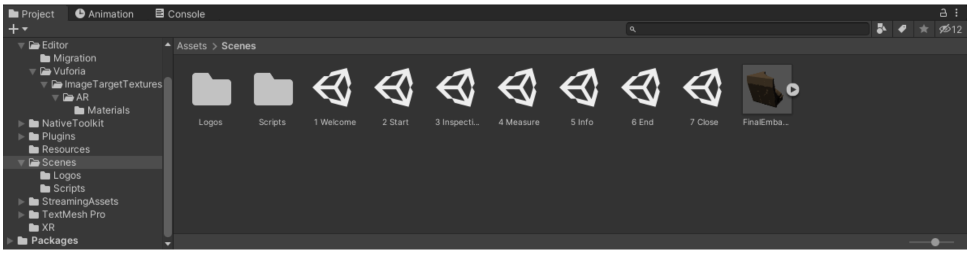


Figure 29 *Project Window in Unity.*
Source: Unity

As showed in the figure above, all the scenes have a number in front so that it is easier to differentiate their order while working in *Unity* and when linking them. Furthermore, this folder includes other folders:

(1) *Logos:* where the different images that are needed during the creation of the *app* are stored.
(2) *Scripts:* where all the scripts created during the development of the *app* are.

The scenes have different purposes although they all have the same structure:

(1) ***AR Camera:*** This camera replaces the default *Main Camera* of *Unity.* It is created by right-clicking in the *Hierarchy* window > *Vuforia Engine* > *AR Camera.* This is a camera game object that includes the *VuforiaBehaviour* to add support for augmented reality *apps* [58]. In all the scenes it has the same configuration and it is as follows in Figure 31.

(2) ***Canvas*****:** This component is created by right-clicking in the *Hierarchy* window > *UI* > *Canvas.* It represents the abstract space where all the UI elements need to be placed [63] and its configuration remains the same in all the scenes (see Figure 30). It is important to highlight that in the *Canvas Scaler* section, the *UI Scale Mode* is *Scale With Screen Size*. This lets the *Canvas* elements fixed and they are not modified with respect to it when the resolution changes and the visualisation of the elements remain the same. Moreover, the *Reference Resolution* is 1280x720.

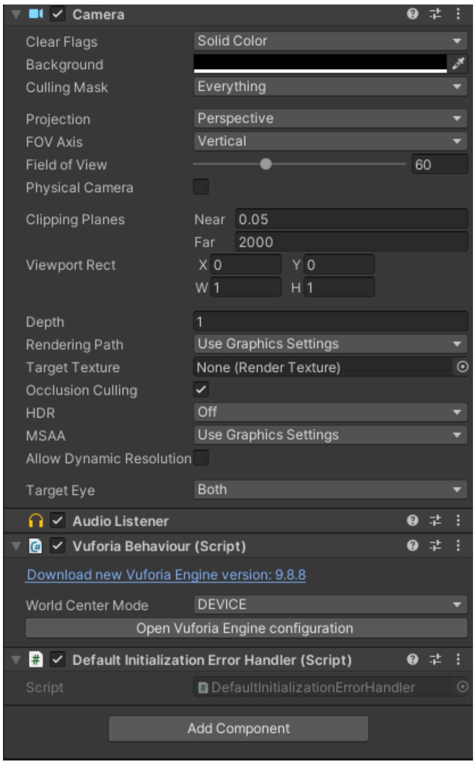


Figure 31 *AR Camera*'s *Inspector* window. *Source: Unity*

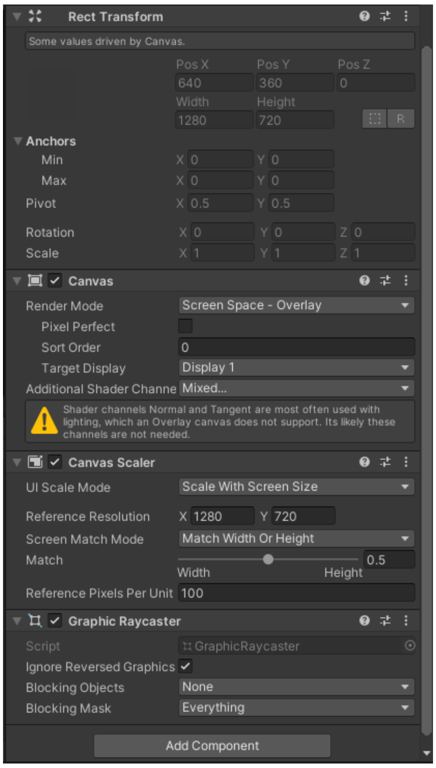


Figure 30 *Canva's Inspector* window. *Source: Unity*

a. ***Panel(s):*** It is the element where the design is made and it can include buttons. For the purpose of this *app* its dimensions are 1280x720 (Landscape).

b. ***Logo:*** This is included on the right corner of all the scenes. It is created by first importing the image in the *Logos* folder. Then, in the *Inspector* window (Figure 32), its *Texture Type* needs to be changed to *Sprite (2D and UI).* Therefore, in order to be included in the *Canvas:* right-click in the *Hierarchy* window > *UI* > *Image.* Rename it as *LogoUPC* and draw the photo from the *Logo folder to the Source Image* field in the *Inspector* window. Select *Set Native Size* in order to achieve the original size and proportions. In order the *Logo* not being displaced from its position on the screen while changing resolutions, in the component *Rect Transform* in the *Inspector* window, the *Anchor Preset* is selected and the *right-top* position is chosen. This *Anchor* allows a relative position of the object with respect to the corner. In the end, the limits of the margins are stablished by changing the positions X and Y.

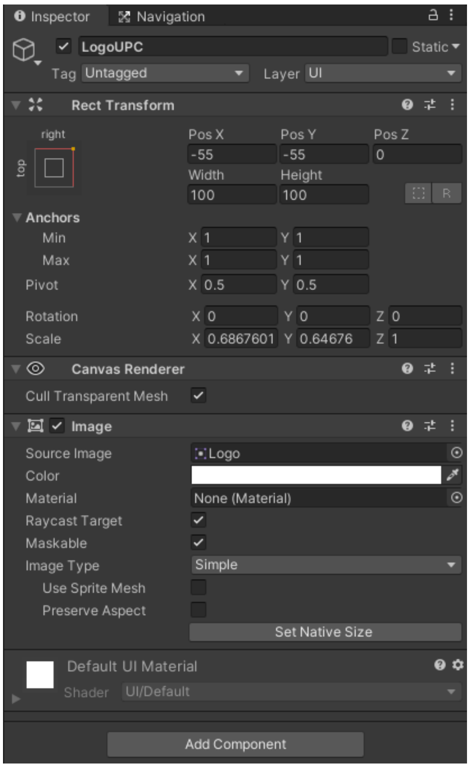


Figure 32 *Logo*'s *Inspector* window.
Source: Unity

c. **Buttons:** These are the *Game Objects* created by right-clicking in the *Hierarchy* window > *UI* > *Button.* They are going to let the user perform different functions all along the inspection. They are also anchored in their respective positions as just explained with the *Logo.*

In the following sections, an exhaustive description of the scenes and their creation with *Unity* is provided.

4.6.1 First scene: Welcome

This is the first scene that the user sees once the *app* is run (see Figure 33). Here, a welcome is given to the inspector and two options can be chosen: (1) start the inspection straightforward or (2) read the instructions in order to know some tips and explanations related to the use of the *app*.

The creation of this scene called *1 Welcome* includes the *Canvas* (explained in section 4.3 Creation of scenes) where all the UI elements are placed: the panel with the title, the two buttons and the panel for the instructions. The other elements than can also be seen in the *Hierarchy* window (Figure 33) are needed for the correct functioning of the buttons.

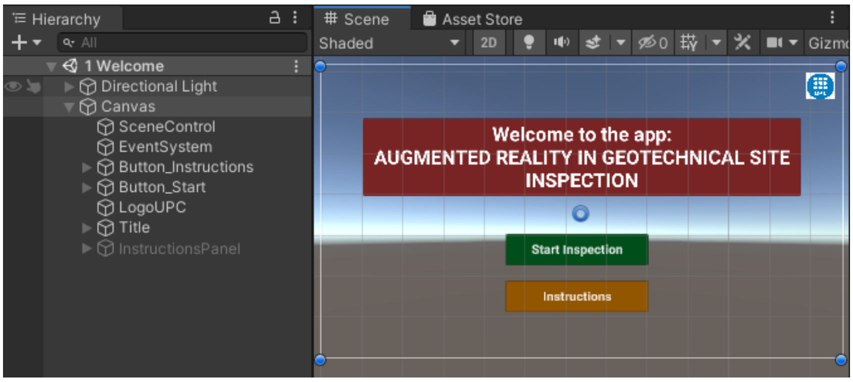


Figure 33 First scene and its *Hierarchy* window.
Source: Unity

In order to add the actions of the buttons, two scripts are needed. The script *"ChangeScene"* (Annex D.1) allows the transition between scenes by means of the creation of a new *GameObject* in the *Hierarchy* window called *"SceneControl".* This is an element that includes the previous script and needs to be drawn to the *On Click* window (Figure 34) of the *Inspector* window, where the next scene the user is led is written, in this case is the second scene called *"2 Start".*

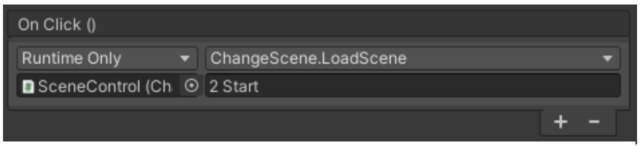


Figure 34 *On Click* window of the *"Start Inspection"* button.
Source: Unity

The *"Instructions"* button, however, is associated to another script called *"Instructions"* (Annex D.2). This allows the visibility of the *"InstructionsPanel"* on the screen (Figure 35). This is achieved by associating the script to the *"Instructions"* button and drawing the *"InstructionsPanel"* (which is deactivated) to the script in the *Inspector* window. Moreover, the action is stablished in the *On click* window, where the button is drawn to it and the options *Instructions > OpenInstructionsPanel()* are selected (see Figure 36).

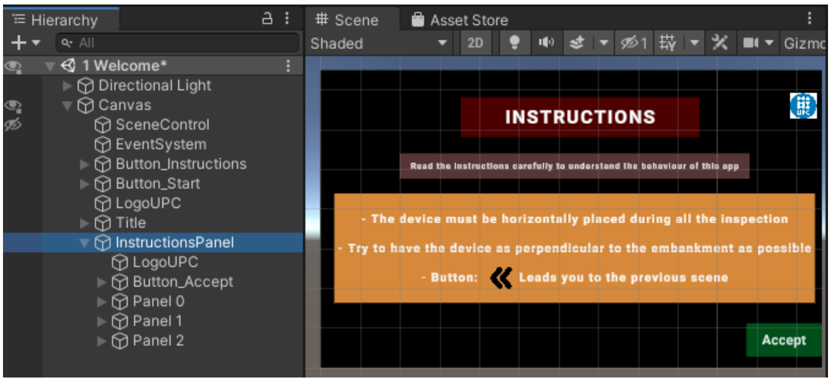


Figure 35 "*InstructionsPanel"* and its elements on the *Hierarchy* window
Source: Unity

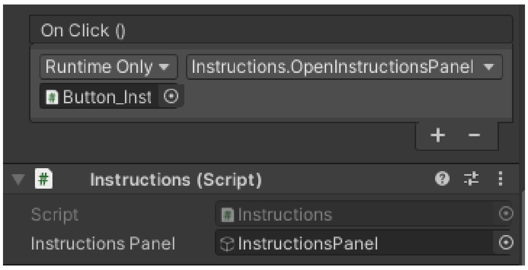


Figure 36 *On Click* window of the *"Instructions"* button and script associated.
Source: Unity

This panel is not a scene itself but it also contains a button called *"Accept"*. This allows closing the *"InstructionsPanel"* and continue in the scene where this panel was opened. To enable this function, the script *"Accept"* (Annex D.3**¡Error! No se encuentra el origen de la referencia.**) is needed and it is associated to the *"Accept"* button, where the *"InstructionsPanel"* needs to be inserted. Furthermore, the *"Accept"* button is drawn to the *On Click* window and the options *Accept > CloseInstructionsPanel* are selected.

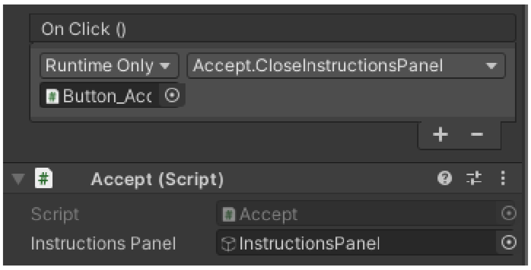


Figure 37 *On Click* window of the *"Accept"* button and script associated.
Source: Unity

4.6.2 Second scene: Start Inspection

This scene, called *2 Start* in Unity, is the scene the user sees when tapping the *"Start Inspection"* button from the previous scene (see Figure 38). Here, different buttons and input field are found:

Buttons:

(1) ***Back*** **Button:** It is positioned in the upper left corner of the screen and it is represented by this symbol: « . If you tap this button, you can go to the previous scene.

(2) ***Next*** **Button:** It is positioned in the bottom right corner of the screen and if it is tapped, it leads you to the next scene. Moreover, this information is sent to the final Excel Form from Google where all the information of the inspection is stored. More information of this form is explained herein (see section 4.4 Final Form).

Input Fields:

(1) ***Inspector's name:*** Here, the inspector has to fill in his name in order to identify the person that did the inspection.

(2) ***Location:*** Text box where the place where the inspection is carried out has to be written. It can be a name, coordinates, kilometric points (PK)…

(3) ***Current situation:*** Whether some cracks are noticed in the rock mass, or the landslide has already happened and the slope has to be measured… Whatever is happening and the reason of the inspection, needs to be written here.

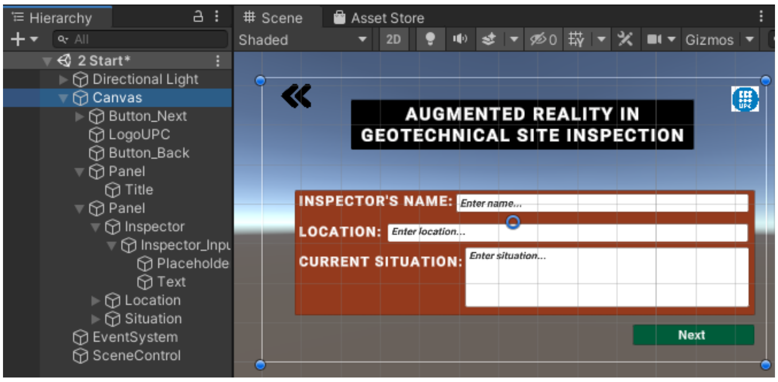


Figure 38 Second scene and its *Hierarchy* window.
Source: Unity

All the previous UI elements are included in the *Canvas* (explained in section 0) and in order to (1) change to the next scene and to (2) send the information to the final form, the *"Next"* button needs to be configured. The former function is created in the same way as in the previous scene: by means of a *GameObject* called *"SceneControl"* that includes the script *"ChangeScene"* (Annex D.1) and drawing it to the *On Click* window, where the next scene is the third one *"3 Inspection"* (Figure 39). The latter, is created in the *On Click* window as well (Figure 39), where the *Canvas* that includes the script *"SendToGoogle"* (see Annex D.7), all the input values and the URL of the form (Figure 40) is drawn. There, the options *SendToGoogle > Send* are chosen (Figure 39).

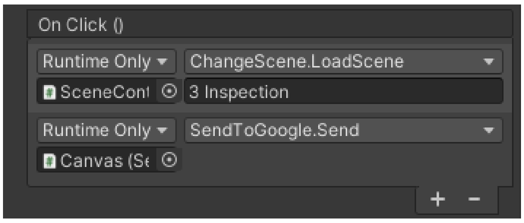


Figure 39 *On Click* window of the *"Next"* button.
Source: Unity

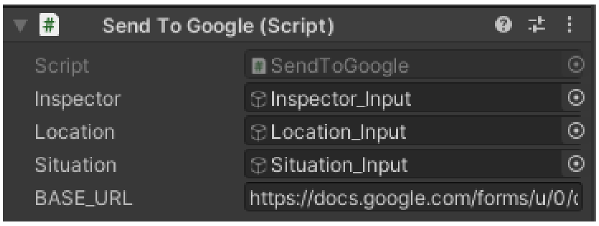


Figure 40 Script associated to the *Canvas.*
Source: Unity

Moreover, the *"Back"* button is configured the same way as the *"Next"* one due to its objective. This button sends the user to the previous scene. Hence, the *GameObject "SceneControl"* including the script *"ChangeScene"* (Annex D.1) is drawn to the *On Click* window, where the previous scene is written manually *"1 Welcome"* ().

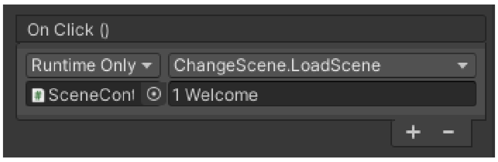


Figure 41 *On Click* window of the *"Back"* button.
Source: Unity

4.6.3 Third scene: Inspection

It is in this scene, called *"3 Inspection"* in Unity (see Figure 42), where the major part of the inspection takes place. There are several buttons that do different actions:

(1) ***Back*** **Button:** It is positioned in the upper left corner of the screen and it is represented by this symbol: **«** . If you tap this button, you can go to the previous scene.

(2) ***"?"*** **Button:** This button makes the *"InstructionsPanel"* visible in the user's screen when tapping it.

(3) ***Add Information*** **Button:** By tapping this button, the inspector is led to the *"Add Information"* scene where some input fields need to be filled with the information measured during the site inspection. More information of this scene is explained herein in section 4.6.4 *Add* Information Scene.

(4) ***3D Model ON*** **Button:** This button activates the visibility of the virtual model.

