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AUGMENTED REALITY APPLIED IN SAFETY EQUIPMENT INSPECTIONS

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ABSTRACT

The construction industry, and in particular a construction site, is a hazardous place for workers who are exposed to several risks. The dynamism and the complex interaction between the workers, machinery and the environment can lead to dangerous risks that need to be resolved. According to the European Union, the Architecture, Engineering, Construction and Operations (**AECO**) industry possess one of the highest accident rates among other industries, primarily due to the significant exposure to a construction site's risks compared to others.

The accident rate is still relatively high despite the effort that the industry has made in terms of Occupational Risk Prevention (**ORP**) during the last years. The vision is to achieve the philosophy of zero accidents, which requires more effective methodologies that improve the capacity and the knowledge of the people involved in a construction site. These innovative solutions, consisting of building up risk-preventive data, training, and developing new technological tools to use on-site, are being studied and implemented by the industry. Nevertheless, there is still potential for enhancement on new methodologies that guarantees the safety of the workers.

Therefore, this thesis aims to study an essential component on a construction site: the safety equipment, expressly its inspection to guarantee its presence. The equipment must comply with the safety requirements to ensure the worker's safety. Some current methodologies are performed by pure visual inspection or a list of items to be checked, depending on the inspection robustness to the operator in charge, the so-called Safety Advisor (**SA**). Hence, this project studies implementing an improved methodology that digitalizes the process and uses Augmented Reality (**AR)** as an extra layer of aid for the safety advisors.

A visit to a construction site from the Belgian international construction company BESIX is done for a better understanding of the procedure. The main pain points and bottlenecks of the process are analysed in order to set the Key Performance Indicators (KPI) and compare them to assess the viability of the proposed solution. Various digital platforms are used as Unity and ARCore, for the development of the AR application. Furthermore, the workflow of this proposed inspection is compatible with the trend **BIM** (Building Information Modelling) methodology, which needs to contain all the information regarding the safety equipment.

Key words:
- Architecture, Engineering, Construction and Operations (**AECO**)
- Occupational Risk Prevention (**ORP**)
- Safety Advisor (**SA**)
- Augmented Reality (**AR)**
- Building Information Modelling **BIM**

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NOMENCLATURE

AECO	Architecture, Engineering, Construction and Operation
ORP	Occupational Risk Prevention
SA	Safety Advisor
AR	Augmented Reality
VR	Virtual Reality
BIM	Building Information Modeling
CPE	Collective Protection Equipment
IPE	Individual Protection Equipment
TRL	Technology Readiness Levels
DSRM	Design Science Research Methodology
LPS	Last Planner System
SDK	Software Development Kit
APK	Android application Package
UI	User Interface
UX	User Experience

1. INTRODUCTION

In 2018, one-fifth of all fatal accidents at work in the EU-27 corresponded to the construction sector [1]. A construction site is hazardous and involves many factors that are potentially dangerous to workers. Safety and health on-site is a subject that is being improved in construction enterprises to protect their workers from potential injuries. In this context, the industry is applying new methodologies that enhance performance regarding Occupational Risk Prevention (ORP). And with technology there is an increase in efficiency of the information exchange, processes and development, which in a complex environment as a construction site, is key.

In regards of this technology implementation, Virtual and Augmented Reality implementations were analysed by Xiao Li et al. [2] who identified a trend of capitalizing on sophisticated immersive VR/AR applications to create forgiving environments for visualizing complex workplace situations, building up risk-preventive knowledge and undergoing training. These several research projects show that AR enhances a person's perception by superposing virtual models in the real environment. This extra information that can be accessed in real-time is an asset that could aid in tasks as the inspection of the safety equipment present on-site.

This research project investigates the potential of the AR implementation in safety inspections to ensure the presence of safety equipment, specifically Collective Protection Equipment (CPE). In the study of this implementation, it is necessary to analyse in-depth the current safety inspection, which has been possible with the collaboration of the construction enterprise BESIX that allowed an on-site visit for a further understanding, and BAM contractors who shared their expertise in ORP and digitalisation. Also, a Belgian start-up Genie Vision who dedicates to developing AR applications in construction and who shared their expertise.

In order to guide this project, the following objectives are set to have a clear view of the achievements proposed.

1.1. Objectives

For the research of this solution, an AR application prototype is created to present the sector the potential use of this tool for them to consider the full development of the application. The prototype of the app is focused on facilitating the task of the operator in charge of the Collective Protection Equipment. This solution is adopted by setting the general objectives and several specific ones, which can be seen in the following sections.

1.1.1. General Objectives

The main objective of this thesis is to study the viability of Augmented Reality (AR) in order to simplify, automatize and make more efficient the process of the CPE inspection. Meaning, enhancing the visualization of the elements to guarantee its presence. For that purpose, the job of the operator in charge needs to be facilitated and adapted to the current safety inspections workflow, in this case focused on the BESIX enterprise. The objective is not to substitute the current procedure, although, to improve it by giving the operator a more robust tool to reduce possible inaccuracies.

In order to achieve this, current methodologies are studied in-depth with the help of a construction site visit done in Liège, Belgium, that consists of an eco-neighborhood building of offices, houses and local shops [3].

This new method in AR is intended to demonstrate the ease of the inspection by comparing the virtual and real models of the CPE in their final locations. Facilitating the checklist of the equipment that needs to be inspected in a construction site. In that way, human error is reduced in favor of the safety workers. To achieve this, the models of the CPE's would need to be previously created in order to be introduced on the infrastructure 3D model.

In order to certify the improvements of this new methodology, various Key Performance Indicators (KPI) are used to assess and validate the potential technological tool. The most common KPI used to asses AR applications according to Jetter et al. [4] and that are suitable for the proposed application are the following ones:

	KPI	Description
Quantitative	**Time to complete the inspection**	Time consumed to fully perform the AR inspection.
	Usability	Assesses how easy a system interface is to use. This contributes to the effectiveness, efficiency, and satisfaction in which users achieve specific goals [5].
	Weight of the app	Depends on the number of elements the app contains.
	Cost	Tentative cost of the app according to the time invested in the app development.
Quantitative	**Hardware**	Defines the hardware that can be used in the application.
	Software	Defines all the software used in the development of this application. It characterises the ease of the app creation.
	Operating System (OS)	Defines what is the operating system that the app is targeted for. The more OS accepted, the more versatile is the app.

Table 1: KPI defined to test the performance and characteristics of the proposed application.

1.1.2. Specific Objectives

- Analyse the pain points and bottlenecks of the current CPE's inspection.
- Check the state of the art of current and emerging technologies applied to safety and health in construction.
- Propose solutions in order to design the virtual elements of the equipment that could be introduced on the BIM software.
- Analyse different software that generates an AR application environment.
- Analyse the software that transfers information among the platforms used.
- Analyse how to consider the time dimension in an AR environment application.
- Create guidance as a base for other creators to develop an AR application in a mobile or tablet device.

1.2. Research Methodology

For the development of this research, the Design Science Research Methodology - DSRM is used as a base that permits describing the process of justification, development and testing done [6]. The phases of this methodology are seen in the following figure.

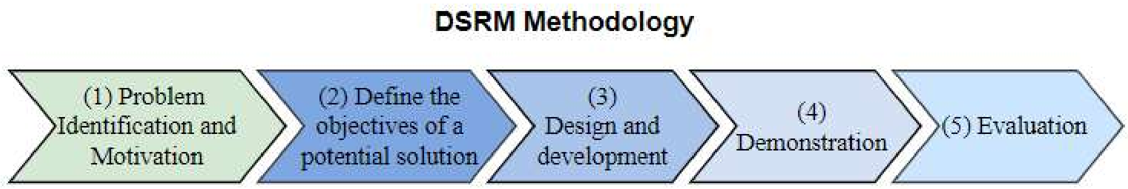


Figure 1: Phases of the Design Science Research Methodology – DSRM.

In the following figure it can be seen the workflow of this research with a detailed explanation of the scenario, activities and tools on each phase.

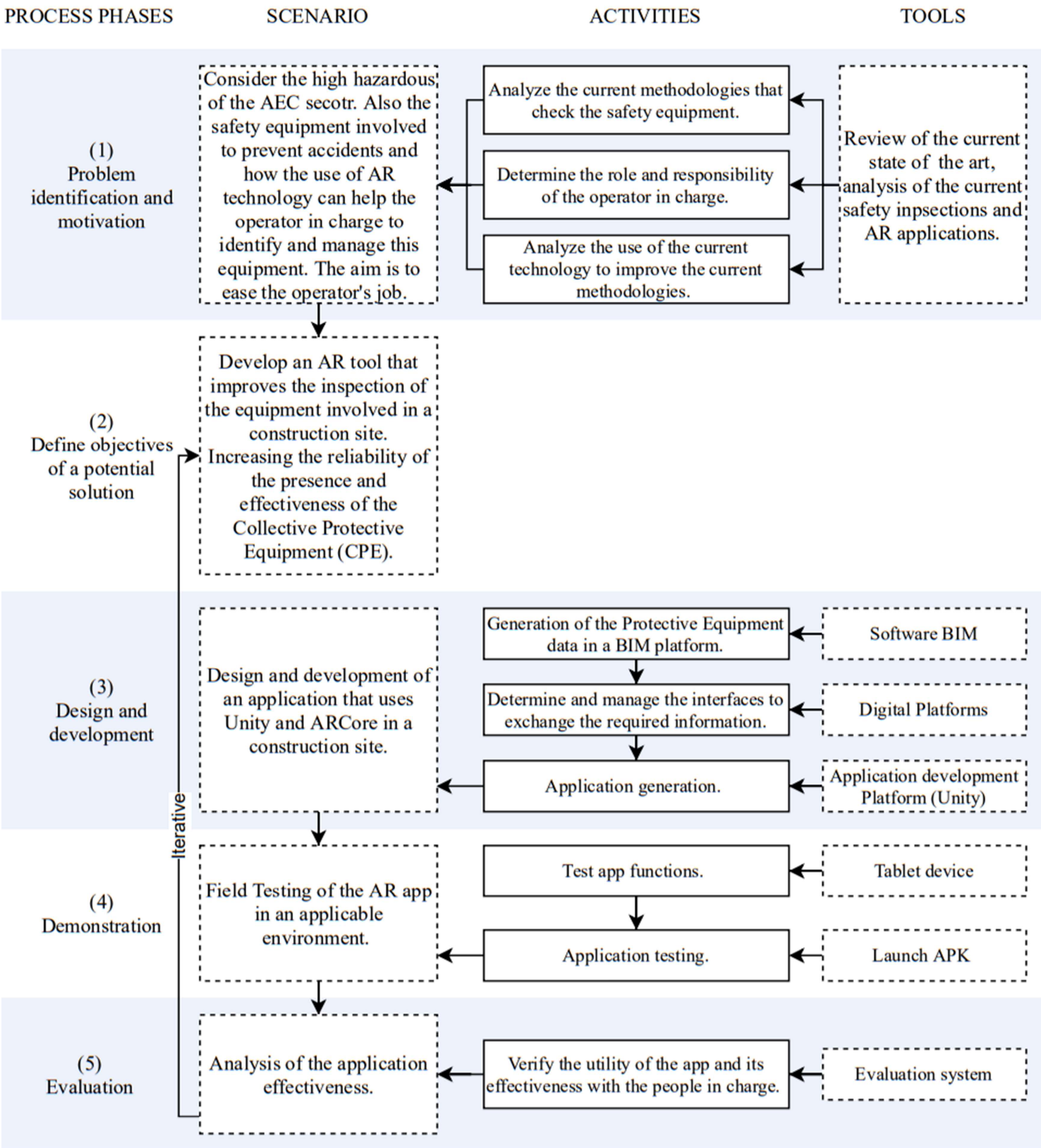


Figure 2: Design Science Research Methodology used for this thesis. Own elaboration.

2. STATE OF THE ART AT THE CONSTRUCTION INDUSTRY

This chapter describes key findings from a literature review and experts involved in the industry to determine the state of the practice related to the construction sector and safety and health in construction. Also, a review of developed AR applications in the domain of research and commercial applications is done.

2.1. Current context in the construction industry

The construction industry is an essential part of the country's economies. In the case of the European Union, it provides 18 million direct jobs and contributes to about 6% of the EU's GDP [7]. For instance, according to Eurostat [8], in 2017, the construction sector contributed 6.3% of the GDP in Belgium and 6.0% in Spain.

As it is known, the construction sector is sensitive to the economic cycles. Furthermore, at the time of writing, the impact of the Covid-19 leads to a crisis that manifests the vulnerability of the construction enterprises and workers to an economic recession. On the other hand, it presents a state of potential stimulation to recover by creating jobs and transforming into a more sustainable and digitalized sector.

In 2020, the European Union agreed on a recovery plan with the vision of a modern and more sustainable Europe [7]. A portion of the stimulus package is destined for the industries that promote digitalization and an ecological transition, which among others, the construction industry is one of the potential beneficiaries to access this budget.

In this scenario, the construction industry is experiencing a change into being a more digitalized sector, but still, at present, there is scope for improvement. For example, in Spain, according to *digital-biz magazine* [9], the construction sector is one of the less digitalized, with the exception of the agriculture and fishing industries. The main reasons are the complexity of the industry and that in its majority is composed of small and medium-sized enterprises whose investments in research and development (R&D) are smaller than in large companies. The more significant investments permit large companies to be higher in technology efficiency, allowing them to compete in the international market.

This situation is also seen on a global scale, where the construction and materials sector is one of the least invested sectors, see Figure 3.

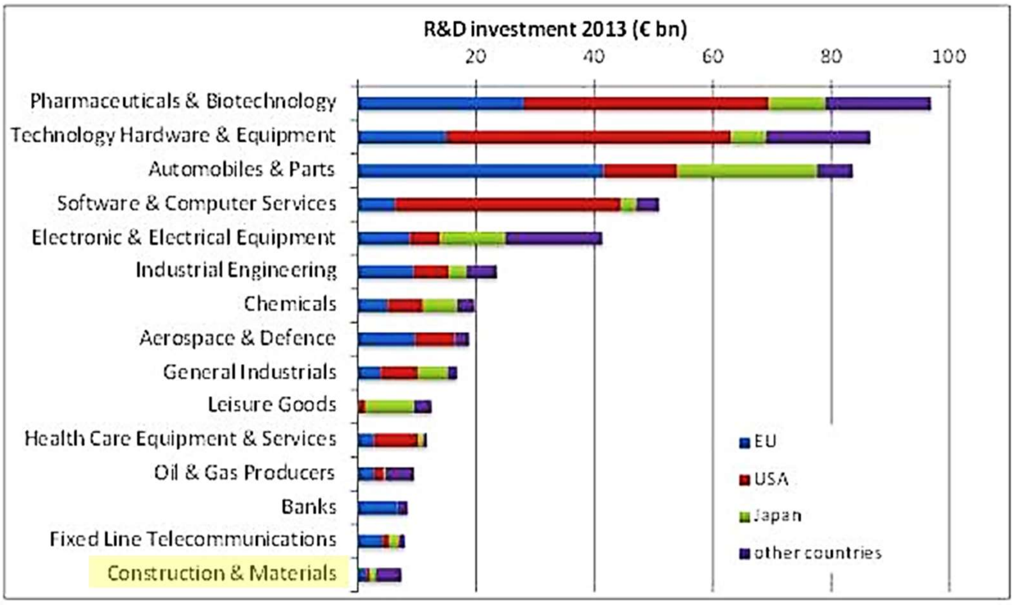


Figure 3: Research and development investment in 2013. **Source:** European Commission.

Although the AECO sector is less digitalised than others, the industry is adopting new methodologies in digitalisation, automation, and an increased use of Information and Communications Technology [10]. In the following section is seen the changes the industry is introducing in order to improve the current state of R&D.

2.1.1. Current Evolution of the Construction Industry

According to Construct Connect [11], a leading network platform in construction, five significant changes are coming to the construction industry. In its annual report, is mentioned that the inevitable rise of technology leads to a modernization of the industry. It helps to avoid the current productivity problems occurring in a construction project, which according to the World Economic Forum [12], it can reduce the costs by 20% of the life-cycle of a project.

These five major changes are in the context of the Construction 4.0 concept which is defined as the finding of coherent complementarity between the main emerging technological approaches in the industry to improve the real-time decision making [13].

Construction Software and Full Integration

Improving communication between the different stakeholders involved makes it necessary to create a more advanced integrating methodology. To overcome this, the trend of relevance adopted by the sector called BIM (Building Information Modeling), is causing a digital disruption in the industry [14]. BIM is a computer-based environment that offers a significant value in terms of collaboration and value throughout the design, construction process, operation and maintenance, and demolition i.e., the life cycle of an infrastructure. See Figure 4.

Figure 4: Life cycle in the Building Information Modeling methodology. Source: Advanced Solutions, Inc. **[15]**.

Furthermore, this methodology gathers all the data regarding a construction project, and it helps in its design, building and management workflow [16]. Several software platforms support this computer-based environment as Revit, SketchUp, and AllPlan, which manages different types of information, also referred to as dimensions.

In Figure 5, the different dimensions can be observed, where the 3D is the visualization of the construction model, 4D (time dimension) when showing the project evolution along with predictions. Also, it provides real-time all cost data in 5D, then the 6D concerns facilities management. Environmental impact analysis is performed in 7D. And lastly, the 8D regards to safety and health on construction site that can include embedded manuals, emergency plans, among other essential information.

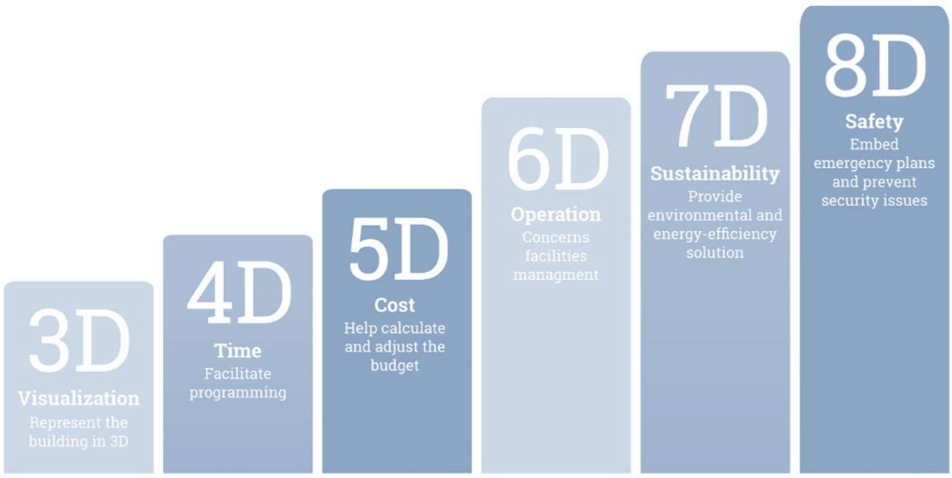


Figure 5: Dimensions in the BIM methodology. Source: DRAWBOTICS **[16]**.

Lean Construction is also an implementation that the industry is accomplishing. Its principles are to maximize value for the client while at the same time minimizing waste [17]. In this methodology, the Last Planner System (LPS) is a workflow proposed to increase worker productivity and accountability through tight scheduling and detailed group planning [18].

In Figure 6, the differences between the planification with and without LPS, can be observed. In the first sketch, the execution is not accurate with the planning, and in the second one, the organization plan changes due to better planning of adverse circumstances. This is accomplished by determining alternative paths that meet the required objectives.

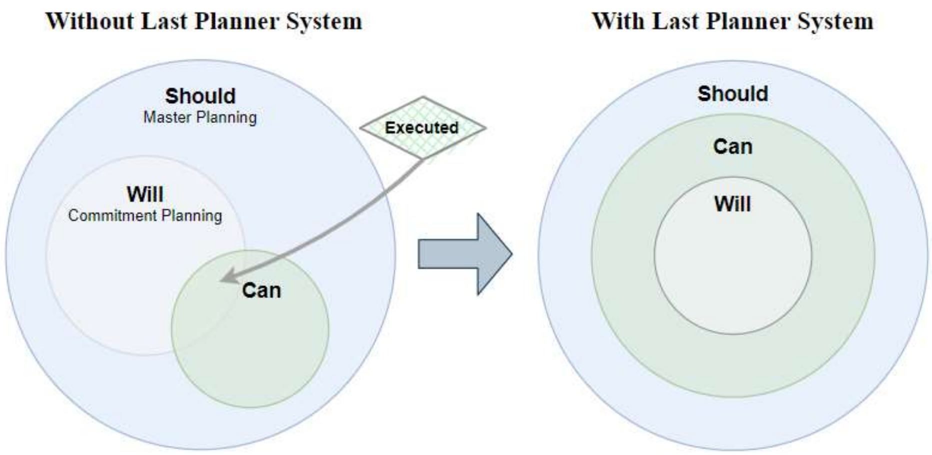


Figure 6: Last Planner Concept. Own Elaboration. Own elaboration from source **[19]**.

Augmented and Virtual Reality

According to the global research and advisory company, Gartner [20], AR and VR are no longer considered an emerging technology. They are defined as the phase of the Plateau of Productivity where the technology's broad market applicability and relevance are contemplated as a success.

This technology can help construction managers have a detailed overview of the project and prevent costly mistakes by superposing the virtual model of the infrastructure. It also can help in safety training by creating virtual reality simulations in hazardous environments. Or help with the visualization in environments with poor visibility as can be in mines or underwater, also crane operators, among other possible applications that are currently being adopted [2].

In following chapters, the concepts of AR, VR and examples of applications are explained in more in detail.

Next Generation of Tools

The evolution of the technological tools in the industries is at a rapid pace. The forthcoming generation devices are more sophisticated and interconnected, enabling them to send and receive data (internet of things). Also, Machine Learning (ML) and Artificial

Intelligence (AI) can benefit the industry in various areas as risk management, schedule management, subcontractor management, construction site monitoring, and ORP, among others [21].

New Workforce Type

The industry is rapidly changing, and so are the people involved. The new generation of workers who are more comfortable with technology will influence the methodologies in the near future. If the industry changes, it can attract more professionals. In addition to that, as mentioned in previous chapters, the EU's goal is to promote a digital transition [22] that will require a more technologically prepared workforce.

Green Construction

Green processes are just not a growing trend in the industry but also across the globe as a movement to protect our planet. Green construction refers to the application of processes that are environmentally responsible and resource-efficient throughout a building's life-cycle [23].

2.2. Safety and Health in Construction

At present, one of the particularities of the construction industry that differentiates it from others as the automotive industry is the workplace, where a construction site is in constant change due to the continuous tasks done by several stakeholders involved. Each final product is different, and its development is subjected to several factors that can have uncertainties causing delays on the project. Since a construction site is a complex place to work due to the many factors involved, enhancing safety can be a tedious task; nevertheless, most companies are developing a series of measures and improvements to protect their workers.

Several solutions came across the industry to improve the current state. Most of them have shown evident improvements in enhancing safety in different fields as hazard identification, training and education, inspection and instruction [2].

In this chapter, a state of the art is done to acknowledge the current situation regarding safety and the improvements developed by the AECO sector to tackle the primary concerns. Also, a review of existing applications is seen in terms of AR and other implementations focused on safety equipment.

Enhancing safety processes is crucial in order to minimise the number of risks on a construction site. It is well known that the construction industry is one of the most hazardous workplaces; however, implementing the proper safety and health prevention techniques can avoid the vast majority of the risks.

The causes of the accidents are due to various reasons. Several papers analyse these causes to define the processes that can be improved with new methodologies. In the university context, several colleagues at the Polytechnic of Catalonia were able to identify the difficulties the industry is having in terms of safety and health and proposed several solutions on different fields of safety with the aid of new technologies as VR and AR. These new methodologies are seen in detailed in following sections.

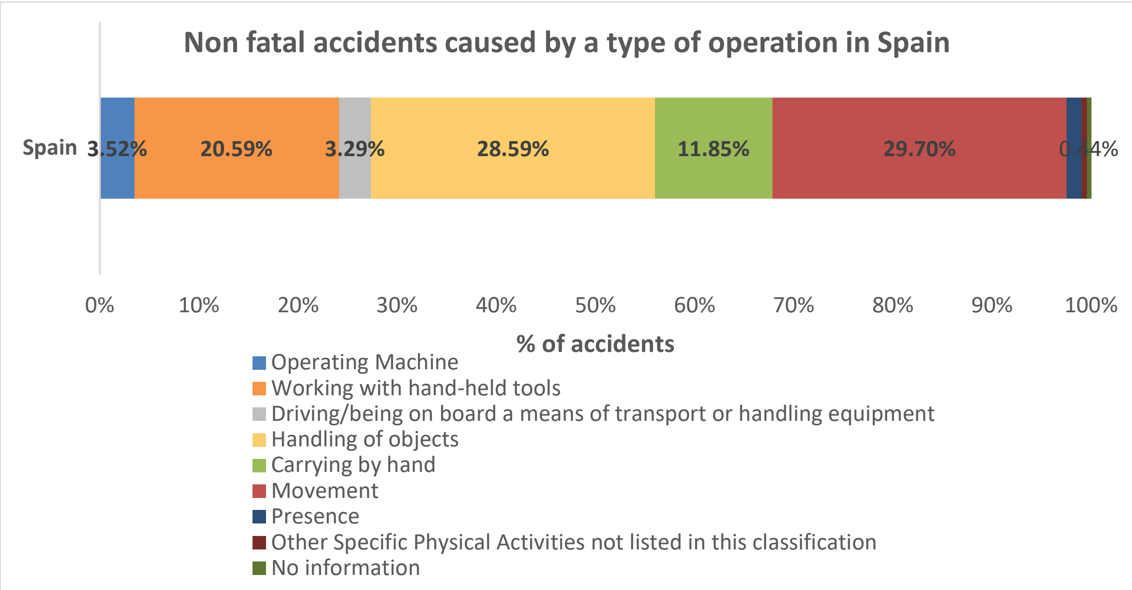
Firstly, in order to analyse the main issues in safety it is checked the statistics regarding the main causes of accidents in a construction site.

2.2.1. Main Causes of Accidents

In a report, O'dwyer & Bernstien [24], a New York law firm specialized in Labour and personal injuries, stated that the most common causes of construction site accidents include:

- Lack of fall protection (CPE's & IPE's) for workers on elevated structures.
- Lack of protection for people on the ground form falling objects.
- Unsafe equipment.
- Unsafe property conditions.
- Tripping hazards from construction materials and debris.
- Missing guards or protections on power tools.
- Lack of safety precautions when working near power lines.

The European platform for statistics, Eurostat, indicates another classification in terms of what is the operation performed when an accident occurs (Graphic 1).



Graphic 1: Percentages of the operation that caused an accident in a construction site in Spain. **Source:** Eurostat.

To complement this classification, in her master thesis, Rojas Erika [25], stated the main risks associated to the construction activities which can be seen in table in the Annex A.

As it can be observed, among other causes, there is a considerable number of accidents related to the safety equipment. Therefore, it is reasonable to study the implementation of a process that enhances a proper state of the safety equipment.

On a construction site, the safety equipment needs to be checked by the safety advisor who frequently performs a safety inspection to guarantee the obeyance of safety regulations within the workers and the equipment. In order to have a better understanding of the safety advisor's tasks, an analysis is done regarding the regulations that defines the guidelines in terms of safety and health.

2.2.2. Regulations in terms of safety and health in construction

The regulatory frameworks are rather similar between the Spanish law (*Ley 31/1995 Prevención de Riesgos Laborales* [26]) and the Belgian law (*Directive 89/391/CEE du 12 juin 1989 visant à promouvoir l'amélioration de la sécurité et de la santé des travailleurs par une politique adaptée de prévention des risques* [27]) both with the objective of providing a legal framework to enhance safety and health in the construction site.

Several decrees were given in both countries in the following years in order to adapt the regulations in a more efficient manner. In this guidance's, the figure of the safety coordinator also called the safety advisor is introduced. Its main role in both legislations is to coordinate the tasks that are done on-site by the several subcontractors with respect to prevention [28]. Furthermore, each national regulatory framework preserves certain specific tasks that are executed during the whole construction project, form the design until the finalization.

In the work of Rojas, Erika [25] a complete analysis of the different factors considered in the Spanish regulatory frame can be seen.

Since in this project there is the opportunity to collaborate with a Belgian construction enterprise, BESIX, and its Engineering Department, a detailed analysis is done in the context of Belgian regulations; even though, as mentioned, it does not differ in great magnitude from the Spanish one.

In the Belgian, regulatory framework, the Belgian Construction Confederation (*Confédération Construction* in French) [29], elaborated the guidance that complies with the Belgian law and also completed a set of recommendations of good practice to implement on-site.

In this framework several plans are considered to be done.

The five-year global prevention plan (Le plan de prévention global quinquennal**)**

This plan determines the employer policies for a period of five years. It is a written version of the general dynamic risk management system. This have to include the risks, the preventive measures, the objectives to be achieved and the services affected, and also individual responsibilities.

The annual action plan (Le plan d'action annuel)

The employer draws up an action plan each year based on the overall prevention plan. This work is done in collaboration with members of the hierarchical line and prevention services. The annual action plan is a written document that tends to concretize prevention activities. Written for the coming year of service, it includes, among other things, the priority objectives of the prevention policy, accidents and incidents that have occurred, as well as the responsibilities of each member.

The usefulness of the overall prevention plan and the annual action plan is not limited to the internal management of prevention. These documents are also useful in the event of recourse to subcontractors and in the situations where a safety coordinator intervenes.

The intern emergency plan (Le plan d'urgence interne)

The employer must establish an internal emergency plan when the risk analysis indicates the need for it. This plan sets out the measures to be taken in the event of an emergency: alarm, evacuation, exercises safety, first aid, etc.

The prevention policies in the construction site (La politique de prévention sur le chantier)

A construction site is a workplace that changes every day. The contractor must therefore adjust his safety policy and working methods to changes on the site, which requires careful permanent detection and analysis of the risks associated with its activities on the site. If necessary, it would be modified its safety plan, strengthen collective prevention systems or provide additional individual protection if the preventive measures in place no longer respond sufficiently to the peculiarities of the new working environment.

Regarding these policies, the main tasks to be done by the safety department in a construction site are summarised.

- Analyse the risks associated with the activities.
- Decide if any changes are necessary to enhance safety measures.
- Improve prevention measures if necessary.

Once the tasks dictated by regulatory framework is analysed, the following chapter analyses the concept of Augmented Reality and its characteristics.

2.3. Characteristics of Augmented Reality (AR)

Augmented Reality is an environment where digital objects, information and real-world elements interact with each other. This mix of components presented can have different immersive levels. From having digital objects interacting with the real world to add also olfaction and temperature senses. The concept indicates that in this way the reality is augmented by providing useful virtual information or objects.

Another technological concept that is in the market is Virtual Reality (VR). The main difference between both is that no interaction with the real world is created in VR, where a purely digital created environment is created and only digital objects and information can be visualized.

Some authors also add the concept of mixed reality, which involves all the environments where digital and real-world elements are mixed. Depending on the quantity of each environment, there are several nominations; a larger virtual environment can be designated as augmented virtuality.

In the following figure there is a representation of the concepts mentioned.

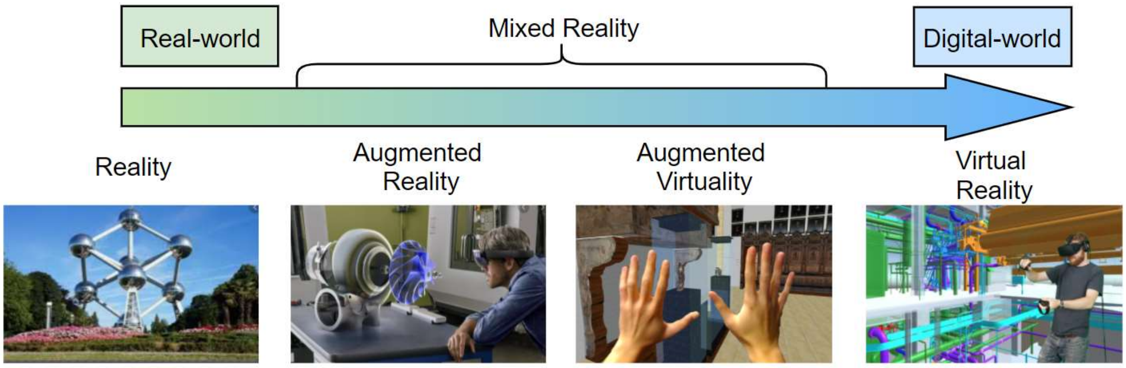


Figure 7: Representation of Mixed Reality concepts in terms of digital and real world. Own elaboration.

Also, some authors differ on the concept of mixed reality, and state that it is an environment where digital and real objects are well complemented. For instance, when a digital object is behind a real one, you would be able to see only the real object, enhancing the realism of the added digital components.

Figure 8: A digital object being covered by a real object. **Source:** Google, ARCore.

The beginning of VR/AR technology was formed decades ago. At that stage, the term VR and AR were not adopted, and experiences were created in order to visualize an environment where someone could see digital objects and interact with them. Its discovery did not have a massive impact on the market due to the lack of ease of implementation.

In the following figure, a chronological diagram regarding VR/AR main events is shown.

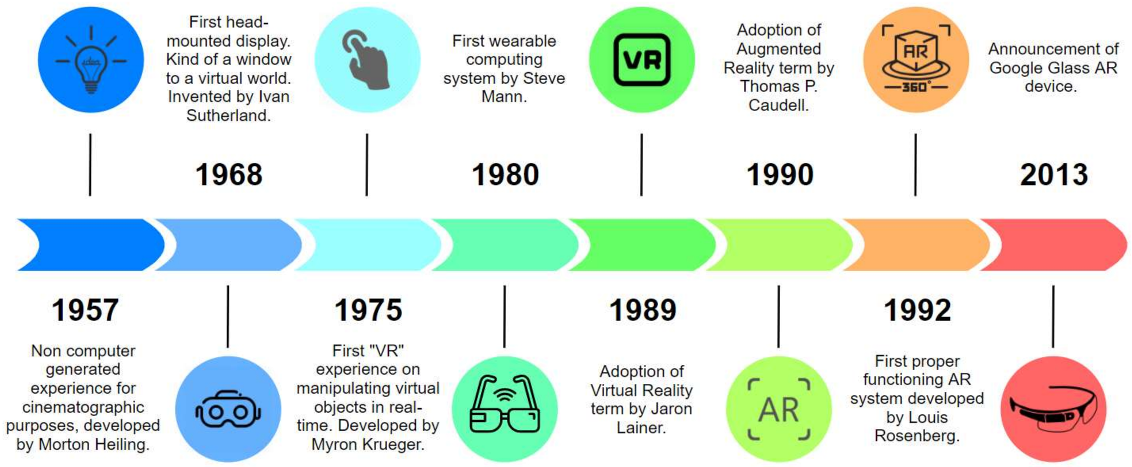


Figure 9: VR/AR main events from its discovery to the beginning of XXI century. Own elaboration. Source: interaction-design.org **[30]**

Since this thesis aims to develop an AR application to visualize the CPE's elements with a tablet device, the availability and options of several platforms for creating AR environments are studied.

Platforms and devices available for creating AR apps

In order to create an AR application, there are several options in terms of platforms and devices. In the study of this research, various ways to develop a complete app that could be customised with desired functions are analysed. Considering that the author's programming skills are acquired in the context of civil engineering studies, the option of using platforms that aided with the development of apps and AR platforms is studied.

In this context, the platform that holds the application and let you create an app without superior knowledge in programming, the so-called game engines are the software as Unity [31] and Unreal Engine [32]. The main difference is that Unreal Engine has higher visuals and it is mainly focused on powerful devices [33]. There are other options for more advanced developers as to create an application directly on Integrated Development Environments (IDE) like Android Studio [34] for Android devices, or Xcode [35] for iOS. These last options are not studied for the aim of this project; instead, the Unity game engine is used due to the compatibility it offers with several AR platforms.

In these AR platforms, its primary function is to provide the game engine with the necessary tools to create an AR app. The options mainly depend on the targeting device, which for mobile or tablet devices, there is ARCore [36] from Google that works with Unity and Unreal Engines. Also, there is Apple ARKit, used for the master thesis of Chavarri [37] and targeted exclusively for iOS devices. Another attractive platform is Vuforia [38], researched for the bachelor's thesis of the author [39] and available to work with Android and iOS devices.

When developing apps for AR glasses devices like the Microsoft HoloLens developed by Microsoft and the Magic Leap, other platforms are also required, which are also compatible with Unity. In the HoloLens case, it is necessary to download the Mixed Reality Feature Tool [40]; and with the Magic Leap, it is required to download the Magic Leap SDK.

In the following figure it can be seen how is the complementation between the game-engine Unity and the AR/VR platforms that are currently in the market.

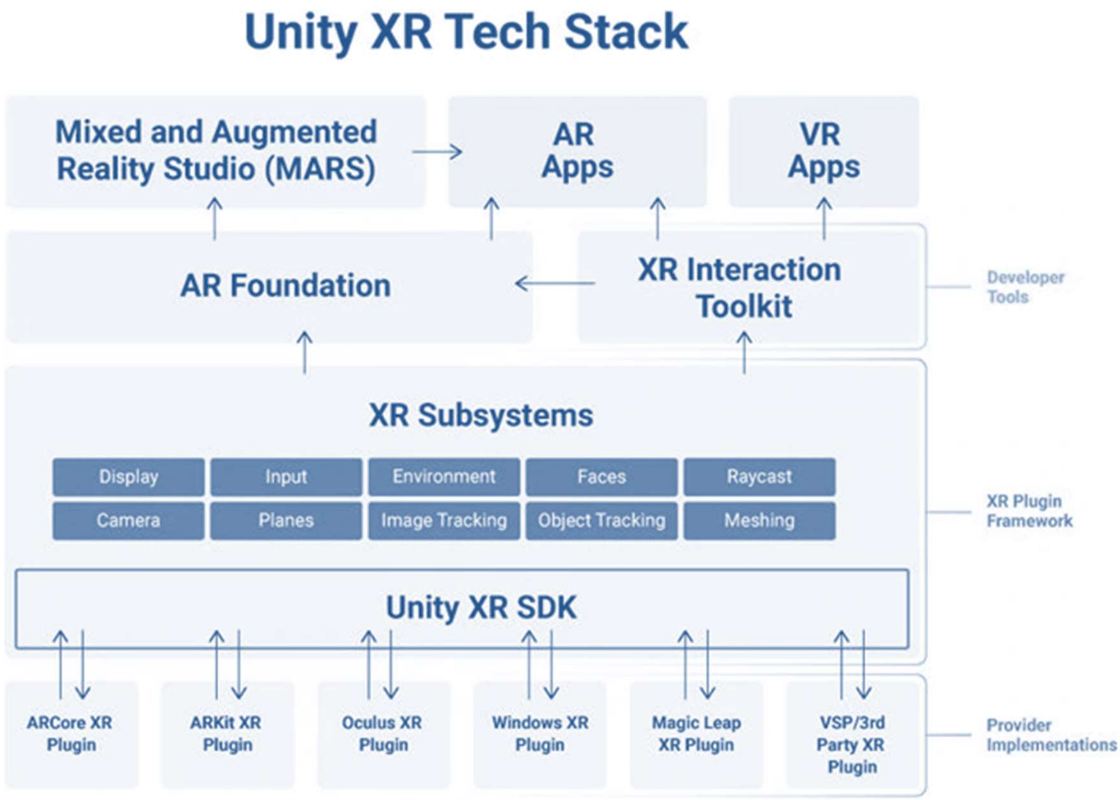


Figure 10: Availabilities of AR platforms complemented with Unity. Source: Unity.

AR/VR applications in construction

AR has evolved from new exciting technology to a growing asset for the AECO and other sectors during the last decade. This context makes this technology commercially viable for the enterprises that may have been reluctant to adopt it initially. Furthermore, the increasing development of more powerful devices contributes to the accuracy of these applications which is a crucial asset in sectors as the healthcare industry, where AR is being applied in surgeries in which precision is critical [41] [42].

The applicability in the AECO sector can be done in several areas. From visualizing structural elements and their detailing, installations systems, visualization of the terrain, etc. From research, it is seen that AR is currently being applied in several construction enterprises. One recent example is the 73-story skyscraper construction project 9 DeKalb Avenue, located in Brooklyn, New York City, US. In this project, the architectural firm, Shop Architects, uses Augmented Reality on site (Figure 11) to receive live updates on the materials used, construction status and dimensions. In an interview in The New York Times [43] they mention that AR reduces the problem of communication from the top of the hierarchy to the workers and that it should prevent some on-site mistakes, avoiding the need for expensive remedies. Also, they state that with AR, they can visualize problems that would not be able to be seen from a computer screen. AR does not only show a fancy 3D model of the construction, it provides a dynamic analysis of what is constructed and what's remaining.

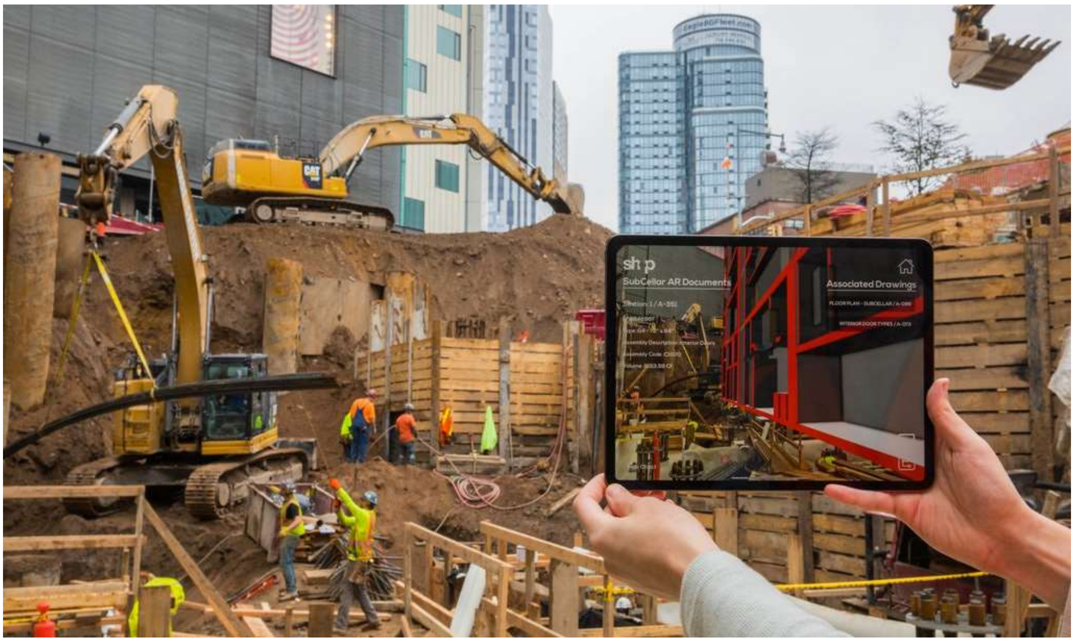


Figure 11: Adam Chernick of SHoP Architects demonstrates new software that can render real-time 3D data about ongoing construction at 9 DeKalb Avenue. **Source:** Hiroko Masuike/The New York Times.