(5) ***3D MODEL OFF*** **Button:** It deactivates the visibility of the virtual model.

(6) ***Measure*** **Button:** It leads to the *"Measure"* scene, where the measurement of lengths is carried out. More information is provided in section 4.6.4 *Add* Information Scene.

(7) ***Screenshot*** **Button:** If the user taps this button, a screenshot is made and saved on the electronic device being used for the inspection. More information of this function is described in this section.

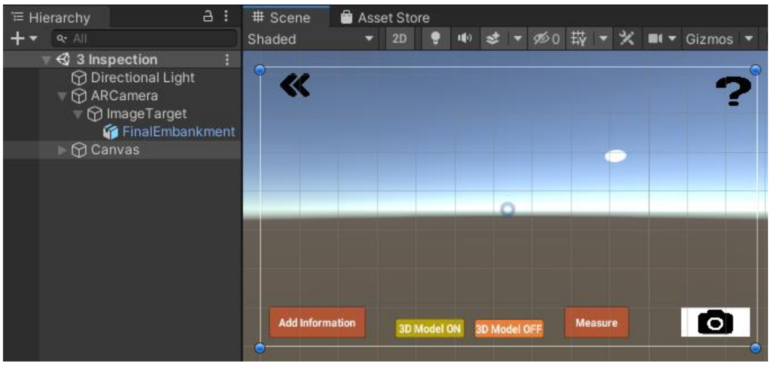


Figure 42 Third scene and its *Hierarchy* window.
Source: Unity

This is the most complex scene created in the whole Unity project, as it includes several buttons that perform different actions. Starting by the *"Add Information"* button, it works the same way as the previous explained buttons that change scenes. The creation of a *GameObject* called *SceneControl* that has the script *"ChangeScene"* (Annex D.1) associated is needed in order to make this function work. Then, this element is drawn to the *On Click* window of the button and the options *ChangeScene > LoadScene* are selected and the next scene once tapped on the button is *"5 Info"* (Figure 44).

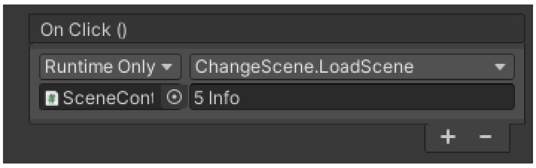


Figure 44 *On Click* window of the *"Add Information"* button.
Source: Unity

The following function is the visibility of the virtual model. Firstly, the configuration of the model needs to be stablished. In order to make the virtual model visible in *Unity,* the *.fbx* file of the geometry from *Slide3* (see section 5.2 3D printing) is imported into the program by drawing the file from the folder in Windows Explorer of the computer, to the *Project* window of *Unity* in the *Scenes* folder (see Figure 29). The visibility of the virtual model is required in this scene, therefore, it has to be drawn to this scene in the *Hierarchy* window, included in the Image Target that is going to augment the content (Figure 45). However, the position of the embankment does not coincide with the coordinates of the Image Target and they need to be changed in order to make possible the superposition of the virtual embankment with the real one when carrying out the inspection. In Figure 45, the position of the embankment is already fixed.

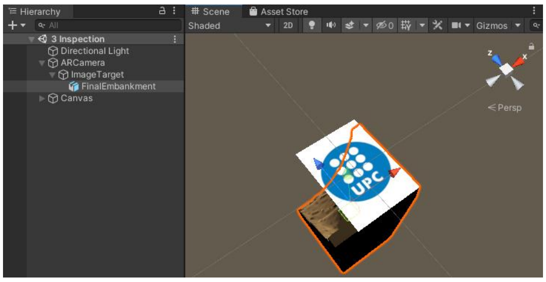


Figure 45 *Hierarchy* window with the geometry added in the Image Target and *Scene* window with both elements.
Source: Unity

Once the model is already placed in the program and on its good position, its visibility in the augmented reality *app* is enabled. So, when the inspection starts, the virtual model is already visible when the Image Target is observed by the device. However, if the user does not want the virtual model to appear in the screen, the button *"3D Model OFF"* can be tapped. On the contrary, if the virtual model wants to be seen again, the *"3D Model ON"* needs to be tapped.

These buttons are UI Elements created in the *Hierarchy* window and their functions are configured in the *Inspector* window > *On Click()* by means of the function *SetActive.* In the *"3D Model ON"* (Figure 46) the ARCamera and the Image Target are activated in order to make the virtual model visible when tapping this button. On the other hand, the *"3D Model OFF"* (Figure 47) needs to have the Image Target deactivated, so that the device does not show the virtual embankment.

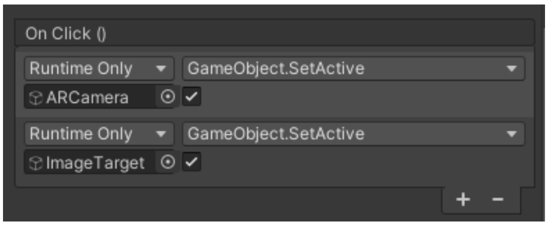


Figure 46 *On Click* window of the *"3D Model ON"* button.
Source: Unity

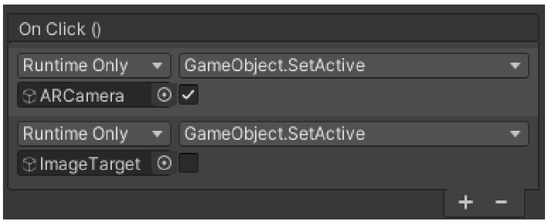


Figure 47 *On Click* window of the *"3D Model OFF"* button.
Source: Unity

Another action the user can carry out during the inspection is taking screenshots just by tapping the camera button. This is achieved thanks to the import of the asset *NativeToolKit*, obtained from the *Asset Store* in *Unity.* Next, in order to allow the program to save the screenshots in the SD Card of the device, the following needs to be followed: *File > Build Settings > Player Settings > Other Settings > Write permission > External (SD Card).* Furthermore, the camera button responsible for the screenshots needs a script associated to it in order to act. This is called *"Screenshots"* (Annex D.5) and it indicates the name of the file (*Screenshot*), the file destination in the device (*ScreenshotInspection*) (see Figure 48) and the file format (*.png*). This button is created with the UI element *Image* in the *Hierarchy* window and the camera image (in *Assets > Scenes > Logos* and previously changed to *Texture Type: Sprite (2D and UI)*) is drawn to the element in the *Source Image* field in the *Inspector* window. However, because this element is an *Image,* it does not behave as a button. In order to be like this, in the *Inspector* window > *Add Component > Button.* Afterwards, in the *Button* script the *Transition* field needs to change to *None* and the function of the button needs to be added. In the *On Click* window, the *"Button_Screenshot"* is drawn and the options *Screenshots > Screenshot* are chosen (Figure 49).

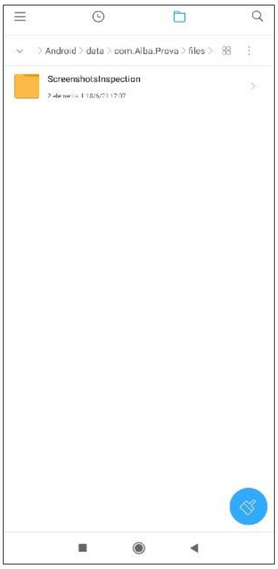


Figure 48 Folder where the screenshots of the inspections are being saved in the phone.
Source: Own mobile phone

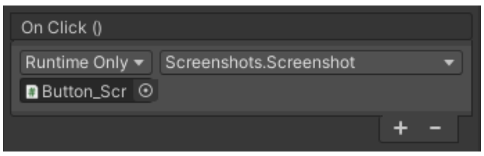


Figure 49 *On Click* window of the *"Button_Screenshot"* button.
Source: Unity

To finish with the buttons, the one that leads to the instructions need to be explained. Like in the first scene, when the user needs instructions, they can press the *"Instructions"* button, in this case, represented by a question mark symbol. Its creations is similar to the screenshot one. Firstly, the image *Interrogante* is found in *Assets > Scenes > Logos* and in the *Inspector* window its *Texture Type* is changed to *Sprite (2D and UI)*. Then, in order to create the button in the screen, in the *Hierarchy* window, a new UI element of the type *Image* is added to the *Canvas.* This new element needs the previous image in order to be represented in the screen, so the image is drawn to the *Source Image* field in the *Inspector* window. Eventually, in order to make this *Image* element work as a *Button,* in the *Inspector* window > *Add Component > Button.* Afterwards, the script *"Instructions"* (Annex D.2) is added to this button where the *"InstructionsPanel"* is drawn. Finally, in the *On Click* window, the *"Button_Instructions"* is drawn and the options *Instructions > OpenInstructionsPanel* are chosen (Figure 50) in order to make the panel visible when tapping the question mark in the screen.

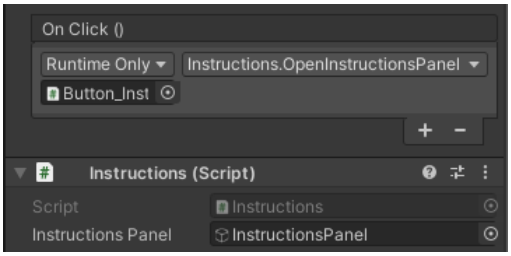


Figure 50 *On Click* window of the *"Button_Instructions"* button and script associated.
Source: Unity

4.6.4 *Add Information* Scene

All the information related to the geotechnical inspection needs to be filled in this scene called *"5 Info"* in *Unity* (Figure 51). There are several input fields where the user can write the responses. The answers can be whereas text or numbers and they can also be uncomplete in case there is no answer for that.

The information considered to be filled in is chosen taking into consideration the different parameters that need to be taken into account in the evaluation of the previous indexes explained in section 2.1.4 Geological indexes, and the information from section 2.1.5 Inspection of landslides. These are the following:

(1) Type of rock
(2) Rock Mass Structure
(3) Length of the discontinuities
(4) Separation between discontinuities
(5) Block size
(6) Boulder volume
(7) Height of slope
(8) Angle of slope
(9) Comments

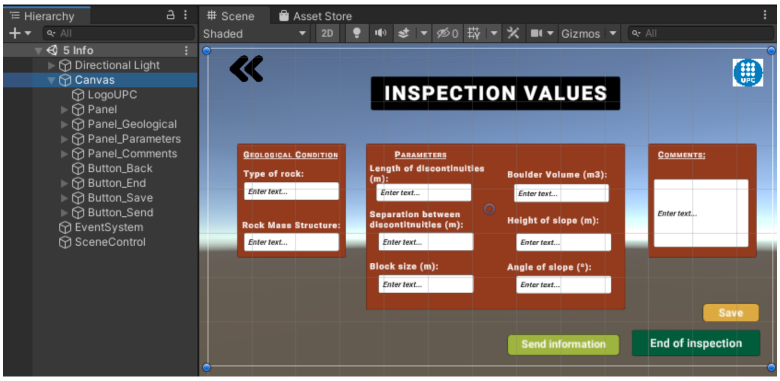


Figure 51 *Add Information* scene and its *Hierarchy* window.
Source: Unity

It also has several buttons:

(1) ***Back*** **Button:** It is positioned in the upper left corner of the screen and it is represented by this symbol: « . If you tap this button, you can go to the previous scene.

(2) ***Save*** **Button:** The completed information remains written in the input field after tapping this button. This way, if the inspector needs to go back to the previous scene, there is no need to write everything again.

(3) ***Send information*** **Button:** By tapping this button, the information filled in is sent to the Excel Form from Google mentioned before where all the answers (including the ones in the second scene) are stored. In section 4.4 Final Form, more information about this form is explained.

(4) ***End of inspection*** **Button:** This button leads the inspector to the last scene.

The first button works as previously explained. It includes the *GameObject* called *SceneControl* that includes the script *"ChangeScene"* (Annex D.1). This element is drawn to the *On Click* window of the *"Back"* button and the options *ChangeScene > LoadScene* are selected. However, it leads the user to the scene *"3 Inspection"* (Figure 52).

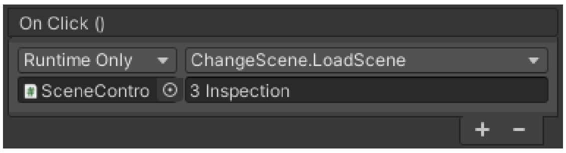


Figure 52 *On Click* window of the *"Back"* button.
Source: Unity

In order not to lose the information of this scene when going to the previous or next scene, the button *"Save"* is associated to the script *"SaveInfo"* (Annex D.6). The input fields need to be drawn into the *Inspector* window, where also, the function of the button is defined in the *On Click*. There, the button is also drawn and the options *SaveInfo > SaveThis* are selected (Figure 53).

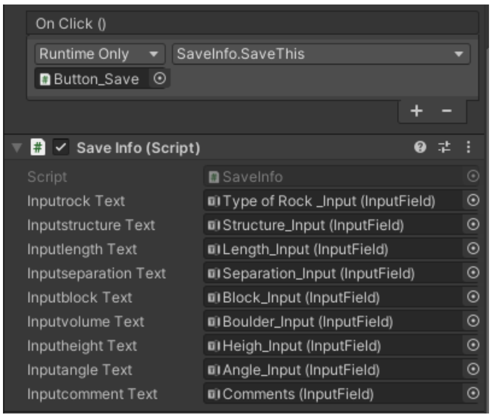


Figure 53 *On Click* window of the *"Save"* button and script associated.
Source: Unity

The *"Send information"* button is the responsible for sending the responses to the Excel Form created at the end of the inspection. This button needs the *Canvas* of this scene to be drawn in the *On Click* window in order to reference where all the input values are from. This *Canvas* includes the script *"SendToGoogle2"* (see Annex D.8) where all the input values and the URL have been drawn (Figure 54). Afterwards, the options of the button are *SendToGoogle2 > Send* (Figure 55).

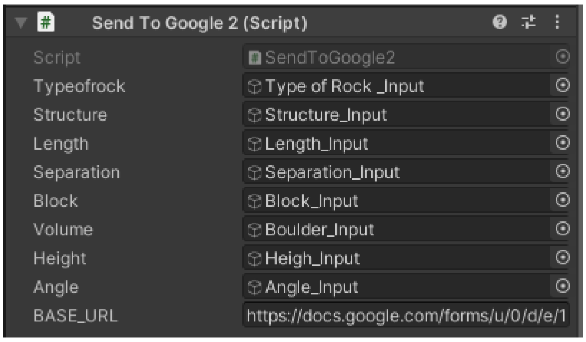


Figure 54 Script associated to the *Canvas.*
Source: Unity

Figure 55 *On Click* window of the *"Send information" button.*
Source: Unity

The last button of the scene is the *"End of inspection".* This is configured in the same way as the buttons that change scenes. It includes the *GameObject SceneControl* that includes the *"ChangeScene"* script (Annex D.1) and it is drawn to the *On Click* window of the button, where the options *ChangeScene > LoadScene > 6 End* are chosen (FIGURE X). This leads the user to the penultimate scene *"6 End".*

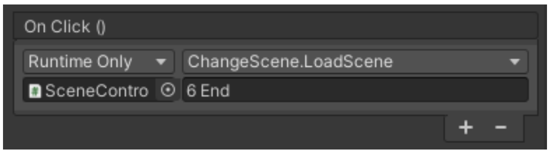


Figure 56 *On Click* window of the *"End of inspection"* button,
Source: Unity

4.6.5 *Measure* Scene

This scene (see Figure 57) allows the user measure lengths, in addition to the previous functions explained in section 4.6.3 Third scene: Inspection that continue having the same behaviour: *"Back"*, *"Instructions"*, *"Add information"* and *"Screenshot"* buttons. However, in this case, the *"Back"* button leads to the previous scene *"3 Inspection"* (Figure 58).

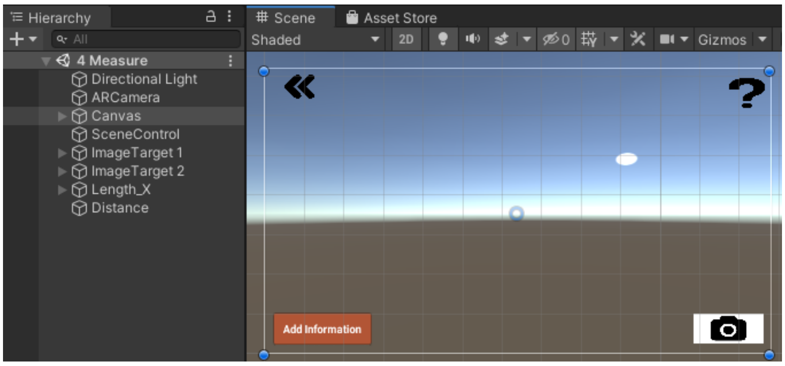


Figure 57 *Measure* scene and its *Hierarchy* window.
Source: Unity

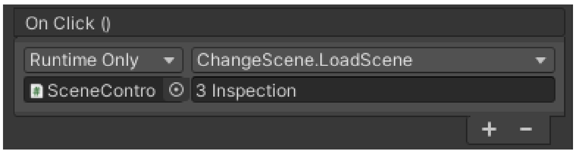


Figure 58 *On Click* window of the *"Back"* button.
Source: Unity

In order to be able to measure with *Vuforia*, two Image Targets are created (called Starting Point (S.P.) and Ending Point (E.P.)). This allows the placement of one element on top of each Target and, as a consequence, when the Targets move, the distance between the points will change.