There are other examples of enterprises that are currently starting to apply this technology. For this thesis, there has been the opportunity to meet with two Belgian international construction companies: BESIX [44] and BAM Contractors [45], wherein the case of BESIX, AR was applied on one of their construction's sites located in Brussels by the Belgian start-up, Genie Vision [46], who showed us their applications developed for construction enterprises.

Genie Vision provides a solution where the BIM model is transferred to their application where workers can access its information with a tablet device (Figure 12). They report a reduction of non-conformities up to 50% when comparing the real construction elements and the augmented virtual model. In their application, they can share all the information in the cloud, coordinate, collaborate in online and offline mode, and report issues, see Figure 13.

Figure 12: Layer Management interface in the AR application developed by Genie Vision. **Source:** Genievision.com

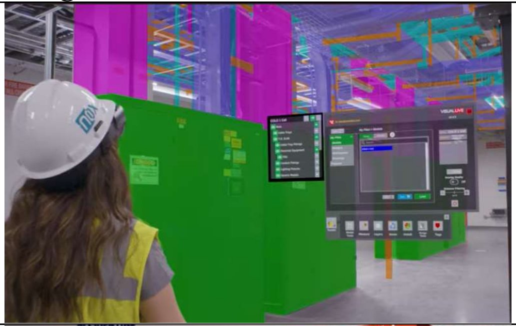
Figure 13: Issue reporting interface due to the non-conformities found on-site. **Source:** Genievision.com

These examples mainly focus on the visualization of structural elements to improve non-conformities and facilitate communication between the different stakeholders. As these enterprises, other companies are developing AR solutions in the construction field as Kiber [47], that offers a wearable headset that incorporates an AR device; and Visual Live also has an AR application to use it on-site [48]. These applications show great potential to reduce the mistakes on-site by visually comparing what is constructed and what is designed.

In the case of safety and health, there are also VR/AR applications that are applied in several fields. In the case of training and education, the conclusion of this applications states that VR/AR experiences enhance motivation in the students to learn about safety. Furthermore, it can be observed that there is an increase in performance in the fields of hazard identification, training and education, inspection and instruction [2].

In terms of hazard identification, some studies stated that there were better results on workers that used VR than the ones who used photographs and documents to identify them [49]. In training and education, VR applications allows the novel workers to get acquainted with a real construction site environment before entering the real site. Several applications were made in this field in the context of the Polytechnic University of Catalonia and CIMNE [50]. One example is a serious game developed by Arnau, Marc which recreates the hazards that workers could encounter on-site [51]. Magaña, Marina developed another application in the field of mining in order to create an experience that raises awareness of mining risks [52]. And as an example, in the field of inspection and instruction, an application developed by Chan et al. [53] created a framework where among various options, an inspection is done with the aid of AR by displaying useful information regarding the risks related to its location so the preventives measures can be improved if necessary.

Apart from the applications mentioned, there are others that are also using AR in the construction field and particularly on the safety and health aspects. In Table 2, another practical AR applications are considered for this research.

Authors	Title	Abstract	Images
Visual Live [48]	Augmented Reality for Construction	Visual Live is a company that creates AR apps for the construction industry. They implement de BIM model on-site to visualize the installation, mechanical systems, structural elements, and electrical systems, among other industries applications. They partner with Microsoft to use the HoloLens, and they have worked with several construction enterprises.	
Master Builders Association of NSW [54]	Augmented reality height safety app launched by Master Builders and SafeWork NSW	AR application applied in safety targeted at young workers to access safety procedures information. It brings digital images and content to the real world in real-time, which are eight times more engaging, according to the research.	
Masoud et al. [55]	PARS: Using Augmented Panoramas of Reality for Construction Safety Training	It states that the current VR applications may differ from what is encountered in the real construction site. Their research developed a tool to train workers in hazard identification with a 360-degree panorama of the site. When validating the experience with a VR application, the workers identify the VR as "easier" and "clearer".	
Amir H. et al [56]	On-site Building Information Retrieval by Using Projection-Based Augmented Reality	Focuses on on-site information retrieval, which helps the engineers and architects to retrieve information by projecting the construction drawings. The application is compatible with the BIM methodology in terms that the drawings are constantly updated. The results showed that using this system, the engineers could retrieve information faster than the traditional way.	

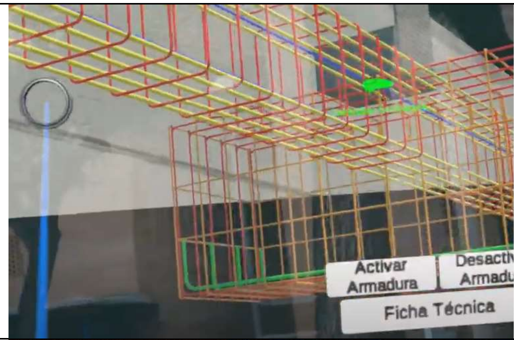
Ramos, Jorge [39]	Augmented Reality applied in Construction Foundations	In this project, an AR application is developed to visualize the reinforcement of the foundations with an AR glasses device called Magic Leap. The aim is to ease the worker's task by superposing the reinforcement virtual model on top of the real one, so the visual comparison is more robust for constructing the rebar and quality inspection.	
Damià R., Jordi [57]	Augmented Reality as an information visualizer device for Construction 4.0	In this thesis, the author proposes an AR application where a structural element is superposed in the real construction site by using GPS coordinates. The viability of this method is validated by the opinion of several people dedicated to the construction industry.	

Table 2: State of the Art in terms of AR applied in construction.

3. ANALYSIS OF THE SAFETY INSPECTIONS

In order to develop an integrated solution to the safety inspections, is necessary to analyse in-depth the tasks of the safety advisors in a safety inspection and its workflow. In previous chapters the tasks of the safety advisor according to the Belgian regulation were analysed. In the Spanish context, according to the functions dictated by law, a workflow of the safety advisors' inspections of the safety equipment can be developed.

The tasks of a safety advisor according to the Spanish regulation framework [58], that as seen in previous sections is similar to the Belgian framework, dictates the following tasks:

- **Evaluate risks**: this is performed before construction and for each phase to analyse the safety equipment required.
- **Plan preventive activities**: where it focuses on the worker's safety education and training, and the emergency procedures.
- **On-site visits**
  Where:
  - Paper work analysis: revision of the safety plans.
  - On-site safety inspections: walk around the construction site to check the presence of the safety equipment (CPE and IPE). In case of any incident, it is reported. Furthermore, there could be consequences for those workers who do not oblige with the safety measures.
  - Report regarding the visit. Contains all the procedures and incidents noted. Pictures and other data can be stored.

In the case of the safety advisor tasks done in the framework of the Belgian regulations, an analysis of a BESIX safety inspections is done to understand adequately how the regulations conform to the inspection's workflow.

Rojas et. al. [59] in their research, they developed a flowchart (Figure 14) regarding these tasks endured by the safety advisor, or the so-called Occupational Risk Prevention technician (ORPt) in the Spanish regulation framework.

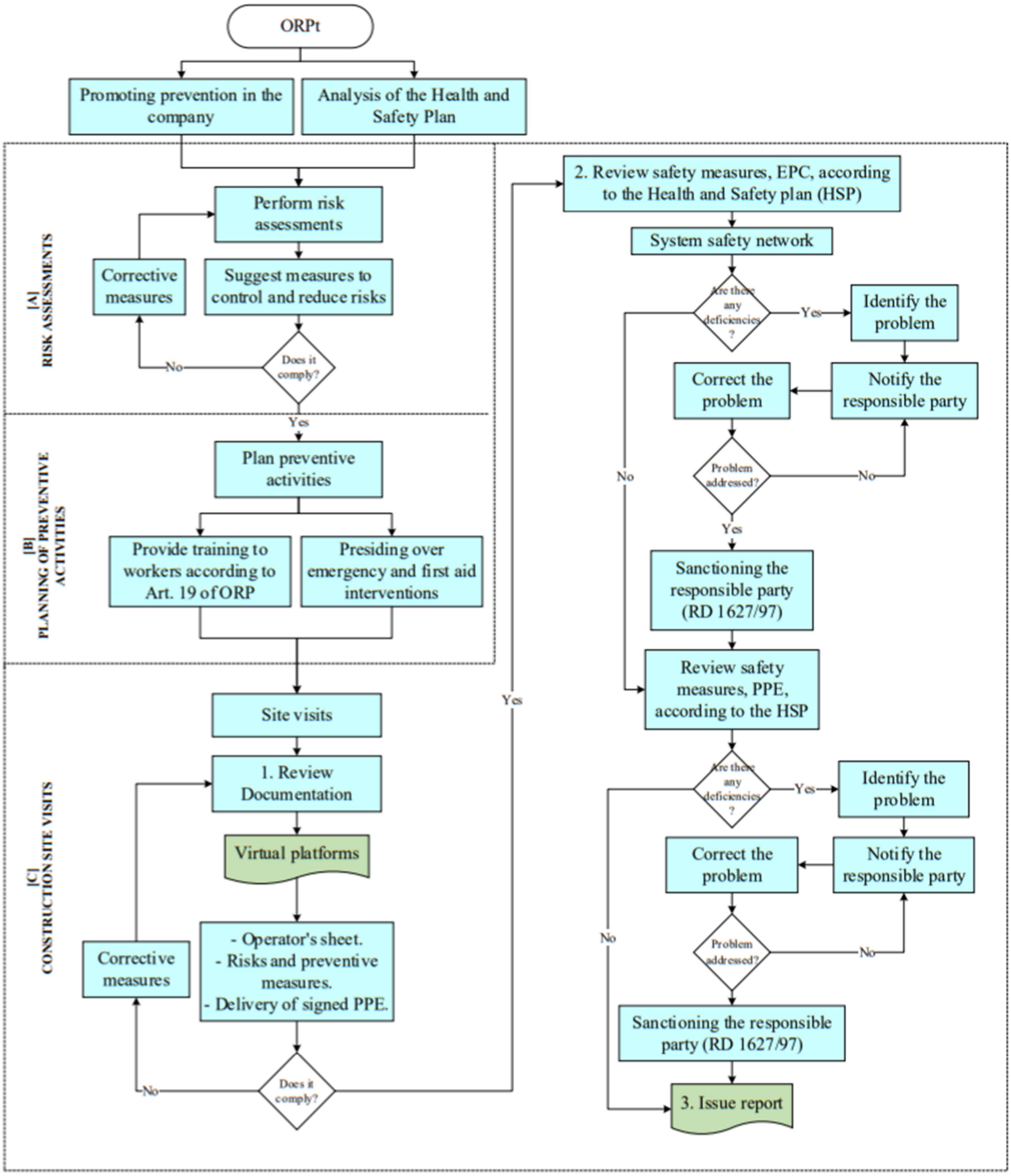


Figure 14: Flowchart of the safety advisor tasks according to the Spanish regulation framework. Source: Rojas, Erika et. al **[59]**.

3.1. Analysis of safety inspections on BAM Constructors and BESIX

As mentioned, during the thesis development, BESIX and BAM Contractors were keen to aid by providing their expertise regarding detailed information about safety inspections on-site. Thus, since in this thesis the intention is to improve these inspections with AR, it was intended to express them the main ideas and objectives in order to get an opinion and guidance from the point of view of two international enterprises.

In the meeting with BAM Contractors, Marisa Moens, Digital Construction Excellence Center Manager; and Robin Collard, Lead Digital Construction Development, showed us their current process during a site inspection. In their case, they developed a digital platform that can be accessed with a tablet on-site. In this platform, all the metadata regarding the construction is interconnected and saved in the cloud. In terms of safety inspections, they introduce the information required beforehand. In the case of the CPE, they save the type of element and its location provided on a drawing plan. Moreover, during safety inspections, in order to certify that the safety elements are present, a checklist is performed and saved in their digital platform. In Figure 15, the flowchart of the inspection performed in BAM contractors is developed.

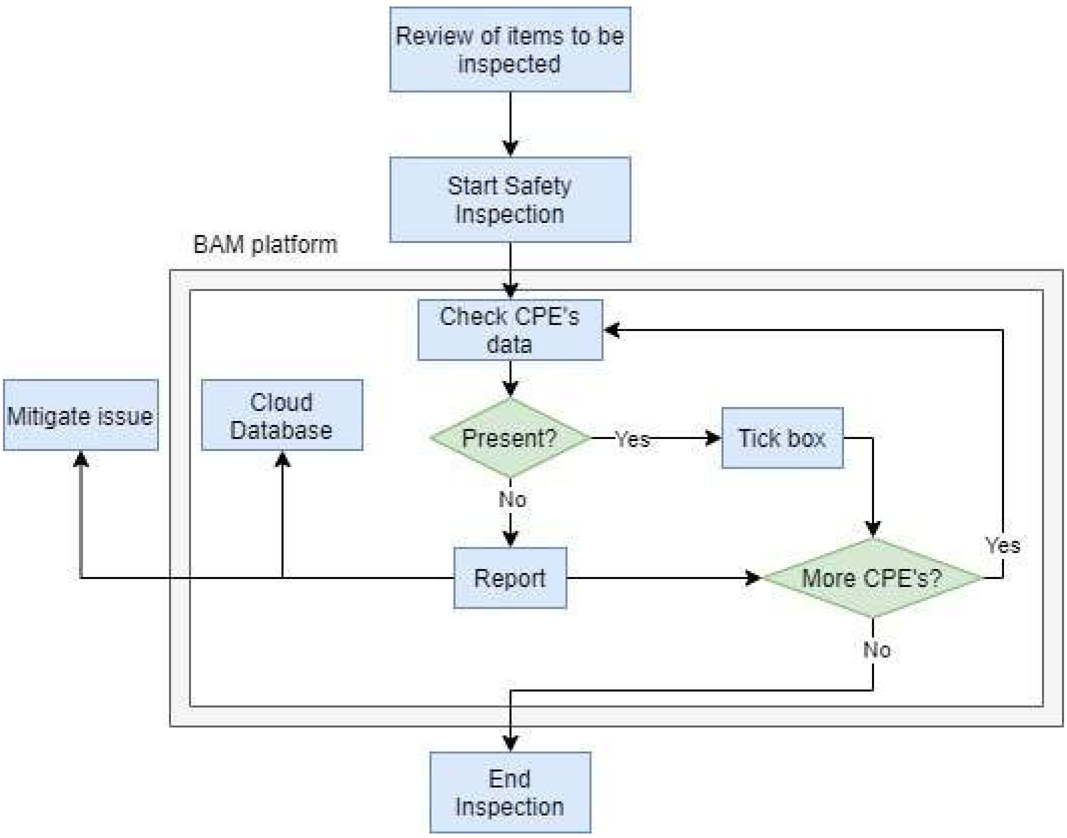


Figure 15: Workflow of the safety equipment inspection done in BAM Contractors. Own elaboration.

In the case of BESIX, there has been the opportunity to first meet with François Lederer, Head of BIM, Digital & Sustainable. When introducing the ideas and the thesis objectives, they were keen to help and provide their expertise and knowledge for the

project development. They saw an interest in the possibility of AR being a differential factor to assist the SA in identifying the equipment by having a comparison of virtual and real CPE elements.
They mentioned several things concerning applying AR on-site. First, they were concerned about creating the safety elements models, which are not currently developed in their company. Subsequently, a solution by François was proposed to facilitate the implementation of these models, which is to create an API that identifies a BIM model and, with Artificial Intelligence, recognize the risks to implement the CPE's needed automatically. In this case, implementing the CPE's models would be eased to make the whole process more efficient in terms of time management. In order to support this idea, according to Quentic, there is a future of AI in ORP. It is currently mentioned that AI models are taught to recognize hazards from many single pictures. Also stated that the automation level using intelligent solutions would rise rapidly in the incoming years [60].

Other concerns were made as to the use of AR glasses device on-site. It was mentioned that they rejected using this device on-site due to the reduction of the worker's visibility. Therefore, the only AR device that is currently used is a tablet.

Also, it was discussed the interoperability of the platforms used. In the case of BESIX, they used specific platforms to manage all the data regarding a construction project. They were interested in knowing how these platforms can complement the application so the SA would not need to change through several apps constantly. It was also suggested to think about API's that would enhance database centralization. In this case, as stated in the objectives, the ease is not to fully implement the application on the company's current workflow but to study the possible implementation of AR to assist safety inspectors.

Finally, it was proposed to visit a site inspection in order to know the details of the SA's tasks on a safety inspection.

3.2. BESIX Site Visit: Paradise Project, Liège, Belgium

This section describes the activities and the characteristics of a construction safety inspection. In this first visit, the safety advisors Patrick Fable and Arnaud Charlier, who have been very helpful in developing the foundation of this thesis, guided through the Paradise Express Project. The project consists of an eco-neighbourhood's buildings of offices, houses and local shops located right in front of the Liège-Guillemins station in the city of Liège, Belgium.

The aim of this work, as previously set in the objectives, is to focus on the inspection of the CPE's by visualising them in an AR environment. Although, by having the opportunity to follow a live safety inspection, it was analysed the tasks performed by the safety advisor.

As it is known, every construction is different and it has its particularities. This work intends to propose to research the functionality of this tool based on a specific and actual workflow from BESIX. At the time of the visit to the Project Paradise construction site, there were constructing three buildings with similar construction phases. It was suggested to one day visit one office building and another day the residential one.

Before the inspection, it was explained by the safety advisors their role in a construction project according to the Belgian regulation framework. Their tasks as a safety advisor are the following:

- Advice and assist the Quality, Health, Safety and Environment (QHSE) Manager in formulating and implementing the QHSE policy for the different work teams.
- Develop a safety culture in collaboration with the QHSE manager and enhance continuous safety awareness of the hierarchy and of the on-site employees.
- Centralise, structure and organise security priorities. Follow the legislation, analyse the risks, promote improvements, write procedures and instructions, inspect the works on-site, formulate advice on safety aspects and installations and coordinate with the subcontractors.
- Advice and support site supervision in the development of QHSE plans and projects.
- Carry out periodic site visits and inspections.
- Organize the welcome information and training for new employees.
- Assist the QHSE manager in the consultative bodies within the organization.

On a construction project, the safety advisor has a Lean Planning meeting with the Project Management team, which is discussed and planned the work for the next five weeks. There is also a weekly on-site meeting with the project management. Changes in planning, advances and delays are discussed in these meetings.

As mentioned, during the on-site inspections, the SAs need to make sure that all the safety measures are being ensured as planned. They check that the workers are performing their tasks in accordance with the safety measures. If not complying with them, the task is stopped, and the safety advisor needs to ensure that the worker performs appropriately. In the case of the CPE a pure visual inspection is performed. Before the inspection during the meetings, they foresee the project's phase and the safety elements needed. With their knowledge and experience, they have to know if any CPE needs to be placed or substituted.

In the case of any incident/observation, which could be a CPE missing, a worker's misbehaviour, risks that need to be addressed, hazardous products, etc; they report it in an application where the SA inputs an icon of the incident, the observation type, an image, a comment, a status and an action, Figure 16.

Icon	Observation Type	Image	Comment	Status	Action
	LSR1		Attention aux ouvertures laissées sans protection. Aucun garde-corps ne semble être installé	NOT OK	Action Required

Figure 16: Example of the report of an observation used in an inspection of BESIX.

This report is sent to the project management team responsible for any accident on a construction site. The SA is responsible for securing and stopping the work if there is a risk.

During the inspection, several incidents and observations were made a compiled in the Annex B. In the following table, an example of several incidents that were reported during the inspection regarding the CPE's can be seen.

1. A barrier missing on one of the stories of the building.

2. An unsafe opening on the staircase shaft.

3. Barriers missing on the central core of the building.

4. Opening not covered with barriers.

Table 3: Observations seen during the inspection at the Paradise Express project. Own source.

Incidents can be classified into three different categories that have different procedures.

- Minor incident: in this case, the safety advisor instructs the worker to correct the issue—for example, a worker not wearing his helmet, which is not reported.
- Major. In this situation, the work is stopped, and it is reported. For example, a CPE is missing.
- Critical. This is the most adverse situation where the work is stopped, and it is directly discussed with the project management team and the work supervisors if that is the case—for example, a flood in one of the levels.

According to this information regarding the inspection, the following workflow of the safety advisors on a construction site inspection is elaborated.