Firstly, the Image Targets are configured in the *Hierarchy* window as explained in section 4.1 Development of the tool and two squares are placed on top of the Image Targets, at their edges (Figure 59), so that the beginning of the Target indicates exactly the starting

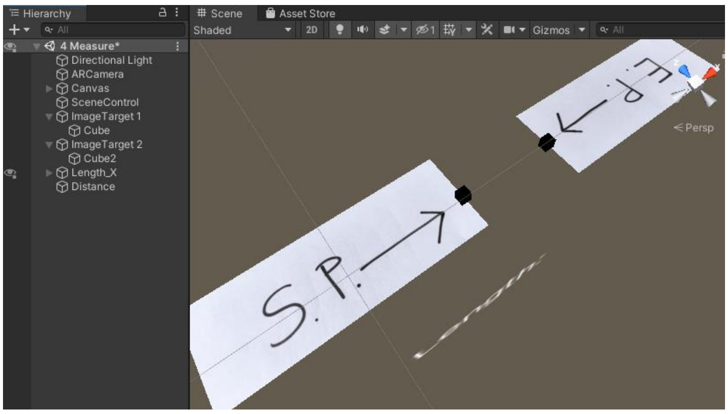


Figure 59 Image Targets with their respective cubes and text where the length is going to be displayed.
Source: Unity

point of the measurement length. Moreover, the measurements are going to be displayed in the screen.

In order to enable the measurement of lengths, both cubes need to have associated one scripts *"Pose"* (for the S.P. Image Target) or *"Pose 2"* (for the E.P. Image Target) (see Annexes D.9 and D.10). These scripts send the information of the position to the script *"Link Pose X"*. Furthermore, the *GameObject* called *"Length_X"*, created to stablish a connection between the cubes, includes the script *"Link Pose X"* (see Annex D.11) where the two cubes need to be drawn in the fields *Game Pose1* and *Game Pose 2* (Figure 60). To finish, so that the measurements are displayed on the screen, the *GameObject* called *"Distance"* is created. It has associated the script *"X_Text"* (see Annex **¡Error! No se encuentra el origen de la referencia.**), where all the previous elements need to be drawn (Figure 61).

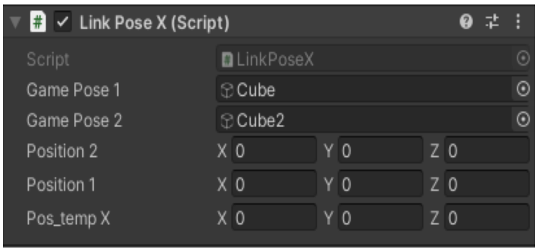


Figure 60 *"Link Pose X"* script associated to the *GameObject "Length_X"*
Source: Unity

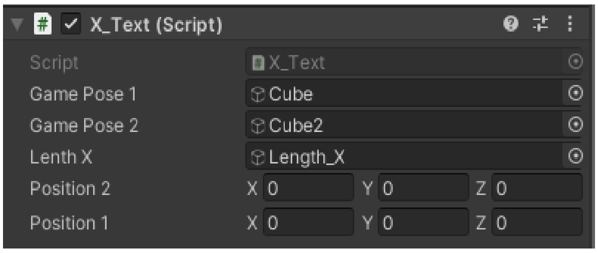


Figure 61 *"X_Text"* script associated to the *GameObject "Distance".*
Source: Unity

In order to develop this measurement function, the Youtube video *"RulAR – Augmented Reality Measuring Ruler – Unity Vuforia Tutorial"* [64] has been used as a reference.

4.6.6 Last scene: End of inspection

With this scene, the inspection is considered as finished. The user is led to this scene by the *"End Inspection"* button in the previous scene *"Add Information"*.

In the screen appears a panel including information regarding the folder where the screenshots taken in the third scene are saved and where the information from the inspection is stored (see Figure 62).
Furthermore, there is a *"Close"* button that leads the inspector to a black screen when tapping it; afterwards, the app can be closed. This button is an *UI element* of the type *Button* that is created in the *Hierarchy* window and it is configured like the previous buttons recently explained that changed scenes. It needs a *GameObject* called *SceneControl* that includes the *"ChangeScene"* script (Annex D.1). Hence, this element is drawn to the *On Click* window of the *"Close"* button in order to be associated with the

script. Then, the options that will tell the button what to do are *Change > LoadScene* and the next scene once tapped on the button is *"6 Close"* (Figure 63).

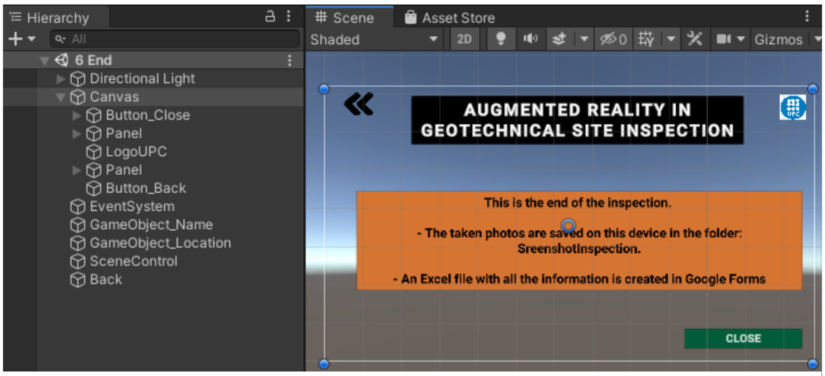


Figure 62 Last scene and its *Hierarchy* window.
Source: Unity

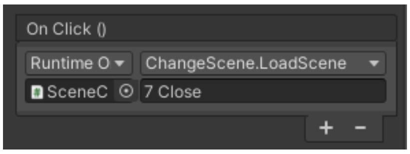


Figure 63 *On Click* window of the *"Button_Close"* button.
Source: Unity

This scene also includes the *"Back"* button that has the same exact configuration as the previous *"Back"* buttons explained in this section (see Figure 64).

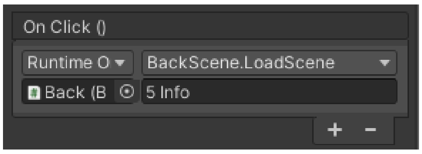


Figure 64 *On Click* window of the *"Button_Back"* button.
Source: Unity

4.6.7 *Close* scene

This scene (see Figure 65) consists in a black panel and its objective is mainly aesthetical so that the *app* is closed when the screen is already black and not with the last scene.

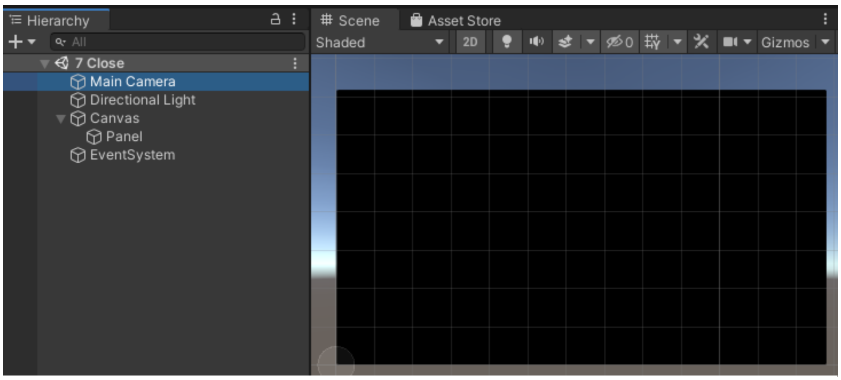


Figure 65 *"Close"* scene and its *Hierarchy* window.
Source: Unity

4.4. Final Form

In order to accumulate all the information that has been collected during the inspection, a form is designed. In this section, an exhaustive description of its creation is presented. To do so, the *Youtube* video *"How to save data to Google Spreadsheet from Unity 3D (No SDK - Plugins)"* [65] has been followed.

Firstly, the type of form used is Google Forms, because it has free access and it enables us to obtain an Excel file with the answers. Once it is created, it is called "Geotechnical Inspection". Afterwards, a brief description is given and the questions that are going to be answered with the inspector's information need to be written (see Annex C to see the Google Form). They are of the type *Short answer.*

Henceforth, the main work needs to be done in *Unity*. To start, the Canvas that have the input fields and the buttons that will send the information to the online form are in scenes: *"Start Inspection"* (section 4.6.2 Second scene: Start Inspection) and *"Add Information"* (section 4.6.4 *Add Information* Scene).
Once identified, in the *Inspector* window in *Unity* (in both scenes) a new component is needed and by clicking in *Add Component*, they are created. These new components are going to contain the scripts that will make it possible to send the information to the Google Form Excel sheet. In this *Add Component* option, the scripts are created by writing the names *"SendToGoogle"* (in the *"Start Inspection"* scene) (see Annex D.7) and *"SendToGoogle2"* (in the *"Add Information"* scene) (see Annex D.8).

In the scripts, the *GameObjects* are created firstly and then, the *strings* in order to store the data from the input fields of the *GameObjects.* Afterwards, a *public void* function, called *Send()* in both scripts*,* is needed in order to store the data prom the input fields into the *string* variables just created. This function is defined differently in both scripts.

Moreover, a *StartCoroutine* called *Post* is defined by taking as parameters the previous *strings.* In order to make it work, an *IEnumerator* is needed to define *Post.* It uses the *GameObjects* defined previously as parameters. Furthermore, because the *WWW* classes from Unity is going to be used in this script, the object *WWWForm* is created. The data is added to this form by the *AddField* method which takes the *GameObjects* and values as parameters. However, it is needed to change this form data information to bytes in order to pass it to a constructor of *WWW* class. Hence, a new object *WWW* is created and it is based on two parameters: *BASE_URL* and *rawData* to its constructor.

To finish, the *yield return www* needs to be written. The former, is obtained from the Google Form created in the first step. Once in the main screen of the form, the *View Page Source* option (when right-clicking the screen) needs to be selected. Here, the BASE_URL for the "Geotechnical Inspection" is found. In order to store this URL in the script, a field called *SerializeField* is created in both scenes, the URL is the same.

Once the BASE_URL is defined, the first values from the *AddField* can be written. They are obtained by right-clicking at the entry fields of the Google Forms page and choosing *Inspect*. Like this, in the attribute of the input field, a text of the type *"entry.number"* is found (see Figure 66). These are the ones needed for the *AddField* first values.

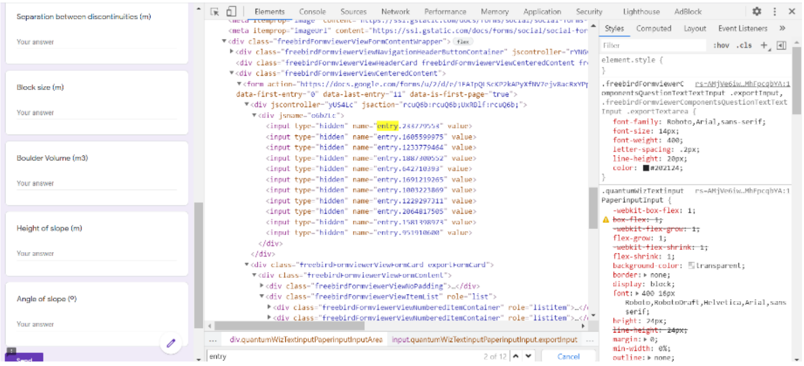


Figure 66 *Inspect* window from the attributes.
Source: Google Form

The scripts, therefore, are finished and it is at this moment when the *GameObjects* need to be linked to the scripts in *Unity*. This is made by means of drawing the input fields to the *Inspector's* window (see Figure 68 and Figure 67).

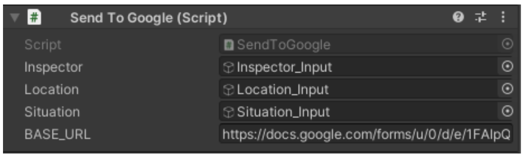


Figure 68 *Inspector's* window from the *"Start Inspection"* scene.
Source: Unity

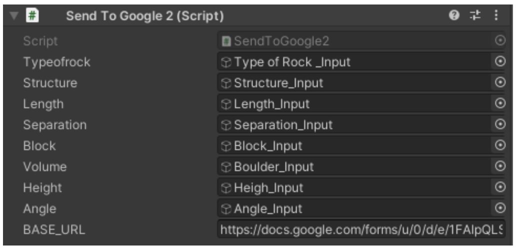


Figure 67 *Inspector's* window from the *"Add Information"* scene.
Source: Unity

On the other hand, the buttons in charge of sending the information written during the inspection to the Google Form "Geotechnical Inspection" need to have this action defined. Therefore, a new event on the *Next* Button (*"Start Inspection"* scene) and on the *Send Information* Button (*"Add Information"* scene) needs to be created, where the respective Canvas needs to be drawn into the *Object* field and the *Function* is *"SendToGoogle.Send"* or *"SendToGoogle2.Send"* depending on the scene. This events are showed in the following Figure 69 and Figure 70.

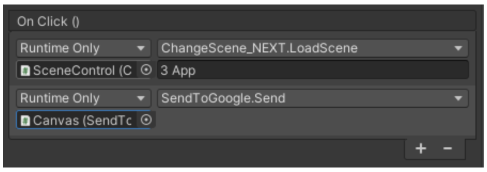


Figure 69 Event on *Next* Button
Source: Unity

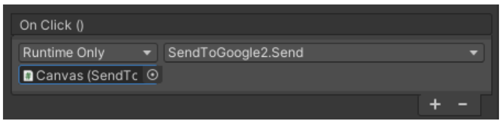


Figure 70 Event on *Send Information* Button
Source: Unity

4.5. Exportation of the *app* to the device

Once the *app* has been created and verified in the *Game* window of *Unity*, it is time to export it to the *.apk* format in order to be installed in the mobile phone.

As explained in section 4.2 Creation of the project in Unity, this *app* has been thought to be used in an Android device. Hence, this configuration needs to be set by means of the following steps: *File > Build Settings > Android* (see Figure 71). When the *Unity* logo appears next to the Android platform it means it is switched and now *Android* is the one chosen. Moreover, in this window, the scenes that are going to appear in the *app* are added in the correct order.

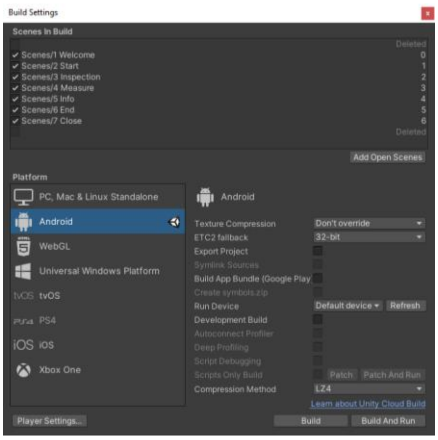


Figure 71 *Build Settings* window of the project.
Source: Unity

Next, the *app* settings need to be adjusted in the *Player Settings* (see Figure 72). First, the *Company Name, Product Name* are set. These are, *Alba* and *AR Inspection*, respectively. In this setting window, there is also set the orientation of the *app.* In this case, the device does not need to rotate, hence, the *Default Orientation* is set as *Landscape Left.* Moreover.

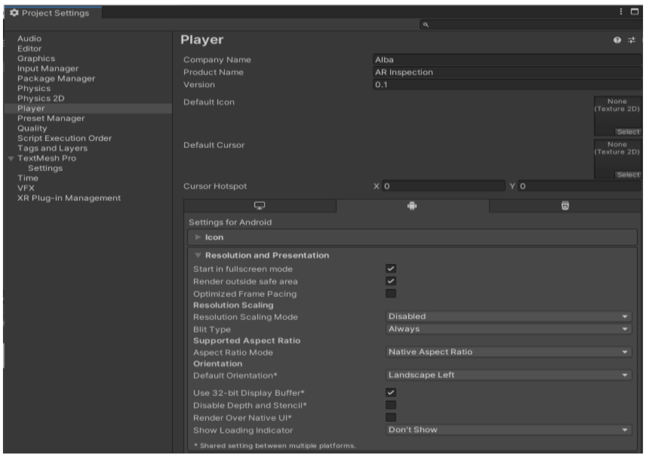


Figure 72 *Player Settings* window.
Source: Unity

The first image that the user is going to face once the *app* runs is selected in the *Splash Image* section (see Figure 73). In this case, the UPC logo has a duration of 3 seconds when the *app* is executed.

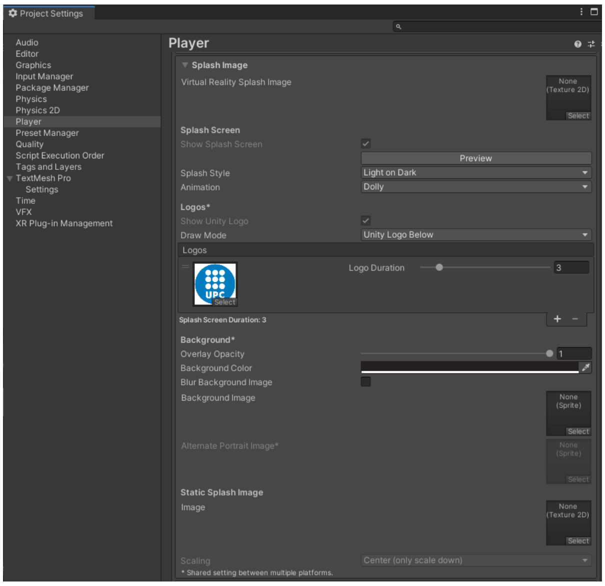


Figure 73 *Splash Image* section in the *Player Settings* window.
Source: Unity.