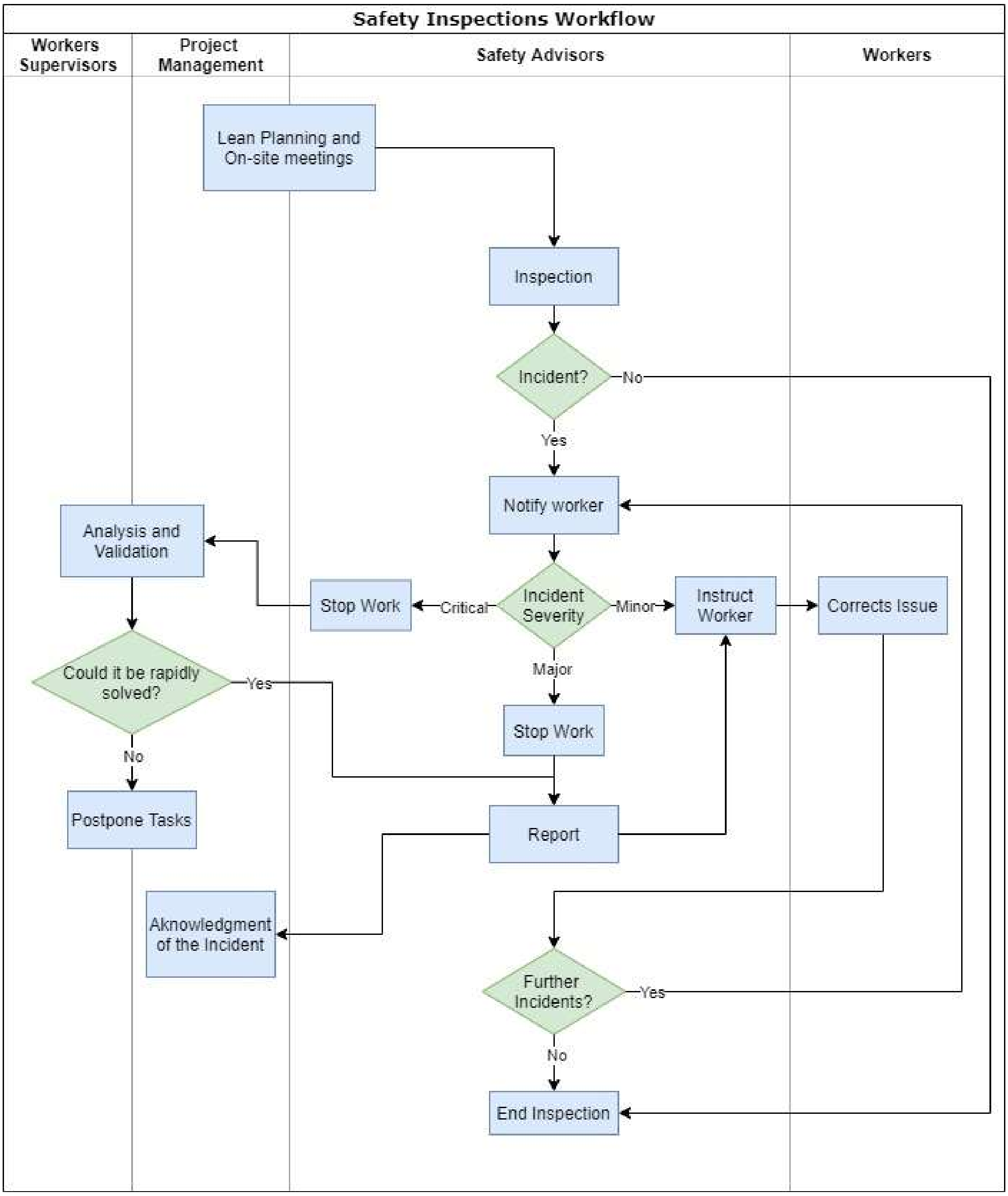


Figure 17: Safety advisor's workflow during the construction site safety inspection.

Once is analysed how is the workflow of a safety inspection, an analysis of bottlenecks (BN) and pain points (PP) is done with the information and observations obtained during the on-site visit.

Type	Matter	Description
PP	Visual Inspection	A safety inspection is performed by a visual inspection. No list of CPE's is used, which can decrease the robustness of the process.
PP	Check elements based on SA's expertise	A purely visual inspection indicates that SA needs to know where precisely a CPE should be placed. In this way, the inspection is highly dependent on the SA expertise.
BN	Ensure safety requirements with subcontractors.	The legislation states that subcontractors are in charge to train their workers in safety. This is not always the case, and some workers lack training. Full proper training cannot be done on-site by the contractors.
PP	Lack of good practice by workers	Some workers do not always obey the safety regulations, even though they know them.
BN	Coordination between report and corrective measures	A time gap between the SA can report an issue, e.g., a CPE missing until it is placed. Waiting times leads to permanent risks.
BN	Coordination with the Project Management when reporting	Project management is responsible by law to endure all the safety measures. When SA reports any incident, they need to be notified before any action is done. It could be more efficient.
BN	Cloud database	Data regarding all the safety equipment is not created. Creating them could lead to a more robust process of a checklist.
PP	Number of apps	Manage several apps in one process is not optimal for the user experience. Centralization of the functions in one app is more convenient.

Table 4: Main pain points and bottlenecks seen in the process of a safety equipment inspection.

In order to quantify (QT) and qualify (QL) the performance of the current inspection, several Key Performance Indicators (KPI) are set. This aids in an evaluation and comparison with the proposed solution. In the following table, the KPI's chosen for the safety inspection performed by BESIX, are explained and marked with according to the feedback received from the SAs.

Type	KPI	Description	Mark
QT	**Time Consumed**	In terms of time consumption, the safety inspection is quite dynamic. SA walks around and checks the area; in case of any incident the reporting is simple and little time is consumed.	Adequate
QL	**Robustness**	Ability to withstand adverse conditions. In the inspection, it entirely depends on the SA and no extra aid that could increase the robustness is provided.	Upgradeable
QL	**Incident Responsiveness**	Ability to withstand adverse conditions. The inspection entirely depends on the SA, and no extra aid that could increase the robustness is provided.	Upgradeable

Table 5: Key Performance Indicators for the current safety equipment inspection.

From the state of the art regarding the inspection, it can be observed that there are different levels of data assistance that the SA has. A first level would be when the SA does not rely on any information, consisting on a pure visual inspection. Another level is when the SA has item information regarding the CPE's either on paper or digitally, see Annex C. Next level is when the inspection is done with several data as the items, location, maintenance notes, etc. Lastly, there is the level proposed that consists on add a layer of a visual comparison in AR. In this case it is determined a new layer of information that can be augmented. From this analysis is introduced the concept of different levels on augmented inspections.

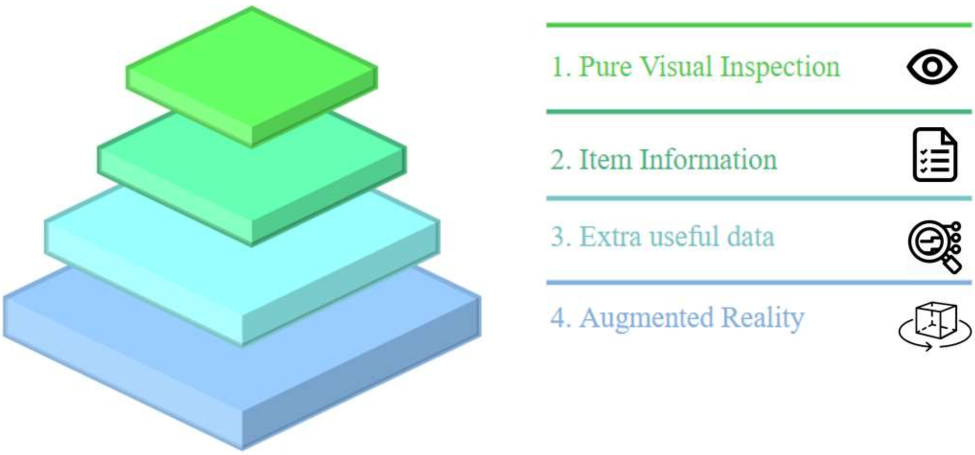


Figure 18: Identified levels of augmented inspection. Own source and elaboration.

Nº	Augmented Layer	Description
1	**Purely visual Inspection**	SA does the inspection with a purely visual inspection with no access to the information of the CPE.
2	**Item information**	During the inspection it is accessed the information regarding the name of the CPE to inspect. See Annex C.
3	**Extra Useful Information**	Not only is provided the name of the CPE, also displays the location of the CPE, the maintenance state and its duration on that place.
4	**Augmented Reality**	Layer where AR is applied in order to have visual comparison during the checklist of the items.

Table 6: Description of the 4 layers of the augmented inspection.

4. CONCEPTUAL DESIGN OF THE PROPOSED INSPECTION

Once the state of the art is done, this section explains the conceptual design of the proposed methodology to aid the safety equipment inspections with AR technology.

4.1. Justification

From the previous chapters, it can be determined that the current safety equipment inspections can be ameliorated by adding another safety layer of guarantee of the equipment presence.

Since the objective of this thesis is to study this implementation, it is necessary to develop a prototype that demonstrates the capabilities of AR in the inspection workflow. The content of the app has to mitigate the main pain points seen in previous sections. Some of these points and bottlenecks are related to safety management rather than the visualization of the elements. The app's functionalities need to address mainly the visualization aspects and adapt the app to a workflow that facilitates communication and data management.

In order to support this solution, as explained, when presenting the idea to BESIX, the QHSE Manager saw potential in the proposal. The safety advisors who guided through the on-site inspections saw the concept as useful for complex constructions sites. Genie Vision, who develops AR solutions for construction enterprises, also saw the idea as an opportunity to research in applying AR in safety aspects.

Due to the difficulties of developing a prototype for a real construction site due to the unmatching timing and the impracticability of having access to a BIM model of an ongoing construction project, the prototype is based on a construction simulation on the laboratory of civil engineering of the ULB, located in building C at Solbosch Campus, Brussels.

This aim of this prototype is to show the concept of the augmented inspection and provides a notion of the maturity of the application, which in the Technology Readiness Level (TRL) scale [61] a level 4, where technology is validated in a lab, is feasible to be achieved. The different levels of TRL are shown in the Annex D.

4.2. Functionalities requirements of the app

The app's requirements need to respond to the objectives and overcome the pain points and bottlenecks of the current inspection. The following table lists the difficulties of the inspection and what functions are developed to overcome these issues.

Difficulties	App functions
Visual Inspection	CPE virtual models are superposed on top of the real models in order to have a clear comparison between what is in place and what is planned to be placed.
Check elements based on SA's expertise	In an AR environment, the CPE needs to be constantly planned and input in the BIM model. In this way, novel inspectors can be aided in the planning rather than in the construction site.
Coordination between report and corrective measures	Real-time information exchange can be introduced in the app to increase the responsive time of applying corrective measures.
Cloud database	The application can implement real time-shared data in the cloud so different persons can access it.
Number of apps	All the digitalized functions needed can be implemented in the app to ease the task of the SA.

Table 7: App functionalities that overcomes the main pain points of the current inspection.

Also, since new CPE's models need to be introduced, it is necessary to study the implementation of these models and consider the constant change of the equipment.

In the case of implementing the CPE models Alcalde, Gerard [62] studied the implementation of the equipment in a Revit BIM model. Several webpages as BIM Object [63] and BIM and Co. [64] various models that can be introduced without the effort of modelling objects in the BIM software, see Figure 19.

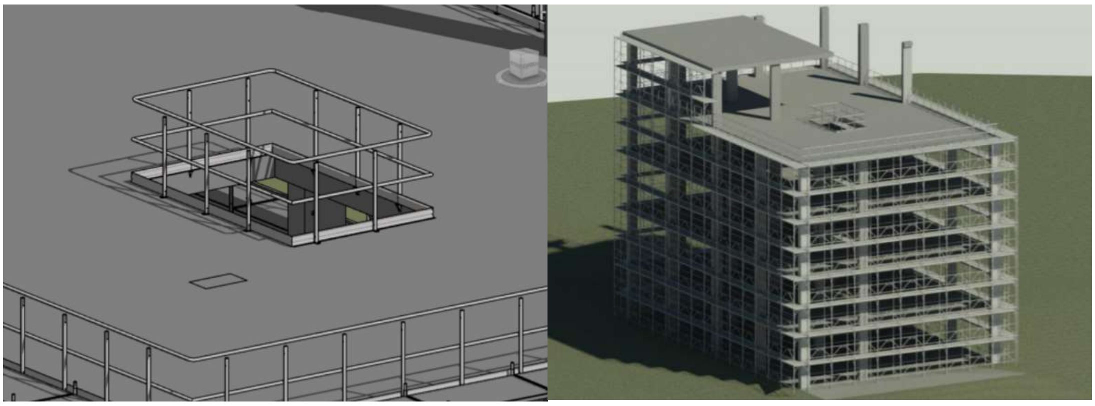


Figure 19: Introduction of the CPE models in real construction BIM model. Source: Alcalde, Gerard **[62]**.

Furthermore, the time has to be considered in the presence of the CPE since it changes throughout the project phases. For this solution, it will be necessary to attach a piece of information regarding the timeline presence of these models. An analysis by Tarancon, M. Antonia [65] was done regarding the time dimension in BIM, stating that planning of the activities is in continuous change and needs to be tracked constantly; unexpected events always occur in construction. In this context, it would be necessary to integrate the CPE as a BIM element of the construction to improve the planning of the safety equipment. This process mean that the CPE 3D models could be transferred to the AR experience without the effort of having to create them. Therefore, the applicability of the concept would be eased on the assumption that the CPE would need to be input in the BIM software. The timeline of these models would be input for the safety equipment planning and this information would be used in the AR experience for showing the models on their planning phases.

Once the aspects considered are determined, it is set the functionalities that can be created on the proposed application. The details of their development are explained in the chapter on the development of the application. It is essential to arrange all these functionalities and how the user interfaces (UI) are organised and presented to clearly understand how the app organisation is and how the user will experience the various functionalities inside each UI screen.

UI nº	UI screen	App functions description
1	Input Basic Information	Input information regarding the SA name and select the project's name.
2	Input Inspection data	Input the data regarding the inspection. Select the construction phase and select the zone that is inspected.
3	Placement of BIM model	Firstly, scan the environment, then input the 3D model with its proper orientation.
4	Initiate Checklist	A panel with a CPE's checklist appears to tick when they are present. Also, CPE's data can be accessed in the list.
5	Incident's report	All the digitalized functions needed can be implemented in the app to ease the task of the SA.

Table 8: Table of the UI screen contents and functionalities.

The design of the five UI is sketched as shown in the following figures.

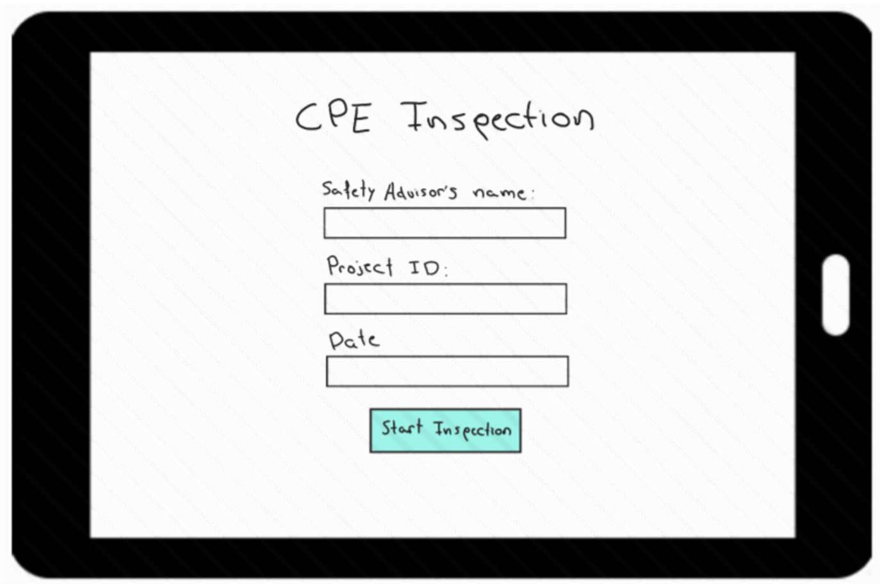


Figure 20: First UI screen design of the proposed application.

In this first UI, the input mentioned in Table 8 is done. A dropdown menu for all the options is designed to not manually type the information and improve the user experience (UX). The data input is automatically fulfilled following the date of the inspection.

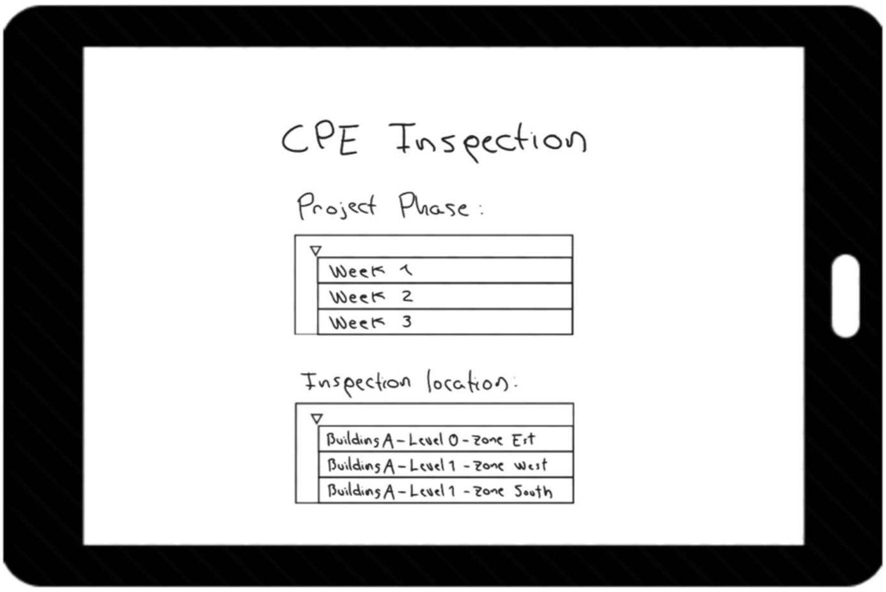


Figure 21: Second UI screen of the proposed application.

This second UI screen inputs the data regarding the project phase and the zone that needs to be inspected. In that case, only the elements according to that data are shown in the app.

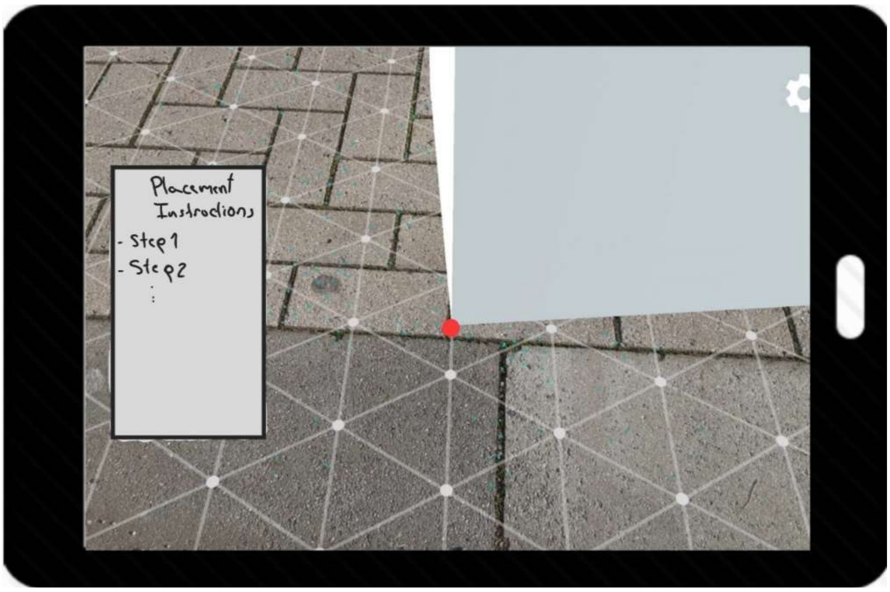


Figure 22: Third UI screen of the proposed application.

In this third UI screen, the 3D BIM model is placed. There are several techniques to place the model. Damià, Jordi [57] input the model by GPS coordinates; Ramos, Jorge [39] placed it by scanning the horizontal floor and then define 2 points of reference that defines the location and the orientation. In ARCore, the default option is to scan the horizontal plane, tap one point of reference, and orientate the model manually. It was also explained that Genie Vision uses an own developed algorithm to have reasonable accuracy. As mentioned, the precision of the model placement depends on the technique used and the device specifications.

Figure 23: Fourth UI screen of the proposed application.

In this third UI screen, the checklist of the CPE starts. In this case, a panel appears with a list of the items that need to be inspected. If there is any incident regarding safety aspects, the UI comprises an option to report.

Figure 24: Fifth UI screen of the proposed application.

In this UI screen, it is seen the report panel where it can be input the fields that were used in the report of BESIX. These fields are the observation type, add image, comments, status and action.

Once the inspection of the elements is done, a button let finish the inspection, and all the data should be transferred to the cloud database used.

Once the application's design is done, the workflow of the app used by the SA can be defined, see Figure 25. In the following section, the application's workflow and how the integration into the general workflow of the inspection can be seen.