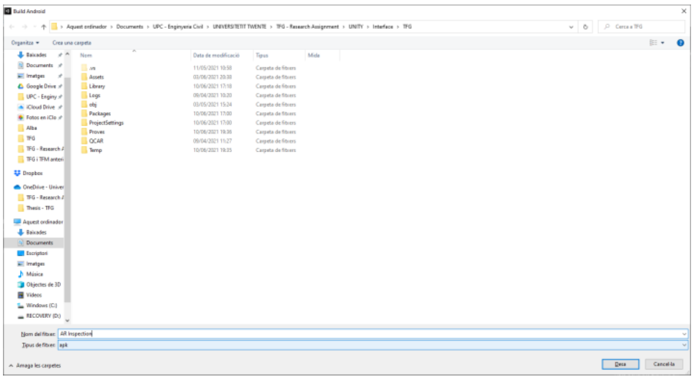


Figure 74 Destination folder.
Source: Unity

In the *Other Settings* section (see Figure 75), it is important that the *Package Name* coincides with the names written in the first step. Also, the *Minimum API Level* is configured, which represents the minimum version of Android that can run this *app.*

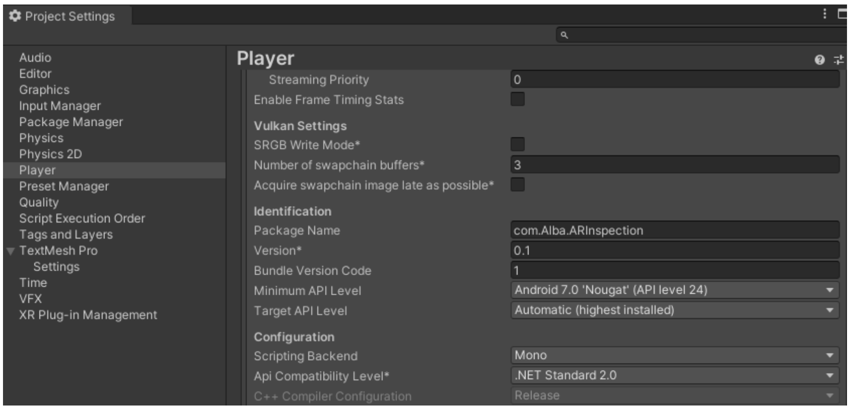


Figure 75 *Splash Image* section in the *Player Settings* window.
Source: Unity.

Once all the settings are stablished, back in the *Build Settings* window (see Figure 71), the *Build* button is clicked in order to create the *.apk* file. Here, its destination folder on the computer is chosen (see Figure 74). Once the file is dowloaded, it is ready to be copied into the phone folder created called *UNITY* (see Figure 76) in order to be installed in the device.

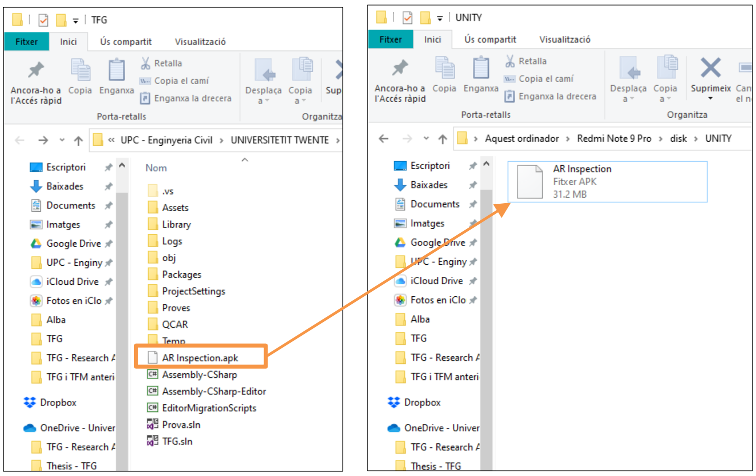


Figure 76 Destination folder of the *.apk* file (left) and *UNITY* folder in the mobile phone.
Source: Windows File Explorer own laptop

Once the file is in the mobile phone, the *app* can be installed and run. Figure 77 shows the phone's folder and the installation process of the *app.*

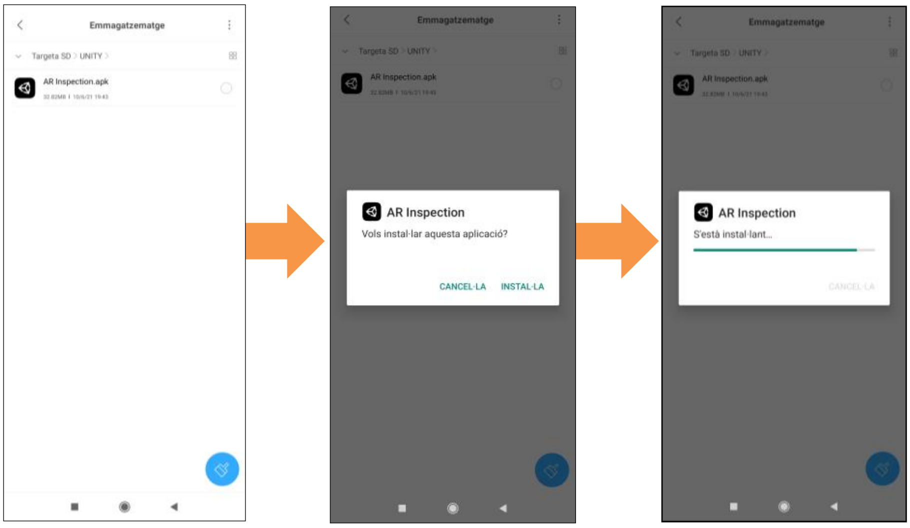


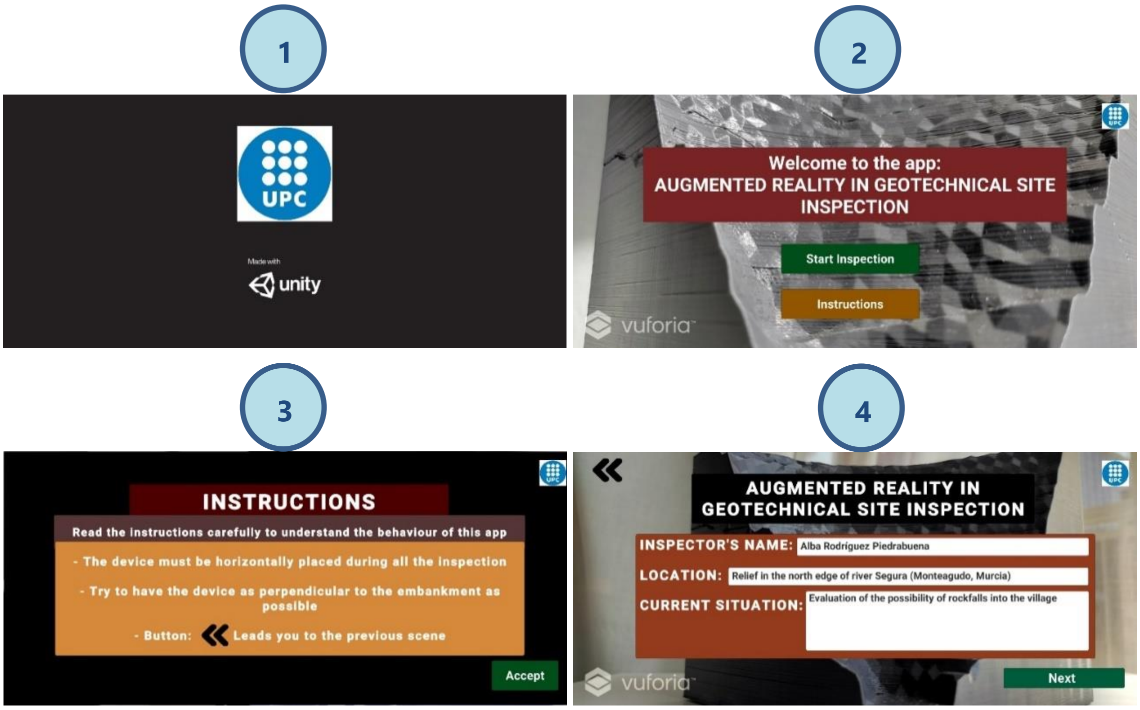
Figure 77 Installation of the *app* in the phone.
Source: Own mobile phone.

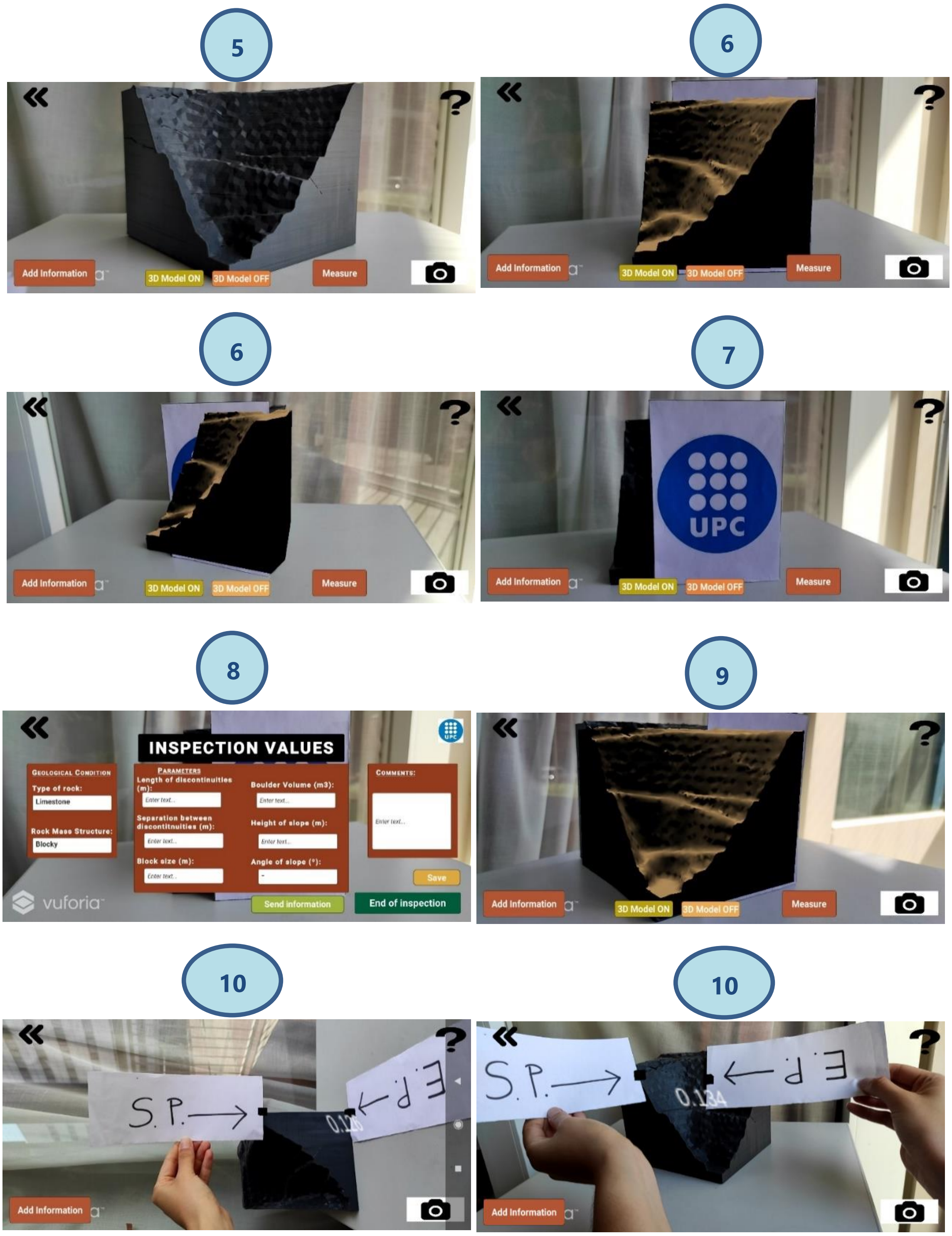
4.6. Functioning of the *app*

The process of the *app,* therefore is the following one showed in the following pages, where the inspection's logics is represented. The information regarding the inspection is based on a real study [66]. However, some of the measurements have been changed according to the dimensions of the scale model.

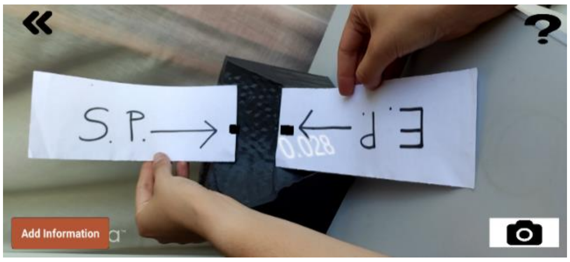
Note that, this is just an example of the iterative process that can be followed during the inspection in order to show all the functions the *app* provides. The steps are:

(1) Splash screen of the *app.*
(2) First scene.
(3) The user decides to check the instructions before starting the inspection.
(4) The information regarding the name, location and the situation are filled in.
(5) Observation of the embankment.
(6) The user taps the *3D Model ON* button in order to activate the visibility of the virtual model in different perspectives and taps the *Screenshot* button.
(7) The user taps the *3D Model OFF* button in order to deactivate the visibility of the virtual model.
(8) The inspector decides to add information about what she/he has observed in the *Add Information* scene and taps the *Save* button.
(9) The inspector goes back to the observation of the virtual and decides to measure some parameters.
(10) The measures are taken.
(11) The user adds information in the *Add Information* scene and ends the inspection first, saving the information added and afterwards, tapping the *End of inspection* button.
(12) The user reads the information of the last scene regarding the inspection and closes the *app.*
(13) The inspector checks the Excel form
(14) The inspector looks at the photos taken during the inspection on the phone.



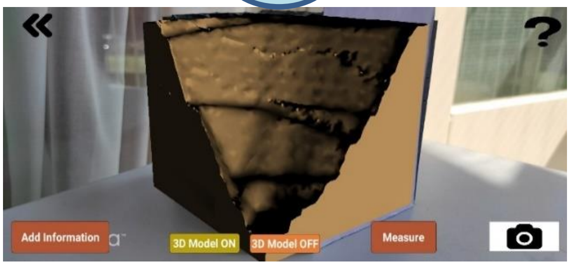

5
6
6
7
8
9
10
10
Add Information
3D Model ON
3D Model OFF
Measure
UPC
INSPECTION VALUES
Geological Condition
Type of rock:
Limestone
Rock Mass Structure:
Blocky
Parameters
Length of discontinuities (m):
Separation between discontinuities (m):
Block size (m):
Boulder Volume (m3):
Height of slope (m):
Angle of slope (°):
Comments:
Save
Send information
End of inspection
vuforia
S.P.
E.P.

10



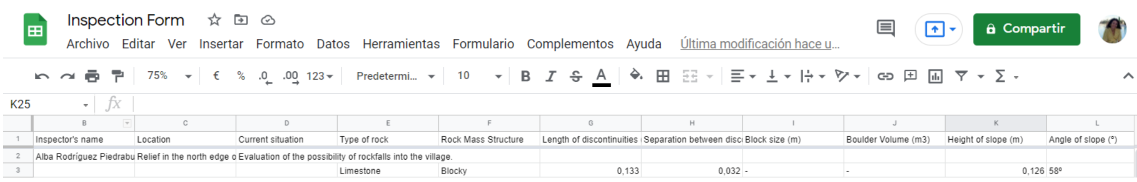
11

12



14

13



	B	C	D	E	F	G	H	I	J	K	L
1	Inspector's name	Location	Current situation	Type of rock	Rock Mass Structure	Length of discontinuities	Separation between disc	Block size (m)	Boulder Volume (m3)	Height of slope (m)	Angle of slope (°)
2	Alba Rodríguez Piedrabu	Relief in the north edge o	Evaluation of the possibility of rockfalls into the village.								
3				Limestone	Blocky	0,133	0,032	-	-	0,126	58°

Chapter 5. Evaluation of the app

Once the *app* is developed, it is time to validate and evaluate its correct functioning. It is important to highlight that during the whole creation of the *app,* evaluations are done in order to improve its development and have the best possible result.

In order to perform the evaluation, an embankment to evaluate the *app* is needed. Nonetheless, due to Covid-19 and the impossibility of working with technical engineers, the testing process cannot be carried out on-site. Hence, a scale model is created specifically for this purpose, which also gives the opportunity to work for the first time with 3D printing. In this chapter, the description of this whole creation is firstly included.

5.1. Creation of the embankment

In order to be able to evaluate the requirements explained previously (see section 3.2 Design requirements), firstly, the embankment needs to be created. This section provides a detailed description of the procedure followed to create this geometry that afterwards is 3D printed. However, a general simplification of the whole process is provided herein.

The additive manufacturing (AM) technology, more commonly known as *3D printing* was chosen in order to learn about this fast-emerging and powerful technology. It is widely used in several fields such as agriculture, healthcare, automotive industry, aviation, production… due to its improvement in the production speed and the reduction of costs of the industries. With the creation of 3D objects directly from CAD designs, many opportunities in the manufacturing industry are blooming [70].

However, in this project, the aim of using 3D printing is, in addition to learn about emergent technologies involved in digitalisation processes and creating the scale-model of the geometry, the learning about the possibilities of this technology when performing the whole circle where the real world is first needed to create a virtual representation that afterwards is back again to the physical world.

To start, the creation of the embankment is made using the program from *Rocscience,* called *Slide3.* Because the main objective is not elaborating a new geometry but having one for the evaluation of the *app*, only a file containing a geometry that could represent an embankment is imported into the program. Afterwards, as not all the chosen geometry is needed, only one part of it is taken and the appropriate changes related to its scale and properties are made. Once the ultimate geometry is created, it can be exported. In this case, it is exported in *.stl* format for the 3D printing and in *.fbx* for the

Unity program. The former is sent to DesignLab in UTwente, where they are responsible for printing the model.

Once the general idea of the process is known, a more specific description of it is explained herein.

Firstly, an already existing file in the *Tutorials* folder from Slide3 program is chosen to work with (see Figure 78).

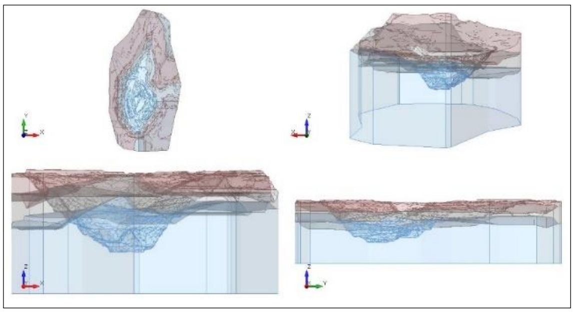


Figure 78 Initial geometry.
Source: Slide3

Due to the fact that the main objective is the evaluation of the app in an embankment, this has to be created first. Therefore, the different geometries that form the general one, need to be *Un-Divided* (see Figure 79) so that a new *External Box* can be created (see Figure 80). This will select the desired volume and delimitate the new embankment. The criteria to create the embankment has been choosing a steep slope and a rough surface of the geometry.

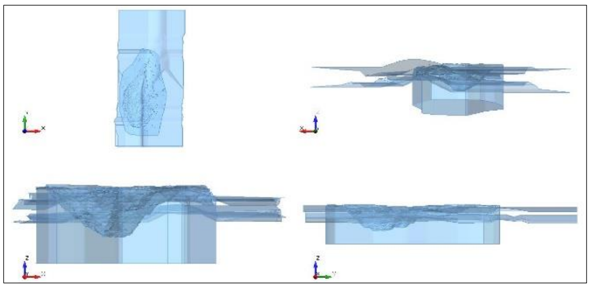


Figure 79 Un-Divided geometry
Source: Slide3

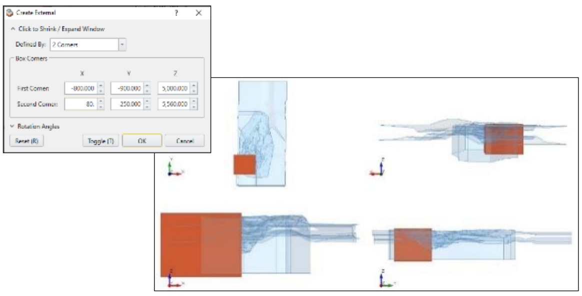


Figure 80 *External Box* with coordinates of the Box corners
Source: Slide3

Once the *External Box* is created, the main interest is the geometry that is inside of it. So, the geometry needs to be divided by means of the tool *Divide All Geometry* and the result of the selected volume is the following one (see Figure 81). Notice that now the *External Box* can be seen because it is selected, but what remains is only the existing geometry inside of it.

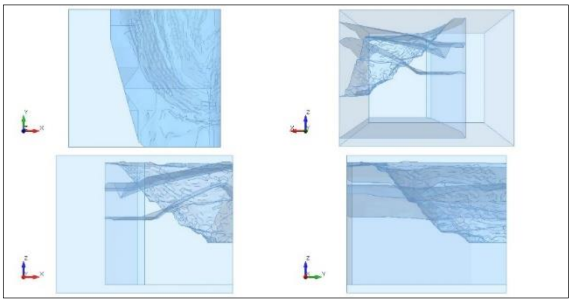


Figure 81 Result of the selected volume.
Source: Slide3

Now, because the *External Box* has created different volumes because of its intersection with some of the layers, these have to be identified and deactivate their visibility by means of the *Excavate* tool (see Figure 82). Moreover, in this step, the properties of the materials are changed: in the already unseen volumes, the material is changed to *No material* and the ones that form the final embankment (visible) are changed to *Rock* material, which needs to be defined (see Figure 83). In this case, the "Cohesion" chosen is 400 kPa and the friction angle ("Phi") is 30º. Furthermore, the "Failure Criterion" chosen is Mohr Couloumb since it has been the one deeply studied during the Bachelor in Soil Mechanics and Continuum Mechanics subjects.
It is important to highlight that these properties are not needed for the objective of the thesis, because what matters in this case is the geometry and any calculus is going to be done with the program.

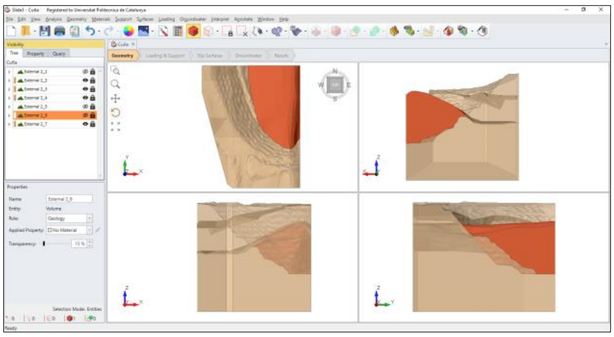


Figure 82 Example of one of the volumes that need to be deactivated.
Source: Slide3

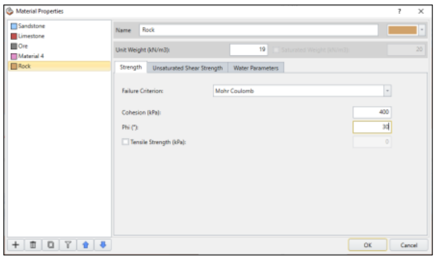


Figure 83 Properties of the new material defined: *Rock*
Source: Slide3

The result of the embankment's geometry is the following one showed in Figure 84:

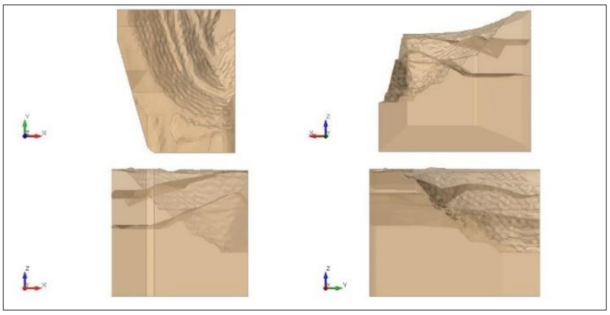


Figure 84 Embankment's geometry.
Source: Slide3

However, the embankment dimensions are real. Hence, they need to be modified (tool *Scale*) in order to fit in the 3D printer. See in Figure 86 the initial dimensions, in Figure 85 the scale applied and in Figure 87 the obtained results. The chosen scale has been a matter of trial an error due to the big dimensions that the embankment had originally.

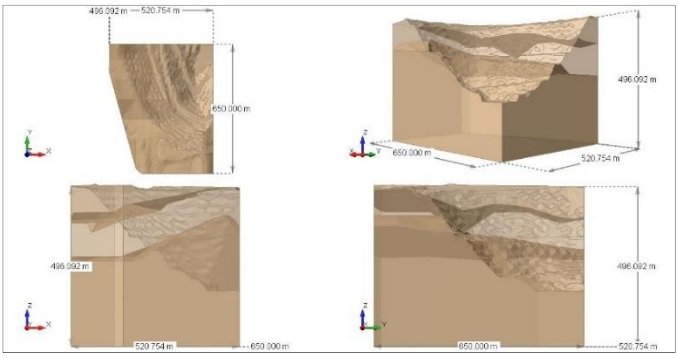


Figure 86 Initial dimensions of the embankment.
Source: Slide3

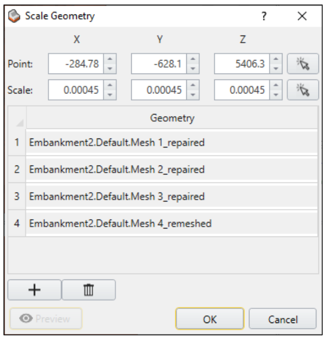


Figure 85 Scale geometry.
Source: Slide3

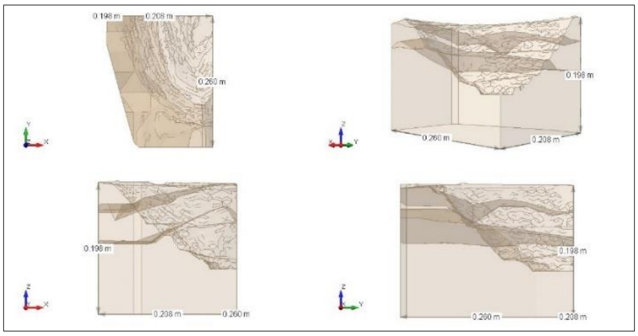


Figure 87 Dimensions obtained after scaling the geometry.
Source: Slide3

The embankment created, therefore, has the dimensions: 0.260m x 0.208m x 0.198m.

Nonetheless, these are not the final dimensions. In the next section of the chapter, new modifications need to be done due to the 3D printing.

5.2. 3D printing

After the embankment's geometry is created, it can be printed. This section provides information related to the 3D printer, in addition to the description of the followed process.

Firstly, the responsible for printing the scale model is DesignLab, as the name indicates, it is the Laboratory of design from University of Twente. Erik, the technician from the laboratory, helps during all the process. The printer characteristics are showed in Table 6:

3D printer model	Ultimaker 2 Extended
Material used	PLA
Filament's diameter	2.84mm
Format file needed	.stl
Colour printing	Grey

Table 6 3D Printer properties.
Source: Information provided by Erik

In order to squeeze the printing volume, the geometry has been rotated (tool *Rotate*) 90 degrees with respect to the X axis. Afterwards it has been exported to an *.stl* file and sent to DesignLab. However, two drawbacks are found:

(1) The geometry does not appear in the printing program.
(2) The dimensions are too big.

Two different approaches are followed in order to solve the stated problems.

(1) Only a shadow is seen on the surface of the printer (see Figure 89), which makes us think about the position of the geometry. Indeed, the coordinates are the embankment real ones and they need to be changed. Hence, the solution is to change the Z coordinate to the coordinate Z=0m. This is done by means of, first, selecting a reference point (corner): X: -284.7m, Y: -627.9m5, Z: 5406.17m in a reference plane. Afterwards, select all the annotated dimensions and geometry and by using the *Translate* tool, everything that is marked moves to the desired position, in this case: to Z=0m (see Figure 88).

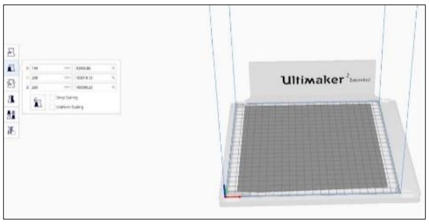


Figure 89 Surface of the printer.
Source: DesignLab

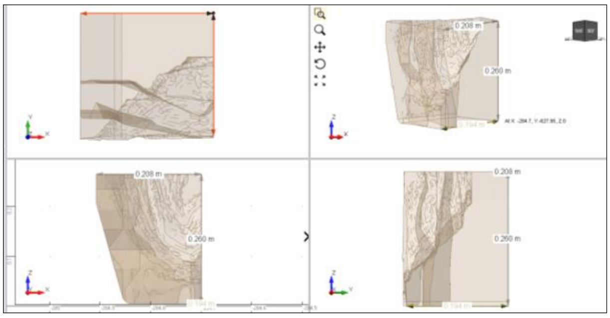


Figure 88 Final position of the geometry.
Source: Slide3

(2) This error is related to the size of the geometry, which is very big (see Figure 90). The bigger the model, the bigger is the amount of material to use. Hence, in order to reduce such amount of material, but at the same time, still have precision for future evaluation of the *app,* a 30% of reduction is decided and the model has been moved -50mm in the Z direction (see Figure 91).This reduction has been calculated manually and set in the configuration of the 3D printer's program. Therefore, the new and final dimensions of the embankment are: **0.145m x 0.135m x 0.126m.** It is important to highlight that Erik, once he has known this is an embankment, he has rotated again the geometry.

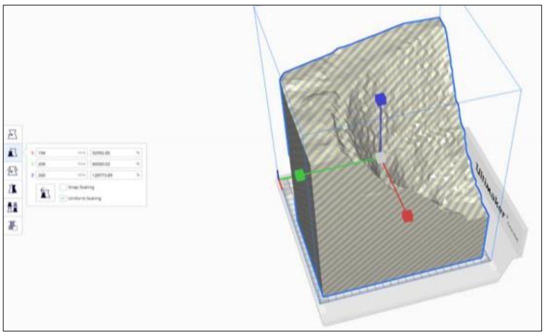


Figure 90 Virtual result of the first geometry.
Source: DesignLab

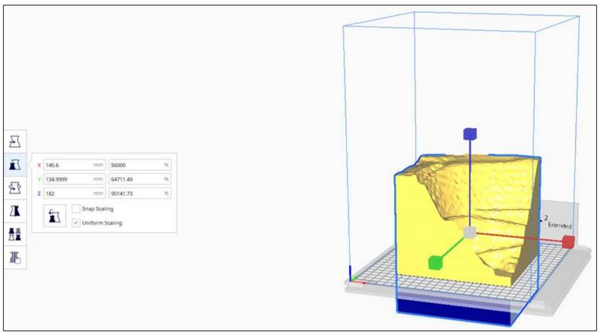


Figure 91 Virtual result of the last geometry model.
Source: DesignLab

The total time to print the geometry was 11hours and 12 minutes and 40,96m of filament were used.

However, when implementing this to practice, there are several problems that need to be solved. Because all these changes have been done in the 3D printer software, the first *Slide3* geometry model is not updated to be imported into *Unity*. Therefore, the proper changes in the dimensions are according to the 30% reduction of the volume mentioned ones in section 5.2 3D printing. This change in the dimensions can be translated in the change of the *Scale* tool showed in Figure 92.

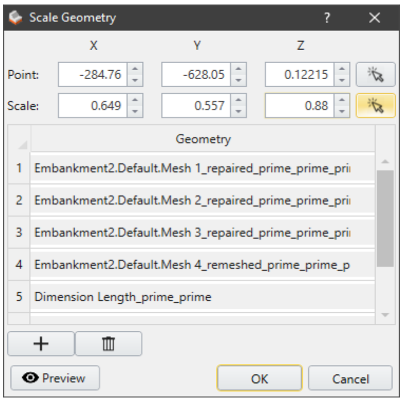


Figure 92 *Scale geometry.*
Source: Slide3

Moreover, in order to remove the 50mm of material from the base, an *External Box* has been created (see Figure 93) and with the same first process explained in the creation of the geometry, by means of the *Divide Geometry* tool, the 50mm are removed. However, extra volumes are created and need to be deactivated in order not to be visible (see Figure 94). In the end, with the *Union* tool, all the geometry forms an only rigid body (Figure 95), and it can be exported to the *.fbx* format.

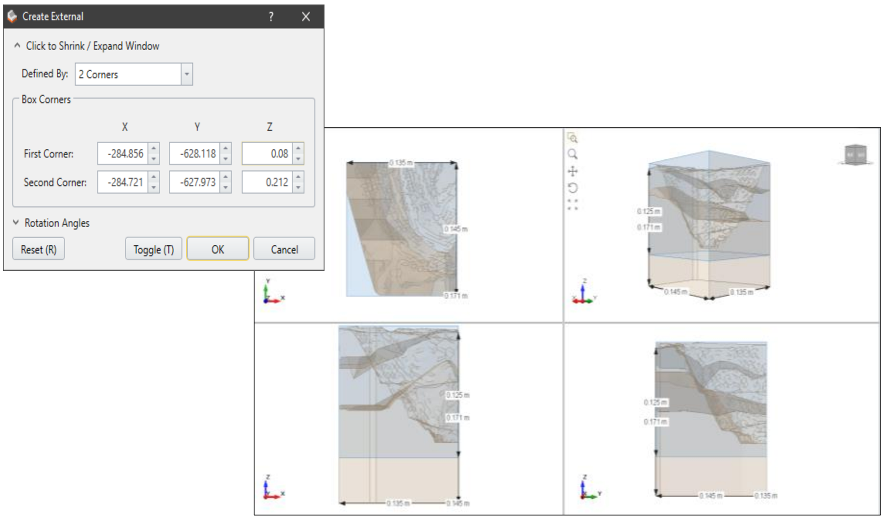


Figure 93 *External Box* with coordinates of the Box corners
Source: Slide3

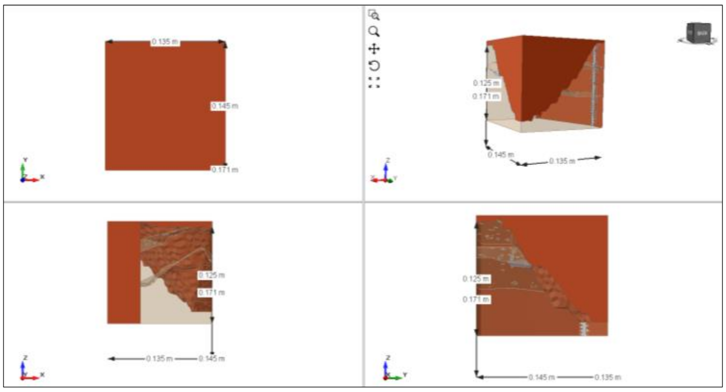


Figure 94 Example of one of the volumes that need to be deactivated

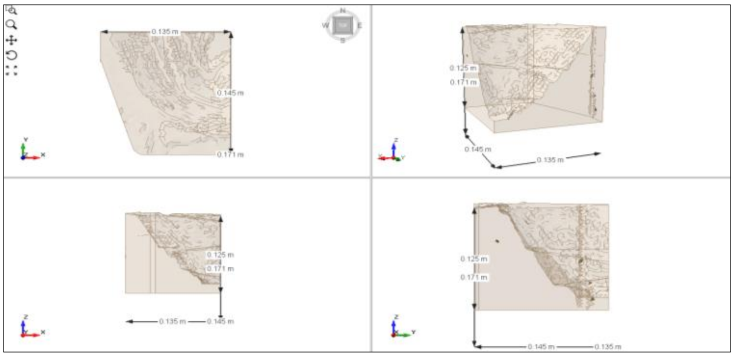


Figure 95 Final geometry model with dimensions.
Source: Slide3

5.3. Evaluation of the system

Once the whole Augmented Reality tool for the inspection of landslides is created, its performance evaluation needs to be carried out by means of the KPIs stated in Table 5.

In the next Table 7 the same table is showed but also including the current values of the *app* in the last column.