4.3. Workflow with an AR inspection

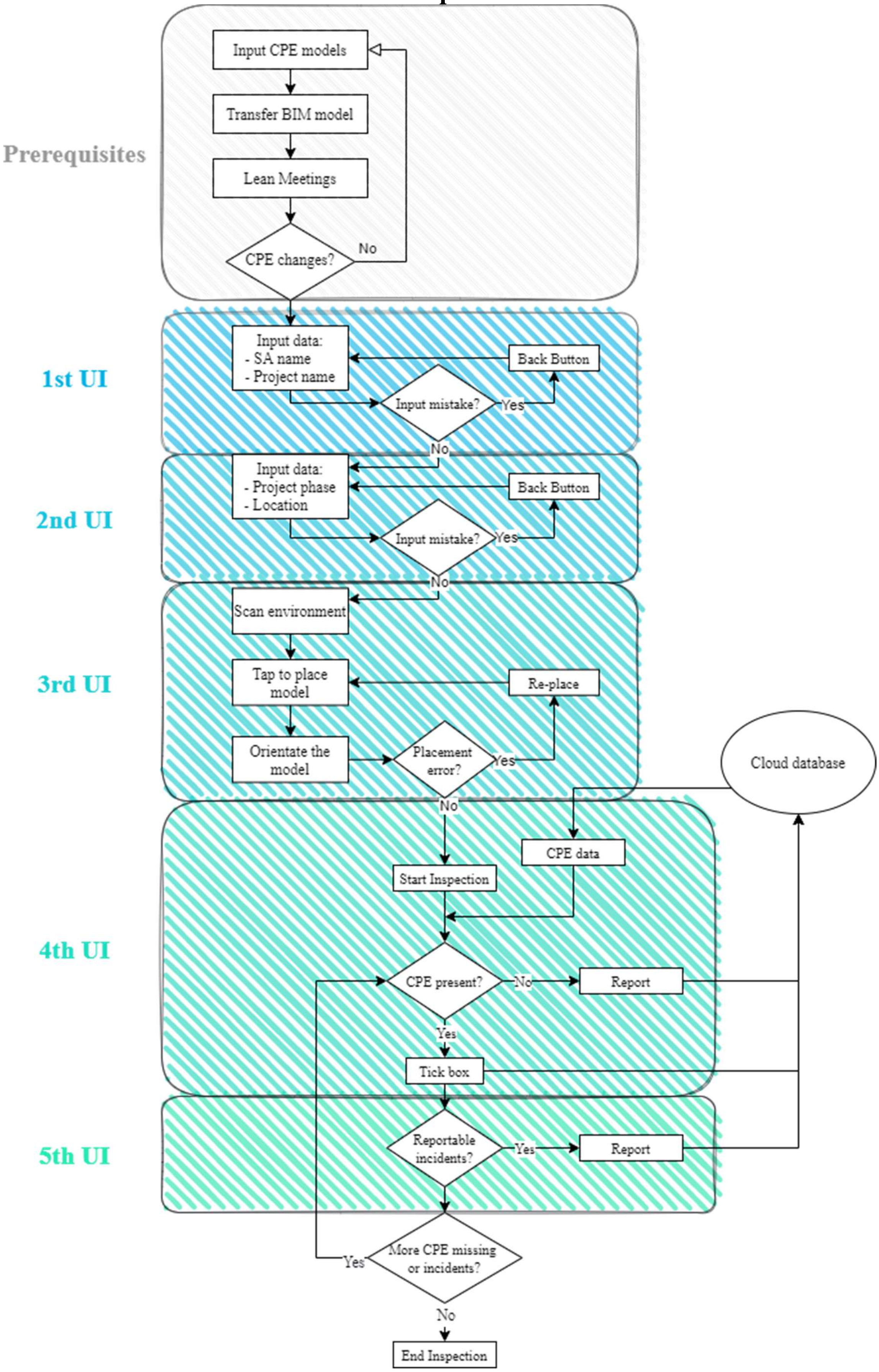


Figure 25: Flowchart of the safety inspection with the proposed application.

5. DEVELOPMENT OF THE APPLICATION

This section details the general guidelines on creating an Augmented Reality application and how the different functionalities provided are of help for this experience.

It is important to mention that the app is developed according to the available resources. In this context, the capability to develop the maximum potential of the conceptual design is not entirely reached due to the limitations of several factors as the power of the devices used, inaccessible paid platforms and the lack of knowledge of advanced programming, among other reasons.

Development Phases

In the creation of an AR application applied in safety equipment, the workflow of Figure 26, is followed.

Figure 26: Workflow of the development of the app proposed. Own elaboration.

Before explaining the different phases, it is necessary to have an overview of the components needed to create an AR app and have sense of the Unity environment.

Software components of the application

As seen in previous sections the choice of the platforms needed are Unity as a software where the application is developed, and ARCore which adequate Unity to work in an AR environment.

In creating the application, first, downloading the platforms and their components is needed. The steps of downloading these components and the configuration into Unity are shown in detail in the guidelines provided in the Unity and ARCore websites. It is crucial to check these guidelines due to the constant version updates of these platforms.

All the components used in the development of this application are the following:

Components	Characteristics
Tablet Samsung Galaxy Tab 6S Lite	Device that runs the application and should incorporate a gyroscope, a good quality camera and a reasonable CPU power. The compatibles devices are seen in the Annex E.
Unity Remote 5	Remote that permits launching the app during its development without building the APK (Android Application Package) constantly. It saves time for the development and it is available in Google Play.
Unity 2019.1.14f1	Development of the app platform with its corresponding version. It can be downloaded from its official website Unity.com
Microsoft Visual Studio	Integrated development environment (IDE) used to program the functions on Unity in the programming language, C Sharp. It can be downloaded directly from Unity.
AR Core	Introduced in Unity as an SDK (Software Development Kit). Downloaded from the developers Google website [36].

Table 9: Components used in the development of the app.

Unity interface main windows

As mentioned, Unity is a cross-platform game engine that allows to develop AR applications for several devices. The platform's user interface is essential to distinguish the main practical windows. This distribution can be seen in the following figure.

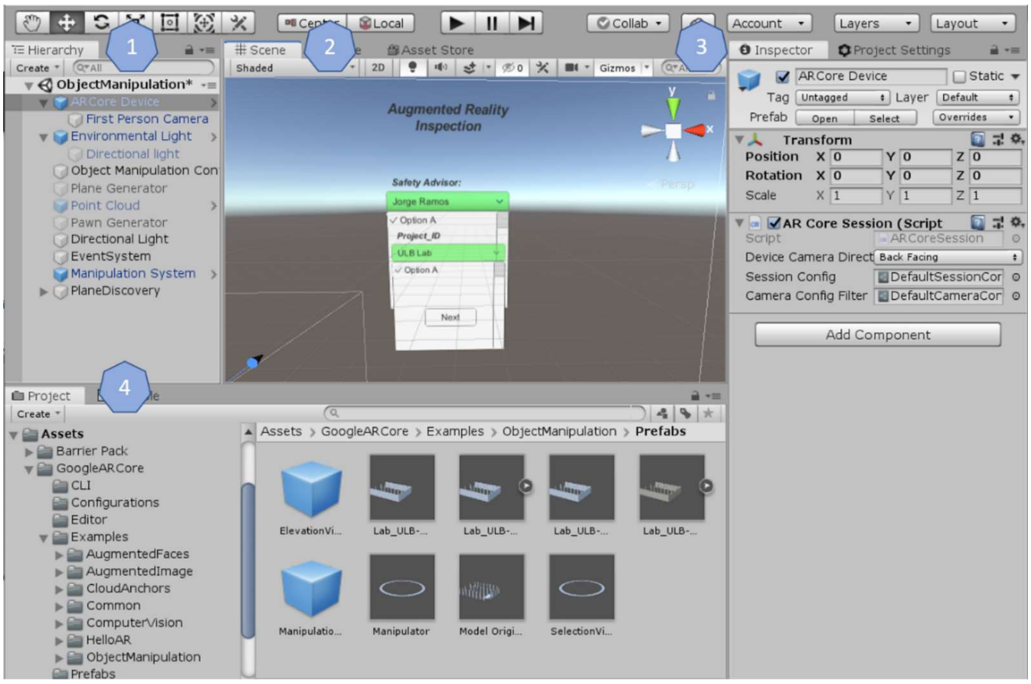


Figure 27: User interface distribution with the main important windows in Unity.

These main windows are described in the following table.

Nº	Unity Window	Description
1	Hierarchy	Contains a list of all the game objects used in the work scene. All the objects used and their hierarchy should be in this window.
2	Scene	Window where the visible game objects of the application are seen. In this window, also, the UI of the app, 3D objects introduced, among other game objects can be visualized.
3	Inspector	It shows detailed information regarding the game object selected in the hierarchy window.
4	Project	Contains all the components needed for the development of the app as 3D models, programming codes, etc. Each component is called an asset.

Table 10: Unity main UI windows and its description.

Once an overview of the components required and the Unity environment is acknowledged, the phases for developing the app are described in the following sections.

5.1. BIM 3D Model

In the first phase, the BIM model of the construction site is created. The 3D model of it is needed to be visualized in the AR environment afterwards. As it is known, this phase is being implemented by many companies in the sector; according to AIA's biannual report [66], 96 per cent of large firms utilize one or more BIM software programs.

For this project, since there is no BIM model of the ULB lab, it is created according to the 2D plans provided by prof. Deraemaeker. In Annex F, it can be seen the 2D plan of the lab level. In Figure 28, it can be seen the location and the part of the building that is modelled.

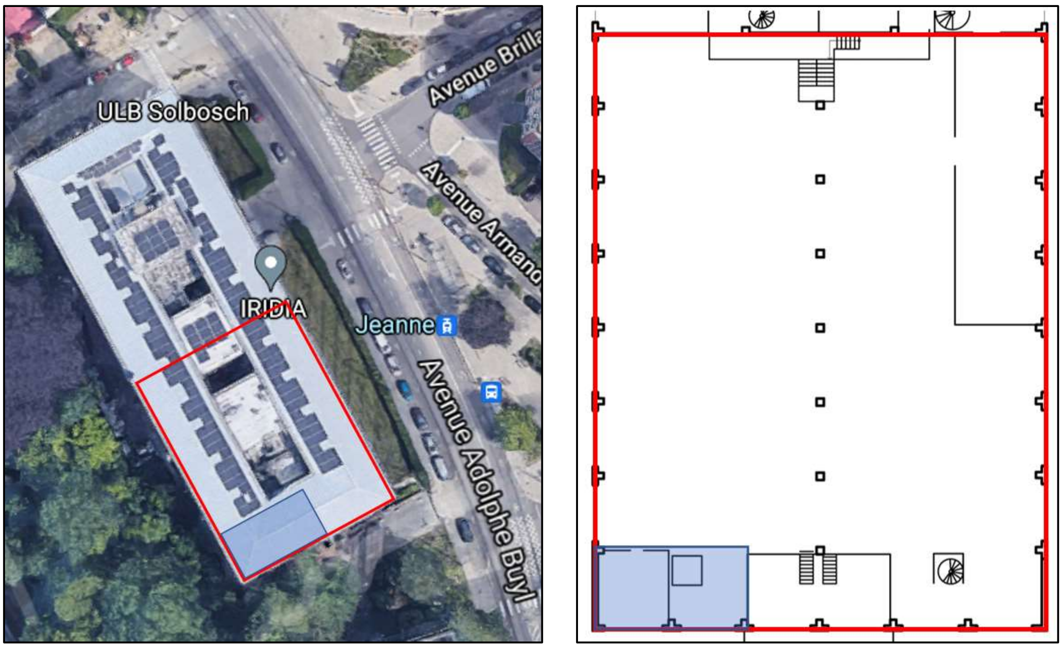


Figure 28: Location of the ULB lab (red) in relation to building C, and location of the construction simulation (blue).

The BIM software used to model the lab and the construction simulation is Revit. It allows designing the building and its components in 3D and access building information from the model's database [67].

Regarding the structural elements, only the columns and walls are modelled to represent the lab building—also, the floor and columns regarding the construction simulation. In the following picture, the 3D model of the construction in Revit can be observed.

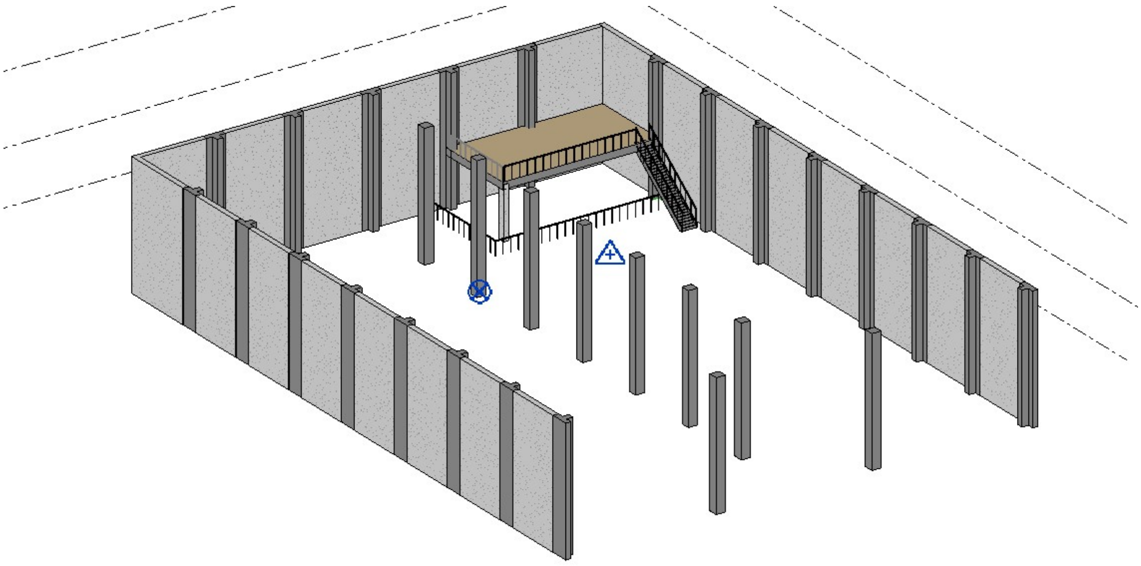


Figure 29: 3D model in Revit of the ULB lab with the construction simulation.

The details of the construction simulation dimensions can be seen in Annex F. Once this model is done, the next phase of creating the CPE models is followed.

BIM model import

When importing the Revit model to Unity, the 3D model is first transferred with the FBX 3D data interchange format, which is compatible with Unity. This process is done in Revit by clicking the File tab and export to the FBX option. Then the FBX file is copied to the desired Unity project folder.

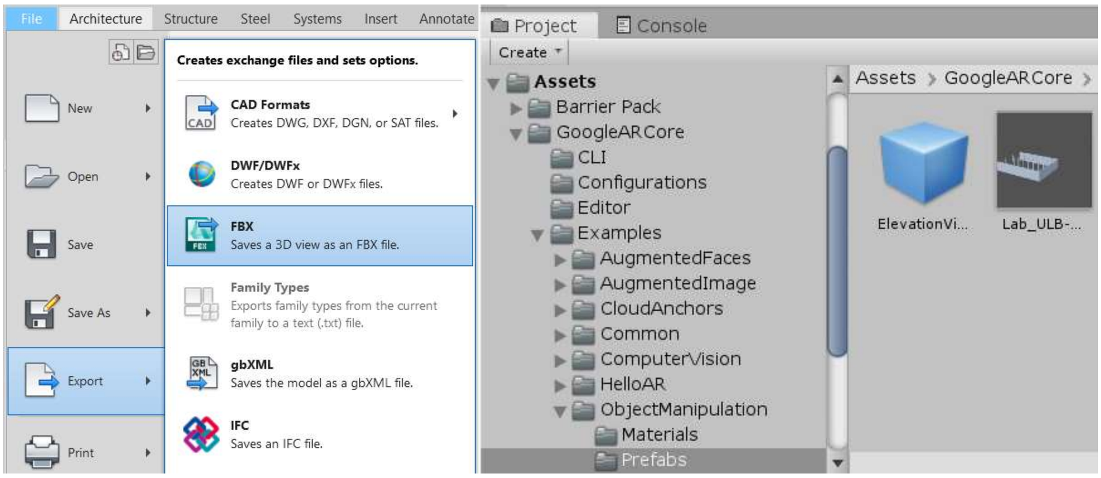


Figure 30: Steps done in Revit and Unity to transfer the 3D model of the construction.

Afterwards, inside Unity, it is needed to erase some of the unnecessary components transferred in the FBX file. This is done by dragging the file from the project window to the hierarchy. In this case, elements as the 3D view and the Levels components from the Revit file are erased.

This process can be done more efficiently. Unity has a program component named Unity Reflect that helps you to connect all the BIM data within the BIM platform and Unity [68]. In that case, the BIM model is directly transferred into Unity, and the 3D model is connected to the BIM data. This option is studied but rejected due to the price of $690 at the time. Even though it is necessary to mention that this option is more efficient in terms of data management between platforms. Furthermore, this option was used to develop the AR application in the 9 DeKalb Avenue construction seen in previous chapters, see Figure 11.

5.2. CPE Models

Since the goal is to have a visual comparison between the virtual models of the CPE and the real ones, it is needed to input the models of the CPE in the 3D BIM model. The most efficient way to do this is to input them directly into Revit, which BESIX is not currently doing. The CPE's are introduced from the Asset Store of Unity for this application, where the 3D safety equipment models' downloading are available.

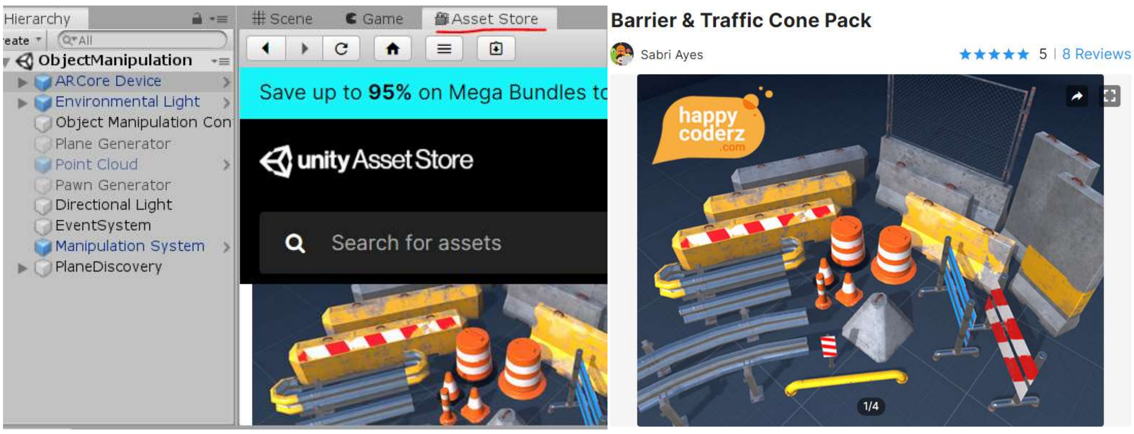


Figure 31: Location of the Asset Store and CPE package downloaded asset.

In order to locate these elements in relation to the 3D BIM model, it is necessary to do previous steps. Firstly, the prefab of the BIM model is opened in order to manipulate its sub-elements. This procedure is done by right-clicking the prefab model in the Project window and select “Unpack Prefab Completely”. In this way, desired elements can be introduced in the 3D BIM model.

Regarding the barriers of the construction simulation, they are placed on the slab edge of level 1 and level 0, covering the area of the construction. In addition, some railings are be added to the stairs. The introduction of this safety equipment into the 3D model is shown in the following figure.

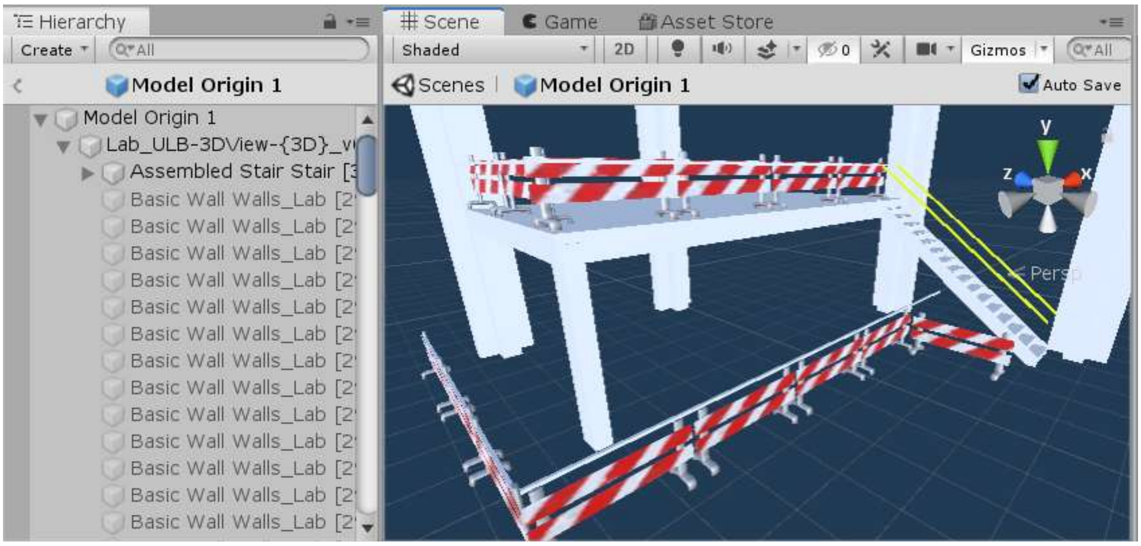


Figure 32: Introduction of the CPE models into the construction simulation model.

Furthermore, to set the phase where this equipment belongs, a script called Object_Information is created to set two parameters to each CPE that defines its phase and the checking state, which reads if a CPE is checked or not. The script is created contains the following lines.