Key Performance Indicators – AR *App*		**Objective Value**	**Current Value**
Quantifiers	Weight *app*	50 MB	**31,4 MB**
	Precision	5 m	**3.3m**
	Usability	40	**37**
Qualifiers	Hardware	Mobile / Tablet / Computer	**Mobile / Computer**
	Software	Unity, Vuforia / ARCore, ARKit Slide3	**Unity, Vuforia, Slide3**
	Operating System	Android / iOS / Windows	Android

Table 7 Key Performance Indicators of the current AR *app*.
Source: Own elaboration based on reference [64]

The weight of the *app* is 31.4 MB (see Figure 96), but this is not such big deal given the growing capabilities of the smartphones. This is a good indicator because it can have more functions on it and still not be as weight as the *usual apps* people have on their phones.

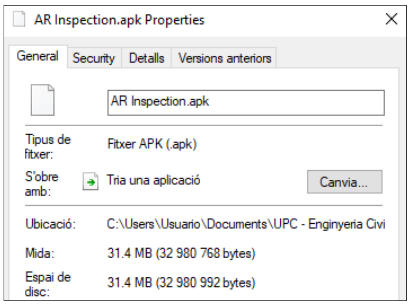


Figure 96 Weight of the *app*.
Source: Own elaboration from Windows Explorer

The precision is valued by calculating the distance is needed for the phone in order to track the Image Target. In this case, it was though a bigger value than the one obtained, considering a big embankment where the objective of the visual inspection is far from the inspector. The current value is 3.3m (see Figure 97). It is important to highlight that also, the bigger the Image Target, the easier it is for the device to identify it from a further distance.

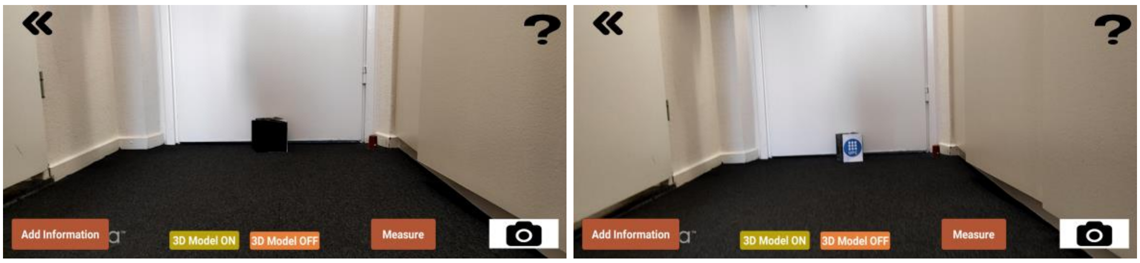


Figure 97 Evaluation of the precision of the *app:* 3.2m distance from the scale model (left) and 3.3m distance from the scale model (right)
Source: Own elaboration

The usability is approximately 37 taps. This is an average number obtained simulating a qualified inspector that needs to go back sometimes in several scenes.

The hardware used for the creation of this app has been a laptop (or computer) and it is created for a mobile phone. However, this could also have been downloaded into an Android tablet, which also leads to the following KPI: software. This *app* was created with the program *Unity* together with *Vuforia* and the *.fbx* file needed was imported from *Slide3.* However, other softwares could have been used for the creation of the *app* and for example, the augmented reality could have been created with *ARCore* instead because it also works with Android, the operating system used in this case. If it had been iOS, the *SDK ARKit* could have been also an option.

Hence, the last KPI refers to the operating system where the *app* could be used. In this case it has only been designed for an Android device.

To finish, it is important to highlight that the distorted colours could happen and it should be considered. In this case, during the creation of the *app* several changes in the colours were showed in the screen when using the *app.* (see Figure 98).

Figure 98 Distortion of the colours while using the app. The left photo shows the real colours, while in right one, the colours are changed.
Source: Own elaboration

Chapter 6. Conclusions and future research lines

6.1. Conclusions

After the exhaustive research regarding the implementation of the Augmented Reality in geotechnical inspections, several conclusions are made.

The first one is that this new emergent technology in the geotechnical study field is still at its early stages and further research of its development is needed. However, its future implementation is promising because it attracts the attention to new ways of working and its innovation. Nonetheless, it has been seen that although the construction is not as evolved as other industries regarding augmented reality implementation, one aspect of the construction, geotechnics, is the one that is less up-to-date because of its mentioned pain point.

Regarding the development of the *app,* it has been a very challenging experience due to the lack of knowledge of the platform *Unity* together with the *SDK Vuforia.* In order to create an *app,* huge amounts of important points need to be considered, and through this work they have been identified, studied and implemented. However, all the time devoted to this creation has been worth it and it has provided me expertise in this field. Furthermore, in order to create this *app*, the necessary high-performance softwares require powerful computers that enable their fast functioning.

In respect to the use of the *app,* it has been a sample in order to show several parameters that could be measured on site and it could enhance the standardisation of landslide inspections. In this case, lengths can be measured and it allows the measurement of parameters that are based on length, such as the separation between discontinuities, length of discontinuities, block size and height of slope. On the contrary, the scripts that allow the measurement of angles and volumes could not be done because of its difficulty and the use of Image Targets. It has been explained that their inspections could prevent them from occurring. Therefore, more visual inspections should be carried out in order to detect the indicators that could lead to future landslides. Moreover, this *app* could improve the reduction of equipment brought on site.

Moreover, related to the 3D printing, this has been a very useful tool in order to be able to develop a kind of micro-laboratory of digital elements. This combination of AR+3D printing could provide solutions for the future of geotechnical and geological inspections, for instance, in the creation of scale models of embankment dams previous to their construction, as a laboratory study, allowing the obtaining of geometric parameters as a prevention of risk before being built; or in the construction industry in general, for example, in the construction of bridges or houses like it is already happening, but the AR component should be added in order to provide the visibility of the future construction.

In the end, this laborious project has been very worth it, regarding the review of all the previous geotechnical and geological concepts explained from previous years in class, the new obtained knowledge regarding, firstly, augmented reality, as well as the situation of emergent technologies regarding the construction industry.

6.2. Future research lines

When performing future researches, the aim should still be focused in two aspects: the implementation of augmented reality and BIM methodology in the geotechnical field study.
The latter, due to the future development of this emergent technology in geotechnics, it is proposed the combination between Finite Element Methods and the visualisation of those results on site using an augmented reality *app*, which would be a big step. Like this, several calculations like the measurement of the Safety Factor could be performed already on site. This could be solved by adding to *Unity* the calculation motor to perform the slope stability analysis.

Furthermore, this could be related with the second aspect, because thsese new results could already be sent to the BIM software that would enable the geotechnical dimension.

Moreover, one of the things that could be improved is the *SDK* used for the creation of the augmented reality in the *app.* If instead of *Vuforia,* the *SDK ARCore* had been used, several more function in the *app* could have been created, such as the calculation of volumes, due to the plane detection that *ARCore* includes and the dispense of markers would also improve the simplicity of the inspection.

To finish this section, I would suggest as a future research line the implementation of artificial intelligence (AI) in Augmented Reality devices for the creation of added-value in the construction industry. This would benefit the sector in such a way that the AI could, for instance, track the risk and quality in real time of the embankments, so that the monitoring that is now being carried out was connected to it in order to prevent risks. This would allow the identification of displacements and alert about the situation. Therefore, the fatality could be avoided or the consequences could be mitigated.

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ANNEXES

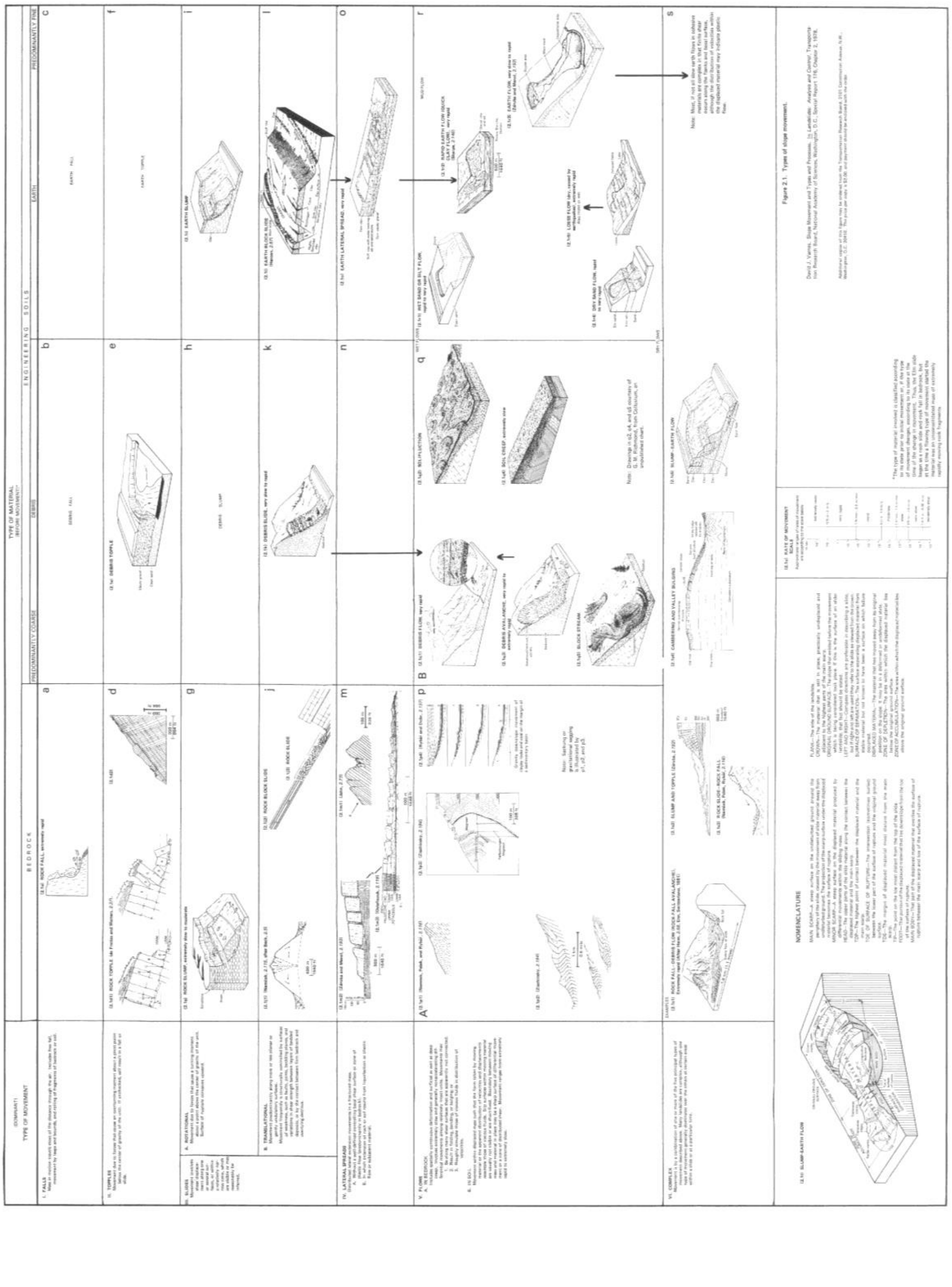
Annex A. Geotechnics: landslides

A.1. Definitions: parts of a landslide

- **Crown:** The practically undisplaced material still in place and adjacent to the highest parts of the main scarp.
- **Flank:** The undisplaced material adjacent to the sides of the surface. Compass directions are preferable in describing the flanks, but if left and right are used, they refer to the flanks as viewed from the crown.
- **Foot:** The portion of the landslide that has moved beyond the toe of the surface of rupture and overlies the original ground surface.
- **Head:** The upper parts of the landslide along the contact between the displaced material and the main scarp.
- **Main body:** The part of the displaced material of the landslide that overlies the surface of rupture between the main scarp and the toe of the surface of rupture.
- **Main scarp:** A step surface on the undisturbed ground at the upper edge of the landslide, caused by movement of the displaced material away from the undisturbed ground. It is the visible part of the surface of rupture.
- **Minor scarp:** A steep surface on the displaced material of the landslide produced by differential movements within the displaced material.
- **Original ground surface:** The surface of the slope that existed before the landslide took place.
- **Surface of rupture:** The surface that forms (or which has formed) the lower boundary of the displaced material below the original ground surface.
- **Surface of separation:** The part of the original ground surface overlain by the foot of the landslide.
- **Toe:** The lower, usually curved margin of the displaced material of a landslide, it is the most distant from the main scarp.
- **Toe of surface of rupture:** The intersection (usually buried) between the lower part of the surface of rupture of a landslide and the original ground surface.

Reference [14]

A.2. Complete type of slope movement classification. Varnes 1978



A.3. New Varnes' classification system.

In the updated version of this classification (2014), O. Hungr, S. Leroueil and L. Picarelli propose the following landslide classification system from Table 8, where the five types of movements remain the same except for the *complex* one. The reason is that the authors consider the *complex* type of movement "*not useful*" because *"almost every landslide is complex to a degree"* – they state – "*and a "complex" class could hold most of the information, without the need for any other classes"* [24]. Furthermore, as it can be seen in the same Table 8, in the type of material classification, there is not a specific column for *debris.* There are several reasons why the authors considered changing the threefold classification: (1) *debris* is a material "*that have been mixed from various components"*, (2) "*the word debris is also traditionally used to describe any material displaced by a mass movement. This wider meaning of the term is not a part of the proposed classification"* and hence, (3) the Varnes' criterion related to debris is considered "*too restrictive"* [24].

TYPE OF MOVEMENT	**TYPE OF MATERIAL**	
	ROCK	**SOIL**
FALL	*Rock/ice fall*	*Boulder/debris/silt* fall
TOPPLE	Rock block topple	*Gravel/sand/silt* topple
	Rock flexural topple	
SLIDE	Rock rotational slide	*Clay/silt* rotational slide
	Rock planar slide	*Clay/silt* planar slide
	Rock wedge slide	*Gravel/sand/debris* slide
	Rock compound slide	*Clay/silt* compound slide
	Rock irregular slide	
SPREAD	Rock slope spread	*Sand/silt* liquefaction spread
		Sensitive clay spread
FLOW	*Rock/ice* avalanche	*Sand/silt/debris* dry flow
		Sand/silt/debris flowslide
		Sensitive clay flowslide
		Debris flow
		Mud flow
		Debris flood
		Debris avalanche
		Earthflow
		Peat flow
SLOPE DEFORMATION	Mountain slope deformation	Soil slope deformation
	Rock slope deformation	Soil creep
		Solifluction

Table 8 Summary of the proposed new version of the Varnes' classification system. The words in italics are placeholders (use only one).
Source: Hungr et al. 2014

A.4. Geological indexes

A.4.1. Rock Quality Designation: RQD

The Rock Quality Designation index was developed by D. W. Deere in 1964 but it was not until 1968 that the engineer and Hendrom published *Rock Mechanics in Engineering Practice* that the RQD concept was introduced and internationally accepted [24][25].

The RQD index indicates "*the percentage of "good" rock recovered from an interval of a borehole"* and it is an index for problematic rocks that are weathered, soft, fractured, sheared… [24] Because it measures the degree of jointing along the core drill hole [26].

In the RQD index formula and the adequate procedure for measuring it is represented. It includes the classification of the quality of the rock depending on this index.

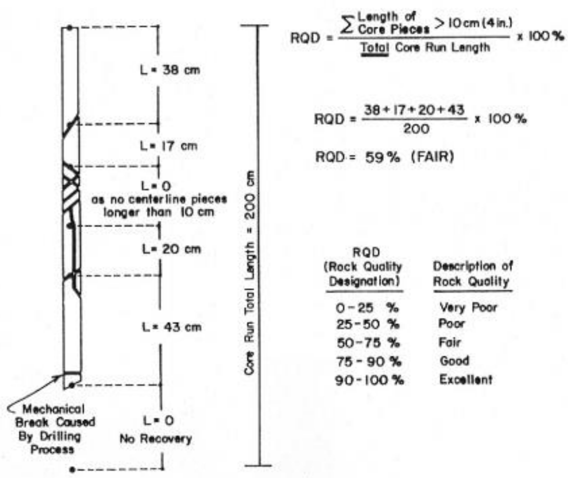


Figure 99 Procedure for measurement and calculation of RQD
Source: Reference [24]

However, the RQD index has some drawbacks. For instance, it does not give any information about the pieces that are less than 10cm long and small variations of joint intercept can change radically the RQD value. Moreover, as the RQD measurement is directional and it is very sensitive to the line direction (it is ode-dimensional), for the same rock mass the value of the index can vary drastically when penetrating it in different directions [26].

Also, because of its dimensionality, eventhough RQD focuses on the degree of jointing, there are difficulties to link this index with other jointing calculations. But it was in 1974 when Palmstrom defined the volumetric joint count (Jv: number of joints per cubic meter) that the expression that correlated the RQD index and the joining was presented [26]:

$$RQD = 115 - 3.3Jv$$

However, after different evaluations, it seemed the above relation between the two parameters was not accurate. Therefore, the new expression was the one expressed below [26]:

$$RQD = 110 - 2.5Jv$$

It can be concluded that the first expression can be more adequate for longer or flatter blogs and the latter, for cubical ones [26].

The RQD index is also included in the calculation of other indexes in later rock classification systems: Rock Mass Rating (Bieniawski, 1973) and Q Barton (Barton, 1974); which are explained herein.

A.4.2. Rock Mass Rating: RMR

In 1973, Z. T. Bieniawski developed the Rock Mass Rating (RMR) classification system that is mainly used for the design and construction of excavations in rock. This index combines six rock mass parameters, measured in the field or collected from borehole data, which are evaluated and summed in order to obtain a value for the RMR, which ranges from 0 to 100. These are [27]:

(1) Uniaxial compressive strength of intact rock material
(2) Rock quality designation (RQD)
(3) Condition of discontinuities
(4) Groundwater conditions
(5) Orientation of discontinuities

The following classification (Table 9**¡Error! No se encuentra el origen de la referencia.**) is obtained from Bieniawski's book *Engineering Rock Mass Classification (1989):*

PARAMETER			Range of values // ratings						
1	Strength of intact rock material	Point-load strength index	> 10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range uniaxial compr. strength is preferred		
		Uniaxial compressive strength	> 250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa	1 - 5 MPa	< 1 MPa
	RATING		**15**	**12**	**7**	**4**	**2**	**1**	**0**
2	Drill core quality RQD		90 - 100%	75 - 90%	50 - 75%	25 - 50%	< 25%		
	RATING		**20**	**17**	**13**	**8**	**5**		
3	Spacing of discontinuities		> 2 m	0.6 - 2 m	200 - 600 mm	60 - 200 mm	< 60 mm		
	RATING		**20**	**15**	**10**	**8**	**5**		
4	Condition of discontinuities	Length, persistence	< 1 m	1 - 3 m	3 - 10 m	10 - 20 m	> 20 m		
		Rating	**6**	**4**	**2**	**1**	**0**		
		Separation	none	< 0.1 mm	0.1 - 1 mm	1 - 5 mm	> 5 mm		
		Rating	**6**	**5**	**4**	**1**	**0**		
		Roughness	very rough	rough	slightly rough	smooth	slickensided		
		Rating	**6**	**5**	**3**	**1**	**0**		
		Infilling (gouge)	none	Hard filling		Soft filling			
			-	< 5 mm	> 5 mm	< 5 mm	> 5 mm		
		Rating	**6**	**4**	**2**	**2**	**0**		
		Weathering	unweathered	slightly w.	moderately w.	highly w.	decomposed		
		Rating	**6**	**5**	**3**	**1**	**0**		
5	Ground water	Inflow per 10 m tunnel length	none	< 10 litres/min	10 - 25 litres/min	25 - 125 litres/min	> 125 litres /min		
		$p_w / \sigma 1$	0	0 - 0.1	0.1 - 0.2	0.2 - 0.5	> 0.5		
		General conditions	completely dry	damp	wet	dripping	flowing		
	RATING		**15**	**10**	**7**	**4**	**0**		
p_w = joint water pressure; $\sigma 1$ = major principal stress									

Table 9 RMR classification of rock masses
Source: Bieniawski, 1989 [27]

However, some adjustments have to be done in these parameters. Nonetheless, for the main purpose of this research, the respective table is not explained.

A.4.2.1. Slope Mass Rating: SMR

The following index was proposed by M. Romana (1985) in order to evaluate rock slopes' stability. The Slope Mass Rating (SMR) is an adapted classification from Bieniawski's and it is obtained by adding different factors to the RMR value [29]. The expression is the following:

$$SMR = RMR + (F_1 * F_2 * F_3) + F_4$$

Where F_1, F_2, and F_3 are "*adjustment factors related to joint orientation with respect to the slope orientation*" and F_4 is a factor that depends on the excavation method used [29].

Therefore, depending on the SMR value obtained, the stability of the slope is defined (Table 10):

SMR	Stability
81-100	Completely stable
61-80	Stable
60-41	Partially stable
21-40	Unstable
0-20	Completely unstable

Table 10 Correlation SMR value with slope stability (Romana, 1985)
Source: Own elaboration based on "Description of SMR classes" [30].

A.4.3. Rockfall Hazard Rating System: RHRS

The Rockfall Hazard Rating System (RHRS) developed by Pierson et al. (1990) [31] is a similar index to RMR but it is related to the assessment of risk exposition to rockfalls [32].

The Oregon Department of Transportation (USA), so as to *"prioritize budget allocations for maintenance and remediation works"* elaborated the classification scheme from Table 11 (Person et al., 1990; National Highway Institute, 1993; Scesi et al., 2001) to identify dangerous slopes that require urgent work or study. It is particularly designed for road cuts [32].

Category		Points 3	Points 9	Points 27	Points 81
		Rating criteria by score			
Slope height		7.5 m	15 m	22.5 m	> 30 m
Ditch effectiveness		Good catchment	Moderate catchment	Limited catchment	No catchment
Average vehicle risk (% of time)		25%	50%	75%	100%
Decision sight distance (% of design value)		Adequate (100%)	Moderate (80%)	Limited (60%)	Very limited (40%)
Roadway width (including paved shoulders)		13.20 m	10.80 m	8.40 m	6 m
Geologic characteristics Case 1	Structural condition	Discontinuous joints, favorable orientation	Discontinuous joints, random orientation	Discontinuous joints, adverse orientation	Continuous joints, adverse orientation
	Friction	Rough, irregular	Undulating	Planar	Clay infilling or slickensided
Geologic characteristics Case 2	Structural condition	Few differential erosion features	Occasional erosion features	Many erosion features	Major erosion features
	Difference in erosion rates	Small	Moderate	Large	Extreme
Block size		0.3 cm	0.6 m	0.9 m	1.20 m
Volume of rockfall per event		2.3 m^3	4.6 m^3	6.9 m^3	9.2 m^3
Climate and presence of water on slope		Low to moderate precipitation; no freezing periods; no water on slope water on slope	Moderate precipitation or short freezing periods or intermittent water on slope	High precipitation or long freezing periods or continual water on slope and long freezing periods	High precipitation and long freezing periods or continual
Rockfall history		Few falls	Occasional falls	Many falls	Constant falls

Table 11 Summary sheet of Rockfall Hazard System (after Pierson et al. 1990)
Source: Pierson, 1990 [32]

This classification method is simple when doing land planning and in not very detailed studies. However, some of the categories listed in the first column of the previous table, can be very subjective to evaluate, hence, the result can be different depending on the professional evaluating the slope. P. Budetta (2003) considered the following categories: ditch effectiveness, geologic character, climate and presence of water on slope and rockfall history; and proposed the following modified methodology [32].

Category	Points 3	Points 9	Points 27	Points 81
		Rating criteria by score		
Slope height	7.5 m	15 m	22.5 m	> 30 m
Ditch effectiveness	Good catchment: properly designed according to updates of Ritchie's ditch design chart + barriers	Moderate catchment: properly designed according to updates of Ritchie's ditch design chart	Limited catchment: wrongly designed	No catchment
Average vehicle risk (% of time)	25%	50%	75%	100%
Decision sight distance (% of design value)	Adequate (100%)	Moderate (80%)	Limited (60%)	Very limited (40%)
Roadway width	21.5 m	15.50 m	9.50 m	3.50 m
Slope Mass Rating (SMR)	80	40	27	20
Block size	30 cm	60 cm	90 cm	120 cm
Boulder volume	26 dm^3	0.21 m^3	0.73 m^3	1.74 m^3
Volume of rockfall per event	2.3 m^3	4.6 m^3	6.9 m^3	9.2 m^3
Annual rainfall and freezing periods	h=300 mm or no freezing periods	h=600 mm or short freezing periods	h=900 mm or long freezing periods	h=1200 mm or long freezing periods
Rockfall frequency	1 per 10 years	3 per year	6 per year	9 per year

Table 12 Summary sheet of the modified Rockfall Hazard Rating System
Source: P. Budetta (2003)

As it can be seen, the "ditch effectiveness" category is more detailed, the "climate and presence of water on slope" category has been changed to a more objective calculation category "annual rainfall and freezing periods" and the "rockfall history" one has been modified to "rockfall frequency".

A.4.4. Rock mass quality: Q-system

The index that values the rock mass quality is Q Barton's index (Barton et al. 1974). It ranges from 0.001 up to 1000 (from very poor to perfectly good qualities). Its calculation depends on the following 6 parameters [33]:

(1) *RQD: Rock Quality Designation*
(2) J_n*: Joint set number*
(3) J_r*: Joint roughness number*
(4) J_a*: Joint alteration number*
(5) J_w*: Joint water reduction factor*
(6) *SRF: Stress Reduction Factor*

And the expression for the rock mass quality Q is:

$$Q = \frac{RQD}{J_n} \cdot \frac{J_r}{J_a} \cdot \frac{J_w}{SRF}$$

As it can be seen in the expression above, Q can be considered a function of three parameters [33]:

(1) *(RQD/Jn): Block size*
(2) *(*J_r/J_a*): Inter-block shear strength*
(3) *(*J_w*/SRF): Active stress*

Therefore, the rock mass quality depending on the Q value can be (Table 13):

Q Value	Rock mass quality
0.001 – 0.01	Exceptionally poor
0.01 – 0.1	Extremely poor
0.1 – 1	Very poor
1 – 4	Poor
4 – 10	Fair
10 – 40	Good
40 – 100	Very good
100 – 400	Extremely good
400 - 1000	Exceptionally good

Table 13 Q values and rock mass quality

Source: Own elaboration based on Figure 1 Reference [34]

These Q values can be obtained from different values for the parameters mentioned before.

A.4.5. Geological Strength Index: GSI

The Geological Strength Index (GSI) was introduced in 1997 by Hoek & Brown. It is an index that focuses on geological conditions for hard and weak rock masses and the results are obtained by means of visual inspection [35].

In 1997 Hoek and Brown elaborated a five qualitative classification of rock mass structures and a five categories of discontinuities in order to estimate GSI on rock mass structures (see Figure 7) [35]:

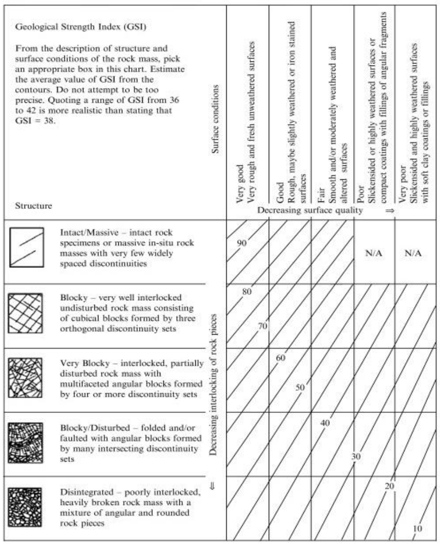


Figure 100 Characterization of rock masses on the basis of interlocking and joint alteration.
Source: Hoek & Brown. 1997

Although professionals agree that this is a *simple, fast, yet reliable classification* [35]and it has been used in lots of engineering projects around the world [36] since its introduction, different results of the GSI can be obtained from the same rock mass being described depending on the engineer carrying on the inspection because of a "*lack of measurable parameters*" to describe the categories from the classification [35].
Hence, this index has been subject to change by many experts [36] and several researchers have developed quantitative measures for the different categories (Cai et al. 2004; Hoek et al., 2013, Sonmez and Ulusay, 1999, 2002) that can be seen in the next Figure 101:

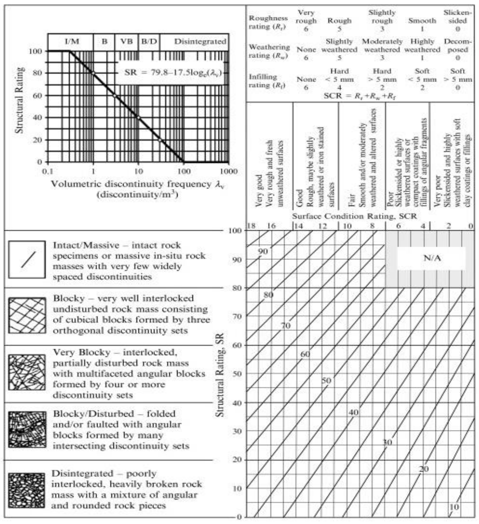


Figure 101 Quantification of GSI chart.
Source: Sonmex and Ulusay (1999, 2002)

A.5. Deficiencies' inspection

TYPE OF DEFICIENCY	LOOK FOR:
SEEPAGE	A water flow or sand boil on the lower portion of the downstream slope or toe area, especially at the groins. Leakage around conveyance structures such as outlet works, spillway conduits, or penstocks. Wet areas or areas where the vegetation appears greener or more lush on the embankment slope or toe area. Blocked toe drains and relief wells. An increase in the amount of water being released from toe drains and relief wells. (Remember to take into account changes in the reservoir level.) Turbidity or cloudiness of the seepage.
CRACKING	**Transverse Cracking:** Cracks perpendicular to the axis of the dam, usually found on the crest. **Longitudinal Cracking:** Cracks parallel to the axis of the dam. Longitudinal cracks may be associated with stability problems in the slopes. **Desiccation Cracking:** A random honeycomb pattern of cracks usually found on the crest and the downstream slope.
INSTABILITY	Slides, scarps, or cracks on the upstream and downstream slopes. Misalignments in the crest and embankment slopes found by sighting along fixed points. Bulges, especially at the toe of the dam.
DEPRESSIONS	Misalignments in the crest and embankment slopes found by sighting along fixed points. Sinkholes found by checking and probing each depression. Remember, sinkholes usually have steep, bucket-like sides while localized depressions have gently sloping, bowl-like sides.
MAINTENANCE CONCERNS	**Inadequate Slope Protection:** Check for bald areas or areas where the protection is sparse or damaged. **Surface Runoff Erosion:** Check for gullies or other signs of erosion. Make sure to check the low points along the upstream and downstream shoulders and groins because surface runoff can collect in these areas. **Inappropriate Vegetative Growth:** Check for excessive and deep-rooted vegetative growth. **Debris:** Check for debris on and around the dam. **Animal Burrows:** Check for damage caused by burrowing animals.

Table 14 Changes to look for in order to identify a deficiency.
Source: Reference ***¡Error! No se encuentra el origen de la referencia.****[40]*

A.6. Comparison of Ground Survey Methods

Method	Range	Accuracy	Advantages	Limitations	Reliability
Compass and pace	Variable	Low; provides only approximate values	Rapid; requires no equipment; may be useful in establishing overall dimensions of landslide	Reasonable initial estimates on uniform terrain without obstacles	Varies with experience of personnel and roughness of terrain
Compass, hand level and tape	Variable	Moderate; provides approximate values	Rapid; moderate accuracy; produces a map or section	Reasonable estimates on rough terrain	Varies with experience of personnel and roughness of terrain
Plane table and alidade	5 to 500 m	1:100	Relatively rapid; moderate accuracy; produces a map	Awkward in rough or steep terrain	Moderate; errors may be due to instrument, drafting, and instability of plane table
Transit and stadia	5 to 500 m	1:200 to 1:500	Relatively rapid; moderate accuracy	Complex corrections needed for measurements along steeply inclined directions	Moderate to good; may be lower in vegetated and rough areas
Transit and subtense bar	50 to 500 m	1:800 at 500 m; 1:8,000 at 50 m	Relatively rapid; most accurate of optical methods; can measure inclined distances	Careful orientation of subtense bar required; may be difficult to use in rough terrain	Good
Direct measurement by tape or chain					
Ordinary survey	Variable	1:5,000 to 1:10,000	Simple and inexpensive; provides direct observation	Requires clear, relatively flat surface between measured points and stable reference monuments	Excellent
Precise survey	Variable	1:20,000 to 1:20,0000	Relatively simple and inexpensive; provides direct	Corrections for temperature and slope must be applied and standard chain	Excellent
Electronic distance measurement (EDM)	20 to 3000 m	1:50,000 to 1:30,0000	Precise, long-range, and rapid; usable over rough terrain	Accuracy is influenced by atmospheric conditions; accuracy over shorter distances (30 to 90 m) is less for most instruments	Good
Total station	1.5 to 3000 m	5 mm minimum error; 1:300,000 over longer distances	Precise and rapid; reduces computational effort and errors; provides digital data; usable over rough terrain	Accuracy may be influenced by atmospheric conditions	Good to excellent
Global Positioning System (GPS)	1.5 m to 40 km	100 m with a single receiver; 1:300,000 with two or more receivers recording four or more satellites; 0.3-cm minimum error	Precise absolute horizontal position; possible precise vertical position	Accurate measurements require 45 to 60 min continuous operation; elevations require receiver dedicated to bench mark; tree limbs over antenna interfere with reception; possible backscatter	Excellent
Optical leveling					
Ordinary (second or third order)	Variable	3 to 6 mm (vertical)	Simple and fast, especially with modern self-leveling instruments	Limited precision; requires good bench marks	Excellent
Precise (first order)	Variable	0.6 to 1.2 mm (vertical)	More precise than ordinary leveling	Requires good bench marks and reference points; careful adherence to standard procedures	Excellent
Offsets from baseline					
Theodolite and scale	0 to 1.5 m	0.6 to 1.5 mm	Simple; provides direct observation	Requires baseline unaffected by ground movements and good monuments; accuracy can be improved by using a target with a vernier and repeating sighting from opposite end of baseline	Excellent
Laser and photocell detector	0 to 1.5 mm	1.5 mm	More rapid than theodolite-and-scale method	Seriously affected by atmospheric conditions	Good
Triangulation	Variable	0.6 to 12 mm	Usable when direct measurements are impossible; useful in tying into points outside immediate area	Requires precise measurement of base distance and angles; requires good reference monuments	Good
Terrestrial photo-grammetry	Variable	1:5,000 to 1:50,000	Records hundreds of potential movements at one time for determining overall displacement pattern	Limited by weather conditions	Good

Table 15 Comparison of Ground Survey Methods (modified from Wilson and Mikkelsen 1978 and Cording et atl. 1975).
Source: Reference [38]

Annex B. Key Performance Indicators (KPI)

This following summary is obtained from the document *Evaluating the application of augmented reality devices in manufacturing from a process point of view: An AHP* 85[67]. In Figure 102 the authors show the hierarchy between the three level criteria and the different features *characterizing a general purpose AR system.*