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

public class Object_Information : MonoBehaviour
{
    public string PhaseParameter;
    public bool Check;

    public void SetParameters(string PhaseParameter)
    {
        this.PhaseParameter = PhaseParameter;
    }
    public void CheckParameter(bool Check)
    {
        this.Check = Check;
    }
    public string getSetParameters()
    {
        return PhaseParameter;
    }
```

This code is easily added on each element at the inspector window, where the properties of it can be accessed and are shown as follows.

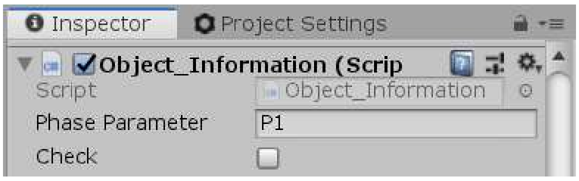


Figure 33: Inspector window for each element with its phase and check parameters.

Once all the 3D models are configurated into Unity, the following development process is to set the AR environment in order to manage the placement and visualization of the elements and manage the UIs that the SA encounters.

5.3. AR environment

In this phase, how to create the functionalities of the application in Unity is described.

5.3.1. ARCore practical assets

When setting the ARCore to work with Unity, an SDK is downloaded, containing several folders in the *Project* window. In these folders, there are several examples of AR applications to get acquainted with a workable environment. These examples contain several assets, which are practical functions to develop an AR app.

For the aim of this project, one of these examples is used to get the essential functions as plane detection on the real environment and 3D objects placement in those detected planes. It is important to consider that these functions are created by several coding programming developed and ready to use for user preference. The example chosen for the application is the Object Manipulation scene which contains the following components in the hierarchy.

Figure 34: Hierarchy components of the Object Manipulation scene.

A brief description of each component's functions is explained in the following table.

Component	Description
ARCore Device	Contains the useful coding files to manage the ARCore session in a Unity scene.
First Person Camera	Sets the camera of the device and it contains the programming codes of the calculation of its position on each frame.
Environmental Light	It contains the code that estimates the real environment lighting and it adjusts the virtual lightening in accordance to the real lightening.
Object Manipulation Controller	Contains the code to control the Object Manipulation app example.
Plane Generator	Contains the code that detects planes on the real environment and it creates a mesh in order to be visualized.
Point Cloud	When detecting planes, firstly a cloud of points is visualized before the creation of a mesh.
Pawn Generator	Contains the code that places the 3D models. These codes can be changed in order to work with the desire placement configuration.
Event System	Manges the sending of events to objects in the application based on input of the buttons, touches, etc.
Manipulation System	Contains the code that allows the user to manipulate virtual objects trough gestures.
Plane Discovery	Contains all the components related to the user interface of the application.

Table 11: Components of the Object Manipulation

5.3.2. Placement configuration

In order to place a 3D object in a plane detected by the device, it is necessary to select a point of origin of the BIM 3D model. This point of origin would need to be easily visible in the real environment to detect the planes accurately around that point. This procedure can be done in Revit by modifying the Project Base Point [69], which maintains the origin in the FBX file. Another option is to change it in Unity. This is done by creating an empty game object in the hierarchy. Then, in the inspector window, its coordinates are changed to the origin of the coordinates system. Once the game object is set, the BIM 3D model is moved so that the new origin desired is placed at the origin of coordinates. Then the file of the BIM 3D model is dragged into the empty game object to make it a child of the element. The result is that the BIM 3D model is set on the origin of coordinates at the desired point. In the following picture, the result of these steps can be seen to set the origin of the BIM 3D model at one of the columns of the lab, which has a clear space to detect the surrounding planes.

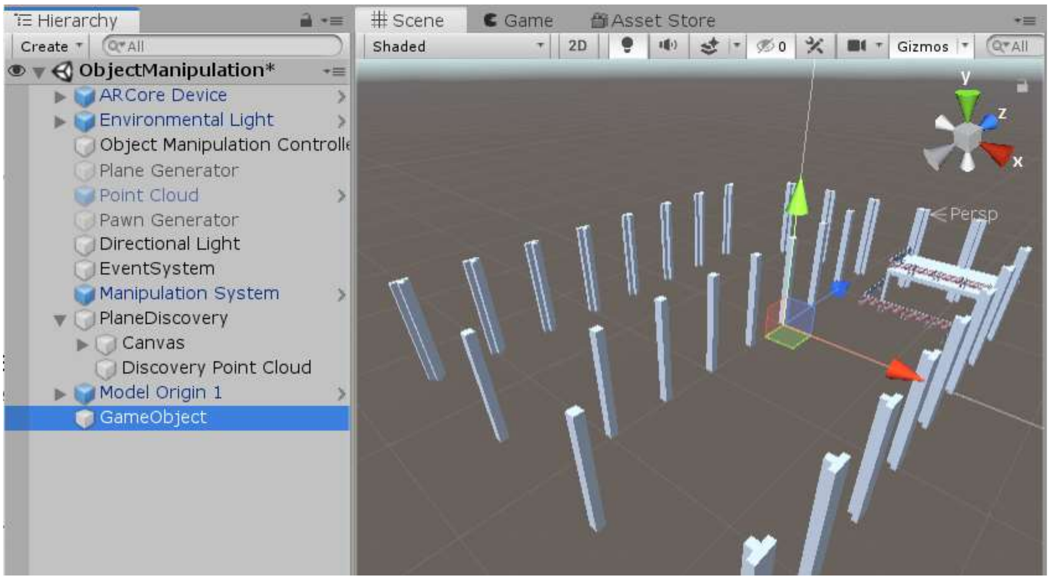


Figure 35: Setting the origin of the BIM 3D model in Unity.

Once the origin is set, as is mentioned, there are several options to place the 3D model in an AR environment. In this case, the one chose is the default option of ARCore, that its code could be modified to change the configuration. The code used can be seen in Annex I. In particular, the piece of code that places the BIM 3D model according to a point previously selected in the real environment is the following.