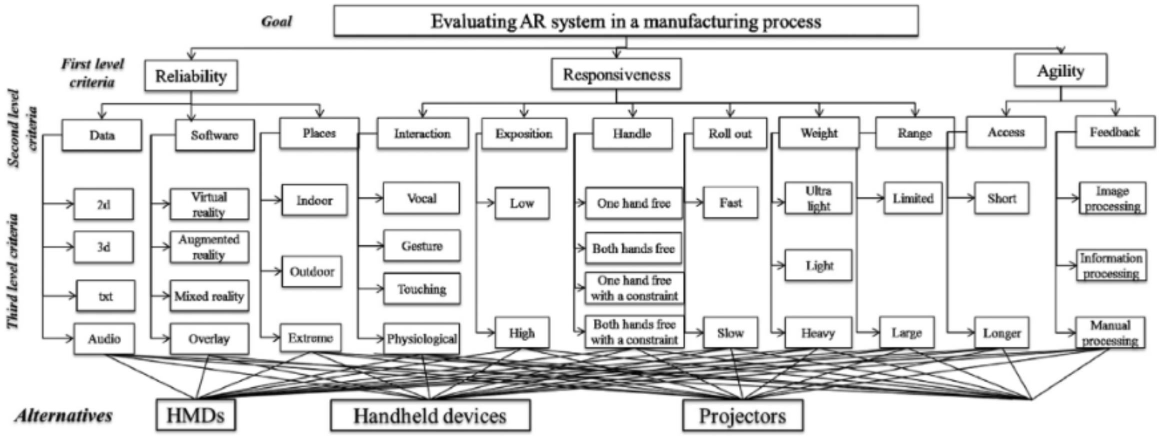


Figure 102 Proposed hierarchy.
Source: Reference [67]

The summary of the previous image is explained as follows:

- **Reliability:** it is the ability of the AR system to provide information in different ways (e.g. formats), in different contexts (e.g. bad viewing conditions) thus guaranteeing an accurate augmented process.
  - **Data:** the data format provided through the AR application: *one main feature of an AR device is due to its capability to transfer in an accurate way information; thus, four types of data format have been outlined, such as 2D or 3D image, but also a text or an audio file. It has to be noted that an AR device could provide a combination of these four types of data with different level of accuracy.*
  - **Places:** the type of environment where the AR application have to work this criterion refers to controlled **indoor** contexts (e.g. within an assembly plant), **outdoor** contexts (e.g. in a plant area outside the factory building characterized by standard operative conditions) or **extreme** contexts which could be both outdoor or indoor contexts with severe operative conditions (e.g. in terms of humidity, presence of dust, etc.).
  - **Software:** software typology supported by the AR device. The software is the key element for the combining of real and virtual objects and supporting information registration, and real-time interaction. Four main

typologies have been outlined according to Milgram, Takemura, Utsumi, and Kishino (1994):

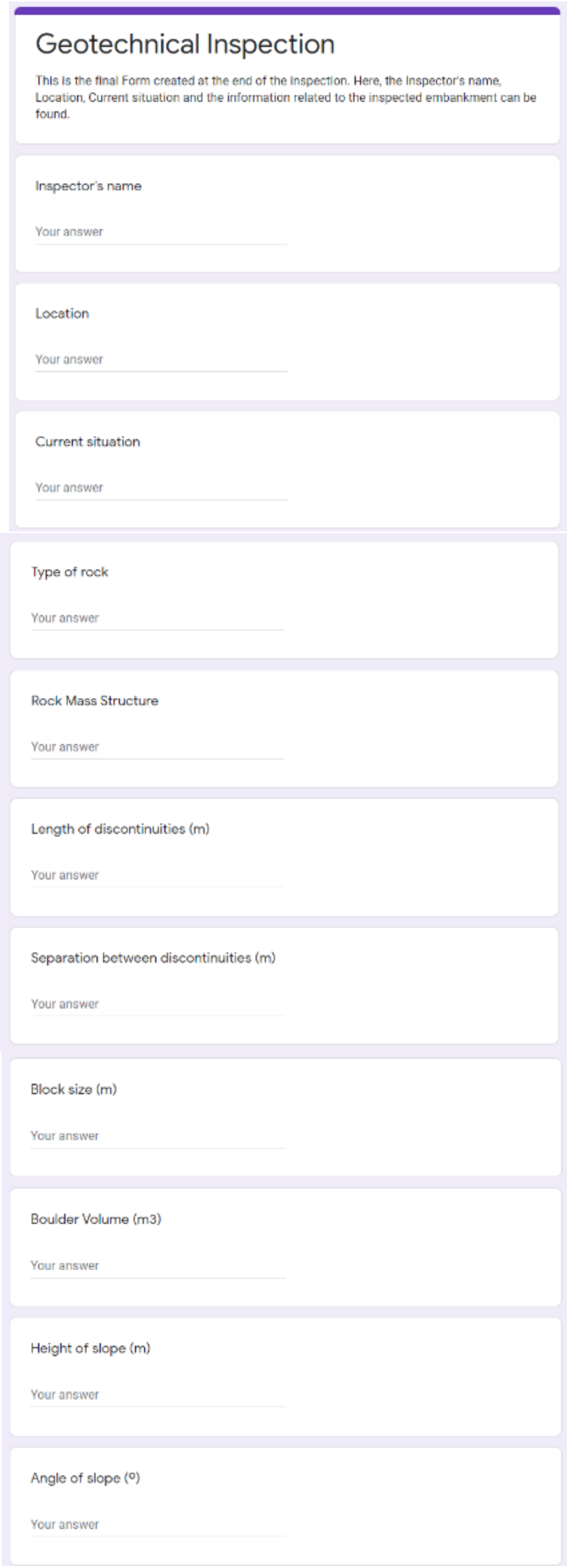
- **Virtual reality:** It usually provides a 3D environment where the user is completely immersed which could be extremely useful for training activities in the manufacturing process.
- **Augmented reality:** On the other hand, augmented reality software integrates the real world with virtual objects, which coexist in the same real world: this capability will allow a more dynamic interaction with the real manufacturing process.
- **Mixed reality:** A mixed reality tool is a type of software where real world and virtual world objects are presented together within a single device and not in a full-scale environment. It provides an overlapping of virtual with augmented reality.
- **Overlay based tools.** Finally, overlay tools usually generate 2D overlapping of information to the real world thus allowing in a more dynamic and simple way the data transmission for the manufacturing area.

- **Responsiveness** : it represents how fast an AR system is “ready” to provide the augmented process
  - **Interaction:** the way of interaction with the AR device: based on equipment typology, user interaction in AR systems could be vocal or a gesture based interaction (e.g. by touching one point of the device or by physiological feedback). These criteria outline the usability level of the specific AR device in manufacturing.
  - **Exposition:** the maximum usage time without interruption characterizing the device: according to most widespread AR systems currently available in the market, two main sub-criteria have been defined, low and high, i.e. respectively less or greater than 15 min. These criteria highlight the service level expressed in maximum usage time provided by each AR device, which could become critical especially if a rechargeable system is not quickly available.
  - **Handle:** the degree of handiness: it refers to the required use of hands during the use phase. Four sub-criteria have been introduced: only one hand free, both hands free, only one hand free with a constraint, both hands free with a constraint. These criteria define the way of interaction between the user and the AR device also highlighting any type of burdens that the device will cause on the workers during its use phase;

- **Roll out:** the maximum start up time: two sub- criteria have been introduced, such as respectively less (fast) and greater (slow) than 15 min. This value has assumed a target level. The roll out group of criteria outline the speed of the start-up process that could be so critical in such manufacturing processes;
- **Weight:** the gross weight characterizing the device: based on current AR products, three sub-criteria have been introduced by evaluating two boundary values: ultra-light, light and heavy. The first one is less than 100 g, the latter is between 10 0 g and 50 0 g, the third one has been defined as greater than 500 g. These criteria highlight a sort of portability of the AR device that could become critical in highly complex process tasks e.g. when a high physical effort is yet required to the worker.
- **Range:** the allowable operating range of the device: it could be limited or larger, i.e. less or greater than a threshold value, e.g. 2 m. These features point out the level of adaptability to complex plant layout of the AR device.

- **Agility**: it is the capability of an AR system to fit variations caused by users and/or the environment.
    - **Access:** the maximum allowable time for data recovery: two sub-criteria have been defined, short and long, such as less or greater than 1 min. These criteria outline how the AR device will allow to update information from/to the central system thus supporting a more agile refresh process.
    - **Feedback:** types of feedback process supported: the AR application enables to automatically acquire, process, and analyse images (image processing sub-criterion) or information (information processing) from the operational field. On the other hand, the AR application could not support any automatic feedback process (manual processing criterion). This group of criteria point out the level of automatic support provided by the AR device.

Annex C. Google Form



Geotechnical Inspection

This is the final Form created at the end of the inspection. Here, the inspector's name, Location, Current situation and the information related to the inspected embankment can be found.

Inspector's name

Your answer

Location

Your answer

Current situation

Your answer

Type of rock

Your answer

Rock Mass Structure

Your answer

Length of discontinuities (m)

Your answer

Separation between discontinuities (m)

Your answer

Block size (m)

Your answer

Boulder Volume (m3)

Your answer

Height of slope (m)

Your answer

Angle of slope (º)

Your answer

Figure 103 Questions of the form

Source: Own elaboration using Google Forms

Annex D. Scripts

D.1. Script: *"ChangeScene"*

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.SceneManagement;

public class ChangeScene : MonoBehaviour
{
    public void LoadScene(string sceneName)
    {
        SceneManager.LoadScene(sceneName);
    }
}
```

D.2. Script: "Instructions"

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class Instructions : MonoBehaviour
{
    public GameObject InstructionsPanel;

    public void OpenInstructionsPanel()
    {
        if(InstructionsPanel != null)
        {
            InstructionsPanel.SetActive(true);
        }
    }

}
```

D.3. Script: "Accept"

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class Accept : MonoBehaviour
{
    public GameObject InstructionsPanel;

    public void CloseInstructionsPanel()
    {
        if (InstructionsPanel != null)
        {
            bool isActive = InstructionsPanel.activeSelf;
            InstructionsPanel.SetActive(!isActive);
        }
    }

}
```

D.4. Script: “BackScene”

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.SceneManagement;

public class BackScene : MonoBehaviour
{
    public void LoadScene(string sceneName)
    {
        SceneManager.LoadScene(sceneName);
    }
}
```

D.5. Script: “Screenshots”

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class Screenshots : MonoBehaviour
{
    public void Screenshot()
     {
        NativeToolkit.SaveScreenshot("Screenshot",
"ScreenshotsInspection","png");
     }
}
```

D.6. Script: “SaveInfo”

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;


public class SaveInfo : MonoBehaviour
{
    public InputField inputrockText;
    string inforockText;
    public InputField inputstructureText;
    string infostructureText;
    public InputField inputlengthText;
    string infolengthText;
    public InputField inputseparationText;
    string infoseparationText;
    public InputField inputblockText;
    string infoblockText;
    public InputField inputvolumeText;
    string infovolumeText;
    public InputField inputheightText;
    string infoheightText;
    public InputField inputangleText;
    string infoangleText;
    public InputField inputcommentText;
    string infocommentText;

    private void Start()
    {
        inforockText = PlayerPrefs.GetString("InfoRock");
        inputrockText.text = inforockText;
        infostructureText = PlayerPrefs.GetString("InfoStructure");
        inputstructureText.text = infostructureText;
        infolengthText = PlayerPrefs.GetString("InfoLength");
        inputlengthText.text = infolengthText;
        infoseparationText = PlayerPrefs.GetString("InfoSeparation");
        inputseparationText.text = infoseparationText;
        infoblockText = PlayerPrefs.GetString("InfoBlock");
        inputblockText.text = infoblockText;
        infovolumeText = PlayerPrefs.GetString("InfoVolume");
        inputvolumeText.text = infovolumeText;
        infoheightText = PlayerPrefs.GetString("InfoHeight");
        inputheightText.text = infoheightText;
```

```
        infoangleText = PlayerPrefs.GetString("InfoAngle");
        inputangleText.text = infoangleText;
        infocommentText = PlayerPrefs.GetString("InfoComment");
        inputcommentText.text = infocommentText;


    }
    public void SaveThis()
    {
        inforockText = inputrockText.text;
        PlayerPrefs.SetString("InfoRock", inforockText);
        infostructureText = inputstructureText.text;
        PlayerPrefs.SetString("InfoStructure", infostructureText);
        infolengthText = inputlengthText.text;
        PlayerPrefs.SetString("InfoLength", infolengthText);
        infoseparationText = inputseparationText.text;
        PlayerPrefs.SetString("InfoSeparation", infoseparationText);
        infoblockText = inputblockText.text;
        PlayerPrefs.SetString("InfoBlock", infoblockText);
        infovolumeText = inputvolumeText.text;
        PlayerPrefs.SetString("InfoVolume", infovolumeText);
        infoheightText = inputheightText.text;
        PlayerPrefs.SetString("InfoHeight", infoheightText);
        infoangleText = inputangleText.text;
        PlayerPrefs.SetString("InfoAngle", infoangleText);
        infocommentText = inputcommentText.text;
        PlayerPrefs.SetString("InfoComment", infocommentText);

    }
}
```

D.7. Script: "SendToGoogle"

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;

public class SendToGoogle : MonoBehaviour
{
    public GameObject inspector;
    public GameObject location;
    public GameObject situation;

    private string Inspector;
    private string Location;
    private string Situation;

    [SerializeField]
    private string BASE_URL =
"https://docs.google.com/forms/u/0/d/e/1FAIpQLScKP2kAPyXfNV7ejv8acRxYP
pceos8N7ogjLWFXCcFCz2hntQ/formResponse";

    IEnumerator Post(string inspector, string location, string
situation)
    {
        WWWForm form = new WWWForm();
        form.AddField("entry.233779553", inspector);
        form.AddField("entry.1605599975", location);
        form.AddField("entry.1233779464", situation);
        byte[] rawData = form.data;
        WWW www = new WWW(BASE_URL, rawData);
        yield return www;
    }

    public void Send()
    {
        Inspector = inspector.GetComponent<InputField>().text;
        Location = location.GetComponent<InputField>().text;
        Situation = situation.GetComponent<InputField>().text;

        StartCoroutine(Post(Inspector, Location, Situation));
    }

}
```

D.8. Script: “SendToGoogle2”

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;

public class SendToGoogle2 : MonoBehaviour
{
    public GameObject typeofrock;
    public GameObject structure;
    public GameObject length;
    public GameObject separation;
    public GameObject block;
    public GameObject volume;
    public GameObject height;
    public GameObject angle;

    private string TypeRock;
    private string Structure;
    private string Length;
    private string Separation;
    private string Block;
    private string Volume;
    private string Height;
    private string Angle;

    [SerializeField]
    private string BASE_URL =
"https://docs.google.com/forms/u/0/d/e/1FAIpQLScKP2kAPyXfNV7ejv8acRxYP
pceos8N7ogjLWFXCcFCz2hntQ/formResponse";

    IEnumerator Post(string typeofrock, string structure, string
length, string separation, string block, string volume, string height,
string angle)
    {
        WWWForm form = new WWWForm();
        form.AddField("entry.1887300552", typeofrock);
        form.AddField("entry.642710393", structure);
        form.AddField("entry.1691219265", length);
        form.AddField("entry.1003223869", separation);
        form.AddField("entry.1229297311", block);
        form.AddField("entry.2064817505", volume);
        form.AddField("entry.1581398973", height);
        form.AddField("entry.951910600", angle);
```

```
        byte[] rawData = form.data;
        WWW www = new WWW(BASE_URL, rawData);
        yield return www;
    }

    public void Send()
    {
        TypeRock = typeofrock.GetComponent<InputField>().text;
        Structure = structure.GetComponent<InputField>().text;
        Length = length.GetComponent<InputField>().text;
        Separation = separation.GetComponent<InputField>().text;
        Block = block.GetComponent<InputField>().text;
        Volume = volume.GetComponent<InputField>().text;
        Height = height.GetComponent<InputField>().text;
        Angle = angle.GetComponent<InputField>().text;

        StartCoroutine(Post(TypeRock, Structure, Length, Separation,
Block, Volume, Height, Angle));
    }

}
```

D.9. Script: “Pose”

```
using UnityEngine;
using System.Collections;

public class Pose : MonoBehaviour {

	public Vector3 pos;

	void Start () {

	}

	void Update () {
		pos= transform.position;
		//Debug.Log("pos is " + pos);

	}
}
```

D.10. Script: “Pose 2”

```
using UnityEngine;
using System.Collections;

public class Pose2 : MonoBehaviour {

	public Vector3 pos2;
	void Start () {

	}

	void Update () {
		pos2= transform.position;
	}
}
```

D.11. Script: “Link Pose X”

```
using UnityEngine;
using System.Collections;

public class LinkPoseX : MonoBehaviour
{

    public GameObject GamePose1, GamePose2;
    public Vector3 position2, position1;
    public Vector3 pos_tempX;
    Vector3 position_difference, size_temp;
    float C, B;

    void Start()
    {

    }

    void Update()
    {
        position_difference = transform.position;
        size_temp = transform.localScale;
        pos_tempX = transform.position;
        position1 = GamePose1.GetComponent<Pose>().pos;
        position2 = GamePose2.GetComponent<Pose2>().pos2;

        float distance = position2.x - position1.x;
        size_temp.z = distance / 2;
        pos_tempX.z = position2.z;
        pos_tempX.x = position1.x;
        pos_tempX.y = position1.y;
        transform.position = pos_tempX;
        transform.localScale = size_temp;
    }


}
```

D.12. Script: "X_Text"

```
using UnityEngine;
using System.Collections;

public class X_Text : MonoBehaviour
{

    public GameObject GamePose1, GamePose2;
    public GameObject LenthX;
    public Vector3 position2, position1;
    Vector3 position_difference, pos_temp, size_temp;
    float C, B;

    void Start()
    {

    }

    void Update()
    {
        position_difference = transform.position;
        pos_temp = transform.position;
        position1 = GamePose1.GetComponent<Pose>().pos;
        position2 = GamePose2.GetComponent<Pose2>().pos2;

        float distance = position2.x - position1.x;
        GetComponent<TextMesh>().text = distance.ToString("f3");

        pos_temp = LenthX.GetComponent<LinkPoseX>().pos_tempX;
        pos_temp.x = pos_temp.x + distance/2;
        transform.position = pos_temp;

    }


}
```