```
if (Frame.Raycast(
                gesture.StartPosition.x, gesture.StartPosition.y, raycastFilter,
out hit))
            {
                // Use hit pose and camera pose to check if hittest is from the
                // back of the plane, if it is, no need to create the anchor.
                if ((hit.Trackable is DetectedPlane) &&
                    Vector3.Dot(FirstPersonCamera.transform.position -
hit.Pose.position,
                        hit.Pose.rotation * Vector3.up) < 0)
                {
                    Debug.Log("Hit at back of the current DetectedPlane");
                }
                else
                {
                    // Instantiate game object at the hit pose.
                    var gameObject = Instantiate(PawnPrefab, hit.Pose.position,
hit.Pose.rotation);
```

As it can be seen, first, it is read the coordinates of the point selected in the virtual plane from the real environment, then checks if the point belongs to the front of the plane and or at the back. If it hits the back of the plane, a debug message is shown, and it reverses the model. If it hits the front of the plane, as it should be, the code changes the origin coordinates of the model to the coordinates that were previously read from the tap input.

Once the placement configuration is set, in Unity it would be needed to drag the 3D model as an input of this code that appear on the Inspector window as shown in the following figure.

Figure 36: Inspector window of the Pawn Manipulator code with the necessary inputs including the 3D model to place.

Once the previous steps are done, the different application UIs are created, which its design is described in the previous chapter. Firstly, the configuration and organization of the UIs inside Unity are explained. Then, the creation of each UI and the codes used to configure the different functionalities are described.

5.3.3. UI configuration

When creating a UI in Unity, there are several options: creating a Unity scene for each UI and creating the UIs inside one scene. For the development of this app, the second option is selected.

For this case, the components configuration consists of creating a Canvas object, which is the area that contains all the UI elements as buttons and text boxes. Furthermore, all the UI elements must be children of the Canvas element. In the app developed, five empty game objects are created that will contain the UI elements at each interface screen. The distribution of these components in the hierarchy window is shown as follows.

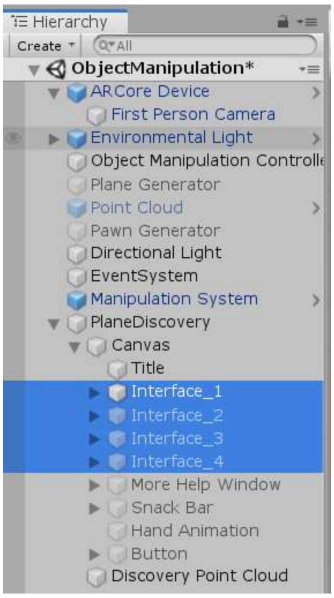


Figure 37: Configuration of the different UIs in the hierarchy window.

Once the overall configuration of the UI is done, the development of each UI is explained.

5.3.4. 1st UI: Input of Basic Information

As explained in the previous chapter, this UI design consists of the safety advisor's name input and the construction project name. Firstly, inside the UI object created in the hierarchy, two dropdown menu objects are created for both inputs: SA and project names, with default options that would need to be set before the inspection. The different options that can be selected from the dropdown menu are input in the inspector window. In the following picture, a view of the dropdown menu and the options that can be added in the inspector window can be observed.

Figure 38: Overview of the dropdown menus in the first UI (1st and 2nd pictures) and configuration of the options in the inspector window for the inspector's name (3rd picture).

For this prototype, as seen, the name options are the supervisors and the author of this project. Regarding the project name, the options are the lab prototype and the project Paradise from BESIX, which is not developed in this prototype.

Once the dropdowns menus are set, a button that introduces the 2nd UI is created. When managing the functions of disabling the first UI and enabling the second, a script that manages the interfaces can be created. Or, since the different UI are organized in packages, the OnClick function located in the inspector window can be used, which allows selecting the objects that can be set active or not when clicking it.

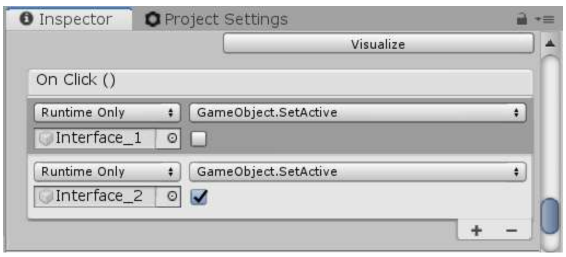


Figure 39: Inspector window of the next button, which allows to activate or deactivate other UIs.

Once all the functions of the first UI are created, then the second UI can be developed with similar UI elements.

5.3.5. 2nd UI: Input of Inspection Data

In the application's design chapter is determined that in the second UI, the data regarding the inspection is input. Firstly, the project phase must be read as a variable to show the objects that belong to that phase, the location of the inspected area, which is also saved as a variable to display the safety equipment that belongs to that location. The creation of these elements is done equally to the ones seen in the first UI, where the distribution of the elements is as follows.

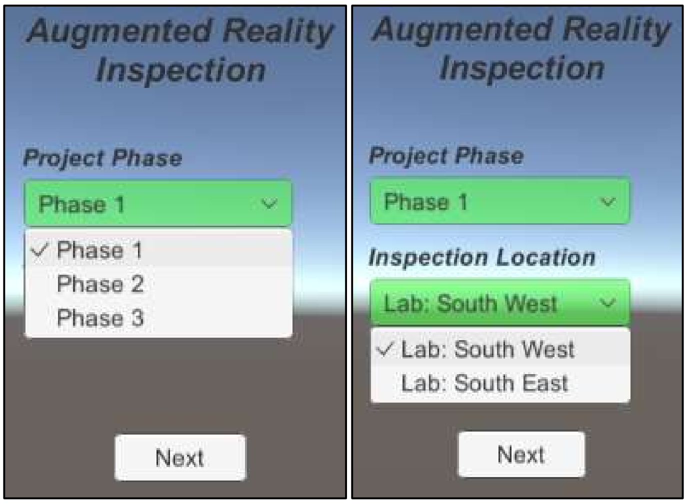


Figure 40: Overview of the dropdown menus in the second UI.

For this prototype, the project phases options are three different phases of the construction simulation. Moreover, regarding the inspection location, there are two options as an example; nevertheless, due to the size of the construction simulation, the inspection can be covered at one time.

In this UI, the next button has the same configuration as the previous UI, with the difference that this time 2nd UI is deactivated and the 3rd UI is activated. This button also activates the game objects that run the AR functions. In the following figure, the elements activated that are necessary for the next UI can be seen.

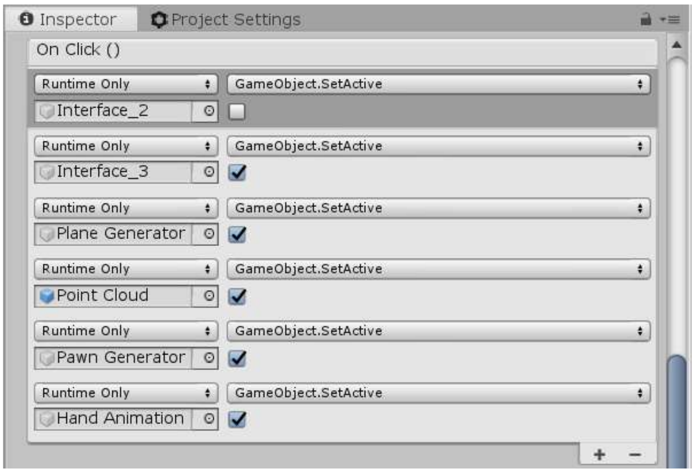


Figure 41: Inspector window of the next button, which allows to activate or deactivate other UIs and the AR functionalities.

5.3.6. 3rd UI: Placement of BIM model

For the third UI's design according to the proposed design, first, it is necessary to display the steps that need to be followed, located at the right of the screen. These steps are the following:

1. Scanning of the floor plane.
2. Tap the model point of origin in the real environment.
3. Rotate the model to the final position.

Since the AR functionalities are activated with the next button of the 2nd UI, it is possible to place the model at the beginning of its appearance. Furthermore, to help the user, a hand animation GIF is provided to let the operator know that it can start scanning the environment. Afterwards, internally, the app starts scanning the environment and creates a mesh of the detected planes. Once the desired plane is created, the user can tap the point of origin to place the model. Finally, once the object is placed, the user can rotate the model to its desired angle. The code to place the model is seen in the previous section; nevertheless, the manipulation script that lets the model rotate and move is shown in Annex J. The UI elements developed for this screen are shown in the following figure.

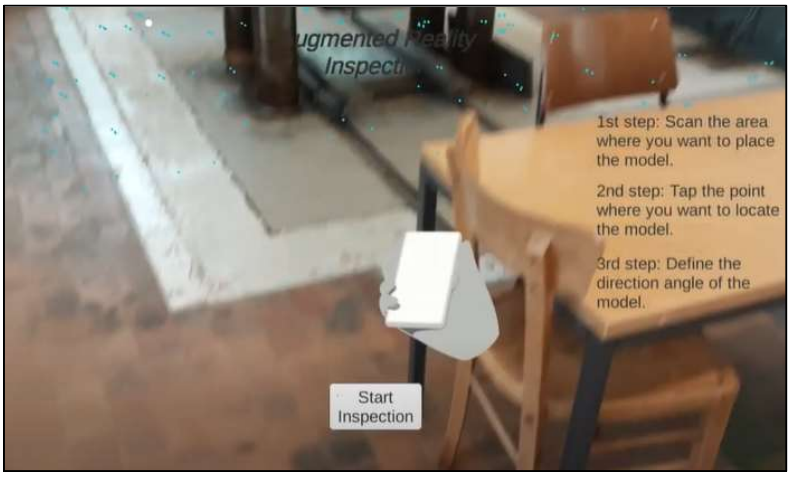


Figure 42: 3rd UI of the application with its elements.

In this UI, a button that indicates the start of the inspection is also added. This activates the 4th UI, which is the checklist of the CPE and deactivates the current UI and the AR functionalities.

5.3.7. 4th UI: Initiate Checklist

This UI belongs to the inspection of the elements with a checklist. The Unity objects for this UI are the following:

- Scroll view: the framework that contains the list of the CPE.
- Toggle: checkbox element containing the CPE name and a check parameter that can be read with a script.
- Report button: changes to the report UI.
- Back button: changes to the previous UI.
- Finish Inspection: it finishes the application, and it saves all the information regarding the checking.

To introduce the CPE's Unity objects in the scroll view is more efficient to run a script that inputs all the CPE and reads all its parameters. In that way, these inputs can be automatised when the CPE are introduced from a BIM model. In this case, since the construction simulation is small in size, these inputs are introduced manually in Unity. In order to do that, in the inspector window of the scroll view object, it can be inserted its contents as toggle objects. In the following picture it can be observed the configuration of the scroll view and the other buttons.

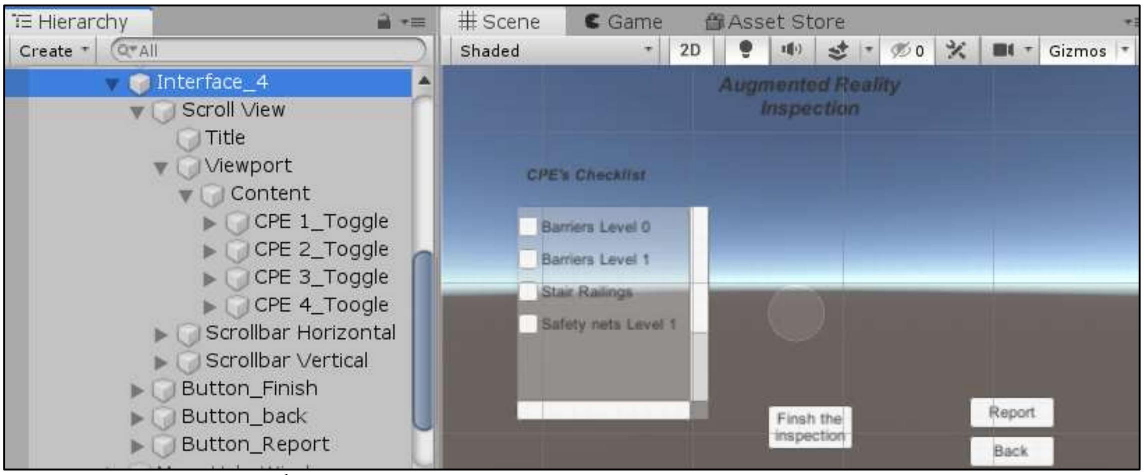


Figure 43: 4th UI of the application with the hierarchy and scene windows.

5.3.8. 5th UI: Report

This UI contains all the elements concerning the reporting of the incidents. As proposed this reporting has five types of input regarding the observation type, incident image, comments, status and action. The objects needed for this UI are the following.

- Text: containing the title of the different fields.
- Input Field: which allows to type in the different field.
- Camera button: This allows to take a picture of the incident.
- Save report button: saves the report with the fulfilled parameters.
- Back to inspection button: returns to the previous UI to continue the safety equipment inspection.

Since the prototype aims to validate the concept of AR as an extra layer in the inspections, this UI is not fully developed. Furthermore, this UI would replicate the report system currently used by BESIX that can be done with commercial applications as iAuditor. This is decided after considering the complexity of acquiring the same workability of commercial apps, taking into account the TRL of the prototype.

5.3.9. Launching the app

To launch the app on the device is necessary to connect it via USB. Beforehand, it is needed to enable the developer mode in the Android settings to allow the launching. These enabling steps are shown in the following picture.

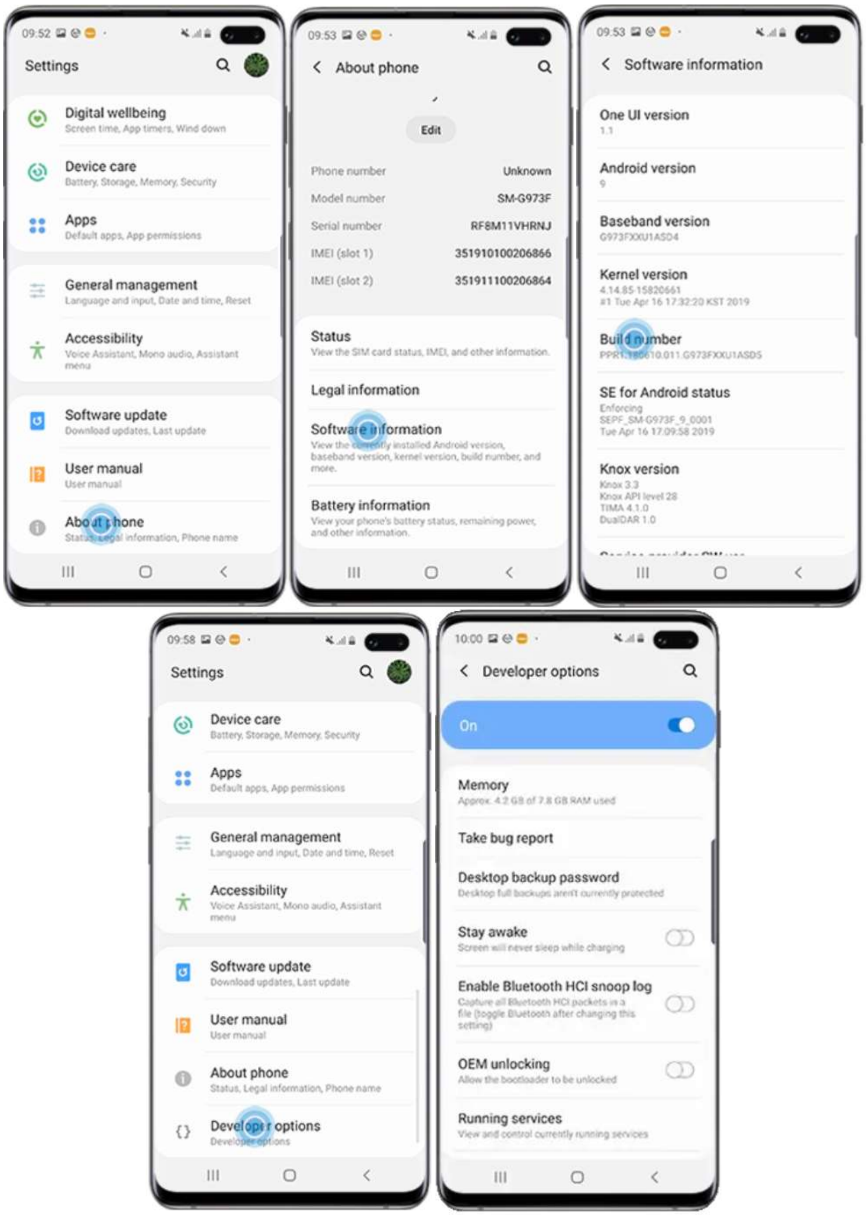


Figure 44: Steps to enable the developing mode in Android Settings. Source: Samsung.com

Afterwards, fill in the data regarding the app is required, which is in the Project settings window in Unity, where there are two fields to define the app. The company and the product name, which is the name that appears in the device app icon. In the following figure, the location of the fields and the names used for the app are recognized.

Figure 45: Input fields regarding the app.

Once this is done, to launch the app is necessary to go to tab Files/Build and Run. Then it takes approximately a minute to launch the app into the device and save the APK into the desired folder.

5.4. Final application developed in the lab

By following the different phases of the application development, the app is implemented in the lab to test its functionalities. These trials were necessary to perceive the possible improvements and iterate on the app development. The app could be improved by performing these iterations, leading to the final application shown in the following pictures for each UI.

First UI

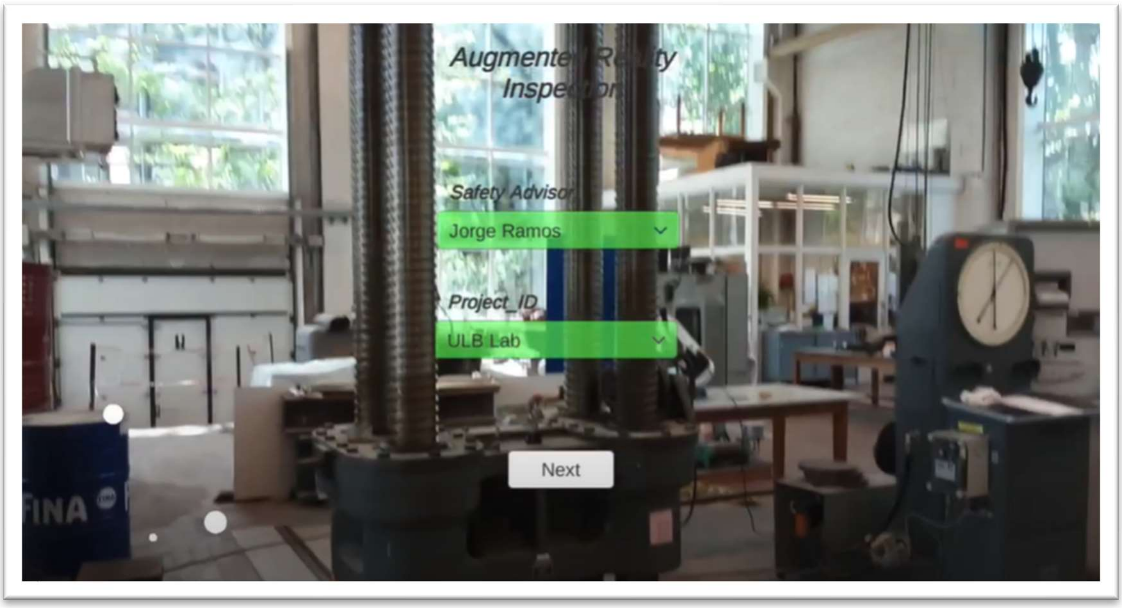


Figure 46: First UI of the app tested in the lab.

In the testing of this UI, the inputs are reasonable in size, and the steps to perform are clear for a pleasing user experience (UX). When testing the dropdown menus, the ease of introducing these inputs rather than typing them is sensed.

Second UI

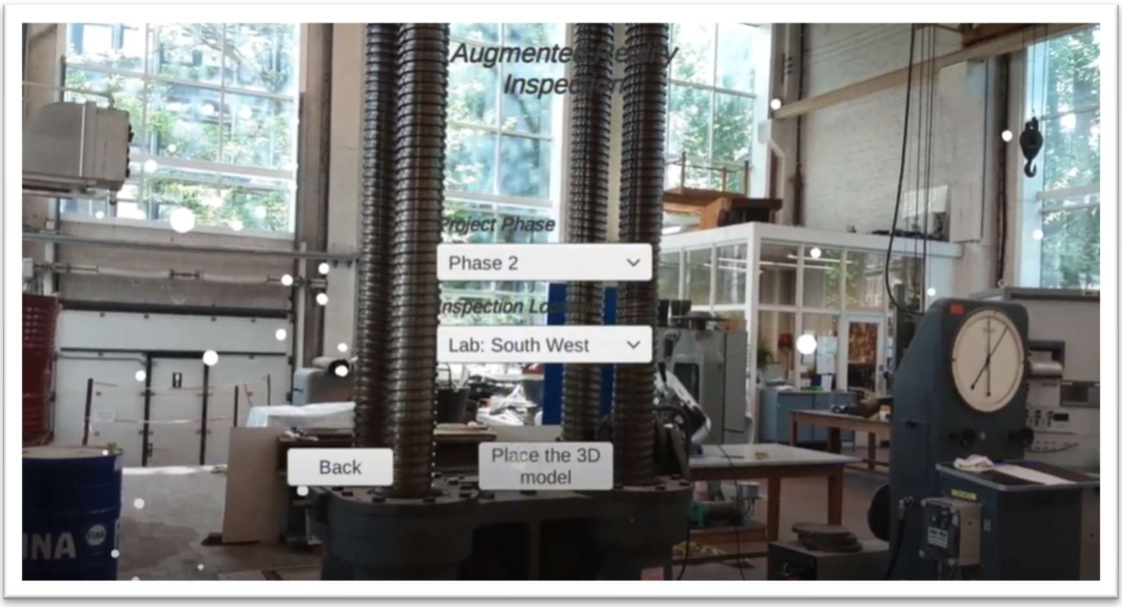


Figure 47: Second UI of the app tested in the lab.

In this UI, the same perceptions as the first UI are conceived since the input type is similar. In this one, the back button is introduced, which worked correctly, and it is comparatively intuitive in terms of UX.

Third UI

In this UI, there are three steps to be followed to place the BIM 3D model. First, the device is moved to scan the environment, and it could be observed that the detection of the planes was rapid and straightforward enough. In the following picture, the scan of the planes with the steps written on the screen can be seen.

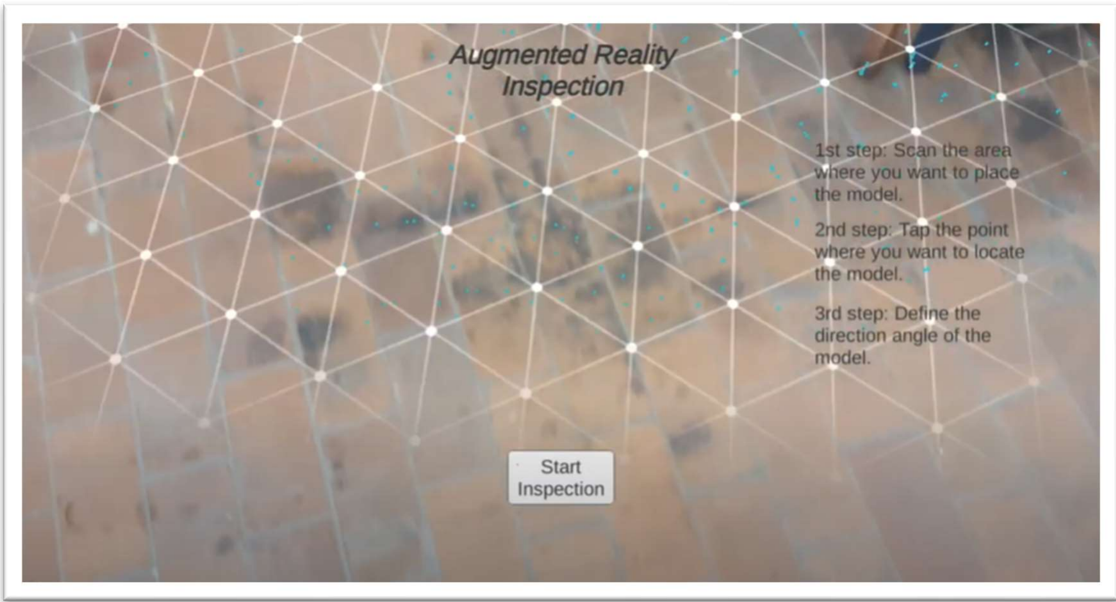


Figure 48: Scan of the real environment and creation of the planes at the third UI of the app tested on the lab.

The second step in this UI is to tap the BIM model origin in the real environment detected by the virtual plane. In this prototype, as seen in Figure 49, the origin is located at one of the column's corner. Once the model is located, in the third step the model is rotated with the aid of a circle illustration which allows you to tap and drag to the desired position.

Moreover, in this UI there is a button that initialises the 4th UI to start the inspection. Also, as in the previous UIs, there should be a back button, and in addition, a replace button in case that the placement of the model is not correct.

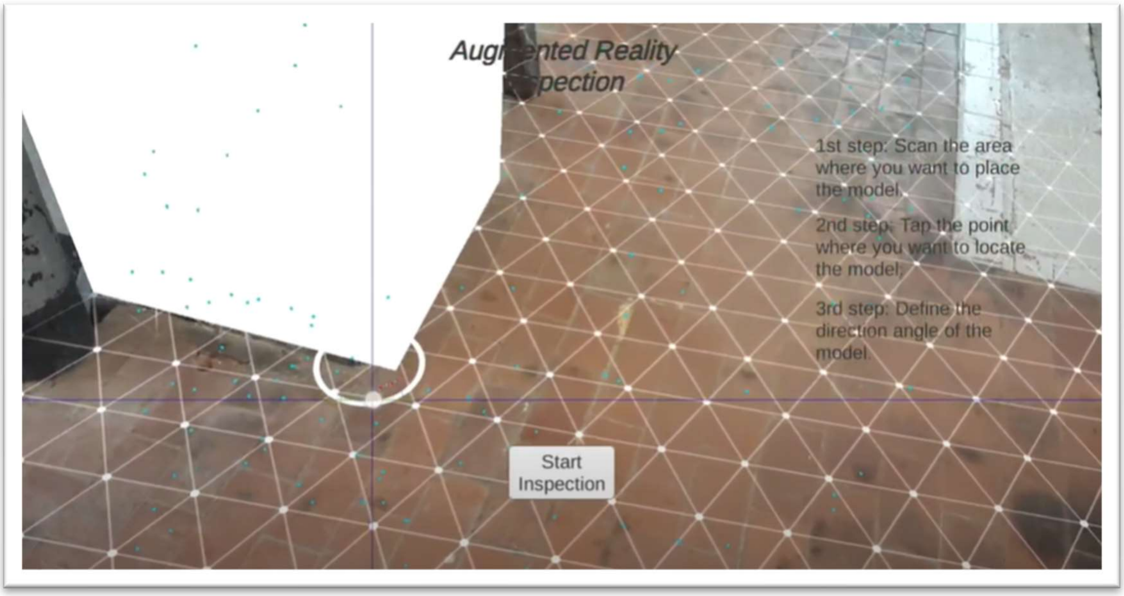


Figure 49: Placement and rotation of the 3D BIM model in the lab real environment at the third UI of the app.

Fourth UI

In this UI, the inspection is performed with the aid of a panel containing the CPE list to be checked. The panel has a scroll bar in order to look through the different elements according to the phase and location inputs. In accessing the information regarding the CPE, a tap on the element name should trigger a panel with the desired information previously introduced in the BIM software. As mentioned, this last function is not developed, taking into account the main objective of this prototype.

Moreover, in this UI, there are several buttons:

- A back button to return to the placement of the model if needed.
- A finish inspection button that ends the inspection and should send the collected data to the database cloud.
- The report button would introduce to the fifth UI, where several inputs are created to report any incident that occurs during the inspection.

The UI of the app tested in the lab can be seen in the following figure.

Figure 50: Fourth UI of the app tested in the lab

From the application testing in the lab, several remarks can be made:

1. The iterative process that the application development experienced. Some functions needed improvements due to the lack of reasonable UX as the inputs of the SA's and project names.
2. The model placement was changed at a first instance due to the impracticality of the origin point first choice area.
3. The application shows the ease and practicality of checking the CPE by visualizing them in AR.

Finally, a video of the prototype tested in the laboratory of the civil engineering at the ULB can be seen accessing the following link.

https://youtu.be/4etAsVml6Sw

6. APPLICATION EVALUATION

This chapter analyses the application in terms of the requirements to develop the app and an evaluation of the result obtained from the trials of the application.

Since the objectives of the thesis are to study the viability of this application and not fully develop a ready-to-use app, it is necessary to validate the concept of AR and exemplify its advantages in terms of safety equipment recognition. As mentioned before, to fully develop an application that is ready to use on a construction site, extra resources are needed as more sophisticated software, additional programming skills, and more powerful technological tools and time.

6.1. Economical context of the final application

Firstly, it is necessary to have an idea regarding the economic costs for the development of this application in the ease of implementation. By considering the time put into developing the app and the resources used, it is determined tentative price of the development till this stage. Certainly, since this is not the full application in the last level in terms of TRL, the final market price is not calculated, taking into account that it would be necessary to consider costs that were not used in this thesis, as paid platforms, app publication licenses and constant maintenance and assessment costs, among other costs.

In terms of the number of hours dedicated to the development of the prototype, taking into account the complexity of the software used, time consumed in researching different platforms possibilities, etc, it can be stated that it has been dedicated an approximated amount of 6 hours per day in the amount of 3 months, which means that in total for the full prototype development it was dedicated 414 hours.

To translate that into economic cost, the average salary of a novel programmer is considered, which in the case of Spain is between 17,000 – 21,000 euros per year. In this case, Damià [57] determined a price per hour of around 8.68 euros. In Belgium, the average yearly salary is 38,000 euros [70] which is translated into around 13 euros per hour. Taking into account the number of hours, the final price for the development of the app is as follow for each country.

Belgium	5,382.00 €
Spain	3,593.52 €

Table 12: Price of the final application in Belgium and in Spain.

In this case, the aim of implementing this new methodology is not to compete with the price of the current inspection solution; however, it is to provide a new tool that adds value to the enhancement of safety at a reasonable price.

6.2. User Experience (UX) Internal Assessment

This section analyses the user experience (UX) and the usability of the developed application according to the personal experience in testing and according to the feedback with others who tried and seen the result of the app. By definition, the user experience includes all the users' emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviours and accomplishments that occur before, during, and after use of the app, according to ISO [71]. In this case, an internal evaluation from the application tested in the lab is performed, also focuses on the perception of the functionalities and the AR environment. Lastly, possible functionalities improvements that were not developed are introduced in terms of UX. These aspects are classified as follows.

Input of the data regarding the inspection

The input information introduced in the first UI's is mainly concerning the name of the inspector and the name of the construction project. At a first instance, this data was introduced via typing each letter on the input box. This was concerning due to the extra time the user would experience typing each name and project on a tablet. Therefore, the UI inputs were substituted by a dropdown menu of the inspector's name that would need to be introduced beforehand. In this way, time is saved, and the UX is enhanced.

On the second UI, there are the inputs of the project phase and the location that will be inspected. In this case, the inputs are also a dropdown menu that is automatically introduced from the BIM model. The project phase could be introduced in terms of a specific date which automatically selects all the CPE elements that should be appearing on that date according to the construction plan. This information needs to be constantly linked and updated in case of any unexpected delays in the construction. Regarding the location, it would depend on the type of construction, but it can be classified in terms of buildings, specific areas, floor levels, etc.

Placement of the 3D model

The placement of the construction model and its safety equipment is introduced by detecting the floor plane, selecting the point of origin, and then manipulating the rotation of the model. As mentioned, more complex techniques are developed with a higher precision, such as Genie Vision, where they developed an algorithm that precisely scans the environment and then places the model. Another more straightforward option is to detect the floor plane and select two points corresponding to this plane and the model, so the location and rotation are set in. As it is seen, high precision can be obtained as in AR applied on surgery.

It is noted that this procedure should be eased for a better UX. As explained, several options are in the market to get the placement as precise as needed for this purpose.

Inspection of the safety equipment

In the 4rth UI, a list of elements to inspect according to the phase and location provided at the second UI appears. As proposed, this UI can also display by clicking the element, desired information regarding the state of maintenance, dates of its presence and map locations that should be automatically introduced from the BIM model. The application developed shows the concept of itemizing the safety equipment in order to be visualized in AR.

Reporting incidents

In the fifth UI, it is reported any incidents seen during the inspection. The inputs of the report are as seen, and they should be directly connected to the cloud database and send to the project management team. Furthermore, this reporting should be accessed in the mid-inspection, and once it is saved, the SA should be able to come back to continue. In the case of the application developed, this UI is not developed due to the multiple available platforms that can be complemented to the app, as iAuditor.

6.3. Augmented Inspection Internal Assessment

Regarding the concept introduced of augmented inspection, specifically to the fourth layer where augmented reality is applied, a clear view on how AR could help identify the CPE can be assessed. With this proposed solution the SA would perform a visual comparison between the CPE real and virtual model, which can be a more robust process in combination with the other layers seen in the augmented inspection, see Figure 18. This extra aid to the SA can avoid mistakes in CPE identification; furthermore, it enhances the access to live information thanks to the cloud database connection.

6.4. Key Performance Indicators

Key Performance Indicators, KPI are essential for monitoring the application's performance, and it helps to identify poor performance and its potential improvement [4]. In the case of this app, several KPI's, quantitative and qualitative, in order to measure the performance and the characteristics of the proposed inspection with the app. In Table 13 the KPI chosen, its description and its value are seen.

	KPI	Description	Value
Quantitative	**Time to complete the inspection**	In this case is difficult to measure due to the dependency of the constructions size. Even that it can be contemplated a more time consuming than a pure visual inspection, but similar to the 3rd layer of augmented inspection.	Similar to 3rd layer of the augmented inspection.
	Usability	In this case the usability of the app it can be objective depending on the inspector profile, even though an objective measure is the number of clicks. The less unnecessary clicks, the better usability and UX.	Without reporting. 11 clicks plus 2 per CPE.
	Weight of the app	In this case it is measured the weight of the APK that is downloaded on the device. This value also depends on the weight of the BIM model.	18 MB
	Cost	As calculated at the beginning of this chapter, it is the cost of the development of this final application in the Belgian and Spanish context.	5,382€ - 3,594€
Quantitative	**Hardware**	Defines the hardware that can be used in the application.	Tablet / smartphone
	Software	Defines all the software used in the development of this application.	Unity/ARCore/Visual Studio/Revit
	Operating System (OS)	Defines what is the operating system that the app is targeted for. The more OS accepted, the more versatile is the app.	Android

Table 13: Quantitative and qualitative KPIs of the application.

Also, it is essential to compare the KPI seen in the inspection performed by BESIX and the proposed one. This evaluation is crucial in order to show and demonstrate the improvements made with the proposed AR inspection. In Table 14, marks are set for the current and proposed inspections with ta description of the KPI used.

KPI	Description	Current Inspection	AR Inspection
Time Consumed	Time taken to fully perform safety equipment inspections. It is a quantitative KPI that would need to be measured accurately in case of a future implementation.	Adequate	Adequate
Robustness	Ability to withstand adverse conditions. In the comparison of this KPI it is considered the ability to reassure the presence of the elements. As discussed, an AR comparison can be more robust than a pure visual inspection.	Upgradeable	Adequate
Incident Responsiveness	This qualifies the agility of reacting at any incident that requires a corrective measure. This is more a management issue but since the reporting should be saved in the cloud database, the access to the report by the project management team would be more efficient and faster.	Upgradeable	Adequate

Table 14: KPI comparison between the current inspection and the proposed one with AR.

As it can be observed, the KPI of robustness and incident responsiveness is improved. In the case of robustness, as mentioned, is due to the extra aid that AR provides to identifying the CPE. Moreover, incident responsiveness is because of the interconnection with the cloud database, which permits sharing the report incidents in real-time with the project management team.

7. CONCLUSIONS AND FUTURE LINES OF RESEARCH

Based on the information obtained in the research project regarding safety and health in construction, the AR implementation in the AECO sector and specifically in occupational safety and health field, the understanding of the different platforms and the knowledge acquired during the development of the application and its evaluation, it can be concluded the following.

It has been able to identify the main pain points and bottlenecks of safety inspection thanks to the on-site visit allowed by BESIX which are: the possible robustness deficit in visual inspections, the dependence on the safety advisor's experience and knowledge, lack of control in subcontractors workers knowledge, possible bad practice from workers, lack of coordination between reporting and corrective measures, and the lack of rapid responsiveness between safety advisor and project management team.

In this context, the safety advisors, are keen to get extra aid during the CPE's inspection, which is crucial to ensure the safety of workers. With the objectives of pursuing the state of zero accidents, the implementation of an AR technological tool has been studied to augment the inspection capabilities to have a more robust procedure. Furthermore, with the aid of BAM contractors, it has been possible to acknowledge another digital solution that has been taken into account for the proposed methodology design. A workflow suited to the AR inspection was developed with all the analysis done. This method also improves one of the current methodology bottlenecks: the timing between reporting and taking corrective measures. Furthermore, this workflow preserves the main tasks of the SA during the safety inspections.

The design of the application needed to satisfy and overcome the pain points of the current methodology. As mentioned, it was not feasible to fully adequate the solution to a real case due to the difficulties of available resources. However, the basis for developing an AR application that could be implemented in a construction company is set. The research objective, which was to show the capabilities of AR on-site, is achieved. As seen, AR applications are being implemented in the industry, for example in BESIX, with the AR solution of Genie Vision who is not currently focusing on ORP. However, they see it as an excellent opportunity to research.

For the development of the app, it has been seen that there are several platforms available in the market. For this project, the game engine Unity with the complement of ARCore is used because it presents several advantages: the feasibility to use for non-advanced programmers, a great UX that makes it easier to understand the platform's functionality and eases the transfer of BIM models. ARCore provides several advantages for AR applications as predefined functionalities which helps in the development of AR experiences, and that was used in this project.

For the development of the application, it has been invested approximately an amount of 414 hours. However, with the knowledge acquired in this project, creating this prototype again would take a total amount of approximately three working days, 24 hours. And, in the case of developing a full application applied on a real construction site, it would take approximately an amount of 3 working weeks, 120 hours. These hours could be reduced if the developer has an advanced knowledge in programming.

Regarding the inspection, it can be concluded that the app offers a digitalised solution that helps the SA guarantee the presence of the CPE and report the incidents that occurred on the same application, reducing the need to manipulate several things at the same time. There would be the same screen for the real elements, the virtual ones, and the items that need to be checked regarding the CPE checklist UI. This increases the perception of the environment, which is crucial for detecting the safety equipment and to insert collected data into a database with information of the building site.

As a summary, a list is created with the main points of improvement from the BESIX traditional inspection to the proposed AR inspection.

- Higher robustness to guarantee the presence of the safety equipment which enhances the workers safety.
- Digitalisation of the process that eases the tasks of the safety advisor.
- Ability to report incidents in real-time regarding the CPE and IPE.
- Capacity to take pictures of the safety equipment in AR showing the possible differences between what is planned and what is executed.

The final application in terms of technology readiness level (TRL) is not an advanced and mature application to be used on-site. However, it demonstrates at an academic level the capability of implementing AR on safety equipment inspections.

In conclusion, taking into account the whole process, it can be said that AR has potential in the ORP field and that eases the safety advisor's inspection with the main objective of reassuring the safety equipment's presence and maintenance, to achieve the goal of the industry which is to reach zero accidents rates in a construction site.

Future Lines of Research

- Iterate on the development of the process in order to achieve a reasonable TRL which will reassure the viability of the implementation.
- Validate the application in a real construction site in order to get an assessment from the safety advisors to improve the app according to their feedback.
- Study the automation of the CPE’s 3D model and data introduction into the BIM software
- Automatise the development of AR and VR applications.

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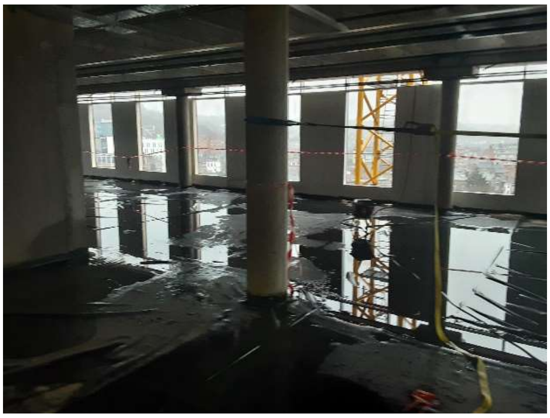
[93] P. Ebbs, “Lean Construction,” 2017. [Online]. Available: https://leanconstructionblog.com/5-Levels-of-the-Last-Planner-System-Should-Can-Will-Did-and-Learn.html. [Accessed April 2021].

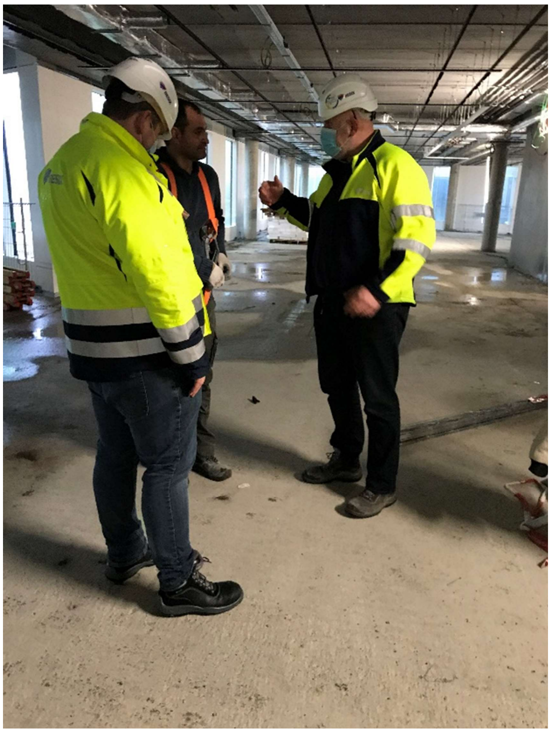
Annex A. Main risks associated to construction activities

	Riesgos	Actividad
1	Caídas a niveles inferiores	Trabajo en alturas o profundidades > 2 m.
2	Contacto eléctrico directo o indirecto	Trabajo cerca de líneas eléctricas y con equipos eléctricos en condiciones húmedas. a. Trabajo en líneas eléctricas aéreas u otros elementos vivos sin protección (en área peligrosa). b. Trabajo cerca de líneas eléctricas aéreas u otros elementos vivos sin protección. c. Trabajo cerca de líneas eléctricas subterráneas vivas. d. Trabajo con equipos eléctricos en condiciones húmedas.
3	Quemaduras causadas por fuego o explosión por una tubería rota	Trabajo cerca de las tuberías de combustible.
4	Inhalación de gas	Trabajo cerca de tuberías de gas.
5	Atrapamiento y asfixia posterior debido a un deslizamiento de tierra	Movimiento de tierras, excavaciones, pozos, trabajos subterráneos y túneles.
6	Proyección de partículas y explosión accidental	Voladuras para excavación, pozos, trabajos subterráneos y túneles.
7	Enfermedad por descompresión	Trabajo en condiciones hiperbáricas.
8	Colisión o atropello por carga en movimiento o su desprendimiento	Manipulación mecánica de la carga.
9	Golpes a las extremidades superiores e inferiores	Manipulación manual de la carga.
10	Colisión o atropello por equipo pesado o vehículos pesados	Trabajo con equipos pesados o vehículos pesados.
11	Cortes, traumatismos cerrados y otras lesiones por equipos livianos	Trabajo con equipos livianos.
12	Quemaduras	Soldadura
13	Lesiones debidas al impacto de la caída de objetos y proyectiles	Demolición manual, mecánica o explosiva; perforación de pozos antes de la voladura de una pendiente de corte y posterior limpieza y levantamiento de campo.
14	Envenenamiento agudo por polvo y toxinas	Demolición manual, mecánica o explosiva de estructuras o edificios, hospitales, fábricas o cualquier otro lugar que pueda contener sustancias tóxicas en particular.
15	Asfixia o envenenamiento en espacios confinados	Trabajo en espacios confinados.
16	Ahogamiento	Trabajo en áreas con riesgo de inundación.
17	Colisión o atropello de vehículos no relacionados con la construcción	Trabajo en áreas con tráfico no relacionado con el trabajo de construcción.
18	Accidente de tránsito	Transporte de equipos y materiales al sitio de construcción.
19	Riesgo estructural	Operaciones o estructuras complejas.
20	Caídas del mismo nivel	Todo tipo de trabajo.
21	Golpe de calor, lesiones relacionadas al frío y quemaduras solares	Trabajo al aire libre en condiciones climáticas adversas.
22	Aumento general de la probabilidad de accidente	Trabajo nocturno o trabajo en condiciones de visibilidad reducida.
23	Lesiones en la espalda	Manipulación manual de la carga.
24	Enfermedades articulares y óseas	Trabajos que implican exposición a vibraciones mecánicas.
25	Sordera	Trabajo que implica exposición al ruido.
26	Enfermedad por descompresión	Trabajo en condiciones hiperbáricas.
27	Enfermedades causadas por el asbesto	Trabajo que implica una posible exposición al asbesto.
28	Enfermedades causadas por la radiación ionizante	Trabajo con equipos que generen radiación ionizante.
29	Silicosis	Trabajo que produce altas concentraciones de polvo de sílice.

Figure 51: Risks associated to different construction on-site activities extracted from Rojas, Erika’s thesis **[25]**.

Annex B. Pictures of the on-site visit inspection





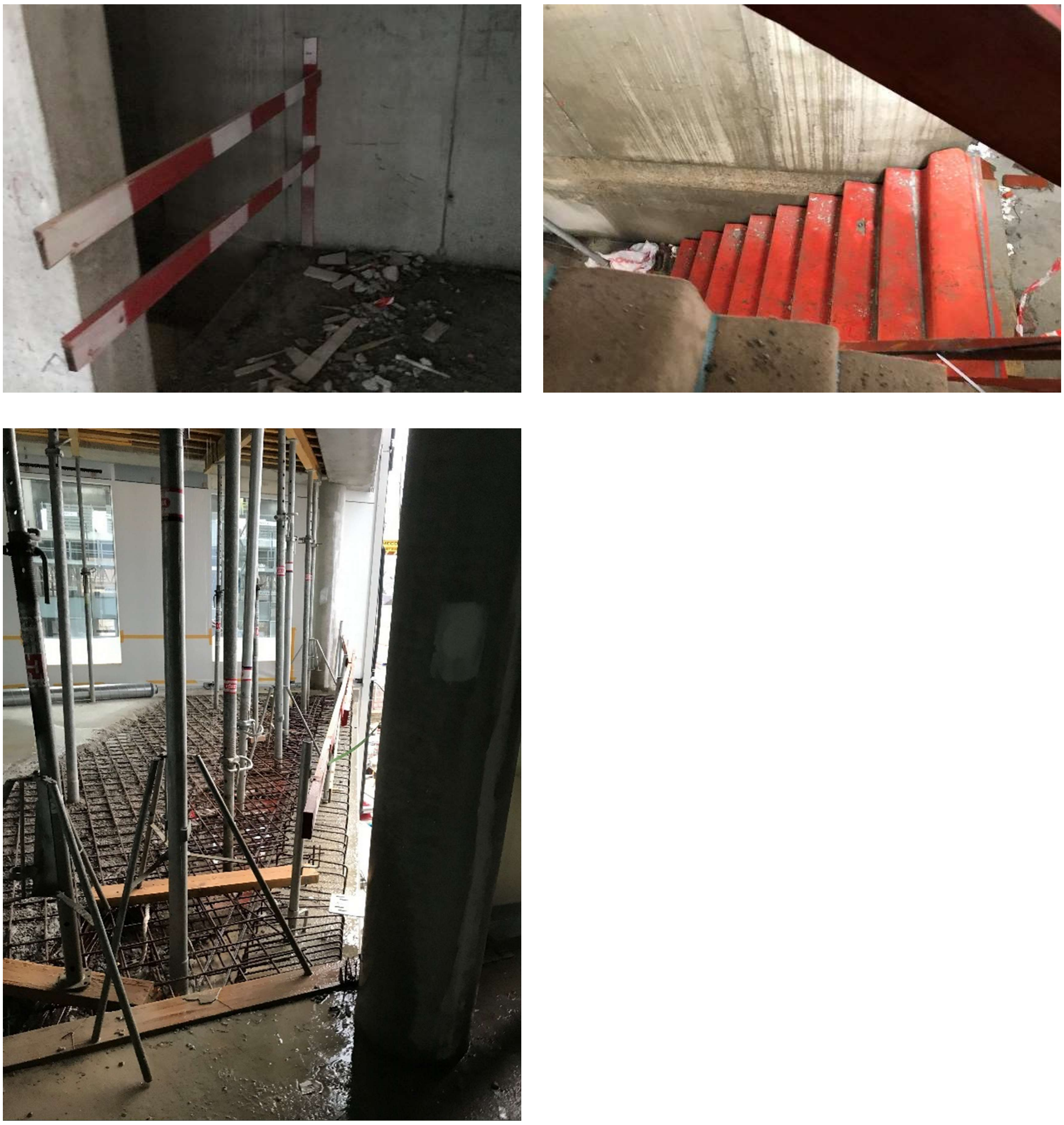


Figure 52: Pictures taken from the on-site visit to the Project Paradise, located in Liège, Belgium.

Annex C. Example of a Checklist of the Safety Equipment

CONTROL PERIÓDICO EN OBRAS DE CONSTRUCCIÓN

FECHA:____/____/______

CONDICIONES PREVENTIVAS REVISADAS

DOTACIONES	INTERFERENCIA A TERCEROS	EXCAVACIONES Y CIMENTACIONES
CARTEL TEL URGENCIA	VALLADO DE OBRA	
BOTIQUIN	ACCESOS A OBRA	**ESTRUCTURAS**
ASEOS, VESTUARIO, COMEDOR	SEÑALIZACIÓN GENERAL	REDES (horizontales, verticales, colocacion)
EXTINTORES	SERVICIOS AFECTADOS	BARANDILLAS
OTROS	OTROS	PROTECCION HUECOS HORIZONTALES
INSTALACIÓN ELÉCTRICA	**MEDIOS AUXILIARES**	ESCALERAS FIJAS
CUADROS Y CONEXIONES	ANDAMIOS TUBULARES	CASTILLETES, ANDAMIOS HORMIGONADO
OTROS	ANDAMIOS BORRIQUETA	OTROS
ALBAÑILERÍA	ANDAMIOS COLGADOS	**CUBIERTAS**
CERRAMIENTOS FACHADA	ESCALERAS DE MANO	INCLINADAS
PARTICIONES INTERIORES	PASARELAS, RAMPAS	PLANAS
GAS, ELÉCTRICA, AGUA,..	PLATAFORMA MATERIALES	OTRAS
PROTEC HUECOS Y ESCALERAS	TOLVA ESCOMBROS	**EQUIPOS PROTECCION INDIVIDUAL**
OTROS	CONTENEDORES	CASCO DE SEGURIDAD
GLOBAL DE LA OBRA	OTROS	BOTAS DE SEGURIDAD
ORDEN Y LIMPIEZA	**MAQUINARIA**	GAFAS DE SEGURIDAD
ZONAS DE PASO	MOVIMIENTOS DE TIERRA	MASCARILLA
ILUMINACIÓN	ELEVACIÓN	GUANTES
ACOPIOS	MAQUINAS, HERRAMIENTAS	SISTEMA ANTIÁCIDAS
OTROS	OTRAS	OTROS

DOCUMENTACIÓN CONTRATA	SI	NO		SI	NO	DOCUMENTACION SUBCONTRATAS	SI	NO
PLAN DE SEGURIDAD Y SALUD			REGISTRO DE EMPRESAS ACREDITADAS			ENTREGA PLAN DE PREVENCION		
LIBRO DE VISITAS			AUT. USO DE MAQUINARIA			FORMACIÓN E INFORMACIÓN		
LIBRO DE INCIDENCIAS			LIBRO SUBCONTRATACIÓN			CALENDARIO LABORAL VIGENTE		
APERTURA DEL CENTRO DE TRABAJO			ENTREGA DE E.P.I.S			TIT. ACRED. Y HOMOLOGACIÓN MAQUINAS		
CERTIFICACION INSTALACION ELECTRICA			ACTA APROBACION PLAN SEGURIDAD			PLAN SEGURIDAD Y SALUD		
ACTA NOMBRAMIENTO COORDINADOR SEGURIDAD SALUD			PROTOCOLO EMERGENCIAS Y PRIMEROS AUXILIOS			DESIGNACIÓN DE RECURSO PREVENTIVO		

*NOTA: LOS ASPECTOS CONSIDERADOS NO EXCLUYEN LA POSIBILIDAD DE LA EXISTENCIA DE OTROS RIESGOS

CONSIDERACIONES

Figure 53: Checklist used in the inspection of the safety equipment. Extracted from the Rojas, Erika's thesis **[25]**.

Annex D Technology Readiness Levels

Figure 54: Technology Readiness Levels. Source: Cloud Watch HUB **[72]**.

Annex E. ARCore supported devices

Manufacturer	Device model						
Asus	ROG Phone	Huawei	Porsche Design Mate 20 RS	Motorola	moto g^9 plus	Oppo	Reno2
Asus	ROG Phone II	Huawei	Y9 2019	Motorola	moto g^9 power	Oppo	Reno2 F
Asus	ROG Phone III	Infinix Mobile	Note 6	Motorola	moto g 5G	Oppo	Reno2 Z
Asus	ROG Phone 5	Infinix Mobile	Note 7	Motorola	moto g power 2021	Oppo	Reno3
Asus	Zenfone 6	Infinix Mobile	Zero 8	Motorola	moto g power	Oppo	Reno3 5G
Asus	Zenfone 7/7 Pro	Kyocera	DuraForce Ultra 5G UW	Motorola	moto g pro	Oppo	Reno3 A
Asus	Zenfone AR	Kyocera	Torque G04	Motorola	moto g stylus	Oppo	Reno3 Pro
Asus	Zenfone ARES	Lenovo	Lenovo K13 Note	Motorola	moto g stylus (2020)	Oppo	Reno3 Pro 5G
Fujitsu	arrows 5G F-51A	LG	G6	Motorola	moto g(30)	Oppo	Reno4 4G
Fujitsu	arrows NX9 F-52A	LG	G7 Fit	Motorola	moto g(10)	Oppo	Reno4 SE 5G
General Mobile	GM 9 Plus	LG	G7 One	Motorola	motorola edge	Oppo	Reno5 A
Google	Nexus 5X	LG	G7 ThinQ	Motorola	motorola edge s	Oppo	Reno5 5G
Google	Nexus 6P	LG	G8 ThinQ	Motorola	motorola edge plus	Oppo	Reno5 Pro 4G
Google	Pixel	LG	G8S ThinQ	Motorola	motorola one	Oppo	Reno5 Pro 5G
Google	Pixel XL	LG	G8X ThinQ	Motorola	motorola one 5G	Oppo	Reno5 Pro+ 5G
Google	Pixel 2	LG	G Pad 5 10.1 FHD	Motorola	motorola one action	Oppo	Reno 10x Zoom
Google	Pixel 2 XL	LG	K61	Motorola	motorola one fusion	Oppo	Reno A
Google	Pixel 3	LG	K71	Motorola	motorola one fusion+	Oppo	Reno Z
Google	Pixel 3 XL	LG	K92	Motorola	motorola one hyper	realme	5
Google	Pixel 3a	LG	Q6	Motorola	motorola one macro	realme	5 Pro
Google	Pixel 3a XL	LG	Q70	Motorola	motorola one power	realme	6
Google	Pixel 4	LG	Q8	Motorola	motorola one vision	realme	6 Pro
Google	Pixel 4 XL	LG	Q92	Motorola	motorola one zoom	realme	7
Google	Pixel 4a	LG	style2	Motorola	moto x^4	realme	7i
Google	Pixel 4a 5G	LG	style3	Motorola	moto z^2 force	realme	7 Pro
Google	Pixel 5	LG	Stylo 5	Motorola	moto z^3	realme	8 Pro
HMD Global	Nokia 3.4	LG	Stylo 6	Motorola	moto z^3 play	realme	Narzo 20 Pro
HMD Global	Nokia 5.4	LG	V30	Motorola	moto z^4	realme	Q
HMD Global	Nokia 6 (2018)	LG	V30+	OnePlus	OnePlus 3T	realme	X
HMD Global	Nokia 6.1 Plus	LG	V30+ JOJO	OnePlus	OnePlus 5	realme	X Lite
HMD Global	Nokia 6.2	LG	LG Signature Edition 2017	OnePlus	OnePlus 5T	realme	XT
HMD Global	Nokia 7 Plus	LG	V35 ThinQ	OnePlus	OnePlus 6	realme	X2
HMD Global	Nokia 7.1	LG	LG Signature Edition 2018	OnePlus	OnePlus 6T	realme	X2 Pro
HMD Global	Nokia 7.2	LG	V40 ThinQ	OnePlus	OnePlus 7 Pro	realme	X3 Super Zoom
HMD Global	Nokia 8	LG	V50 ThinQ	OnePlus	OnePlus 7T	realme	X7 5G
HMD Global	Nokia 8 Sirocco	LG	V50S ThinQ	OnePlus	OnePlus 8	realme	X7 Pro 5G

HMD Global	Nokia 8.1	LG	LG Signature Edition 2019	OnePlus	OnePlus 8T	realme	X50 Pro
HMD Global	Nokia 8.3 5G	LG	V60 ThinQ	OnePlus	OnePlus N10	realme	X50t 5G
HTC	Desire 21 Pro 5G	LG	V60 ThinQ 5G	Oppo	A72	realme	V5 5G
Huawei	Honor 8X	LG	VELVET 5G	Oppo	A72 5G	realme	V15 5G
Huawei	Honor 10	LG	WING 5G	Oppo	A92	Samsung	Galaxy A3 (2017)
Huawei	Honor View 10 Lite	Motorola	moto g^{5s} plus	Oppo	A92s	Samsung	Galaxy A5 (2017)
Huawei	Honor V20	Motorola	moto g^{6}	Oppo	A93 5G	Samsung	Galaxy A6 (2018)
Huawei	Mate 20 Lite	Motorola	moto g^{6} plus	Oppo	A94	Samsung	Galaxy A7 (2017)
Huawei	Mate 20	Motorola	moto g^{7}	Oppo	F11 Pro	Samsung	Galaxy A7 (2018)
Huawei	Mate 20 Pro	Motorola	moto g^{7} play	Oppo	F15	Samsung	Galaxy A8
Huawei	Mate 20 X	Motorola	moto g^{7} plus	Oppo	F17 Pro	Samsung	Galaxy A8+ (2018)
Huawei	Nova 3	Motorola	moto g^{7} power	Oppo	F19 Pro+	Samsung	Galaxy A20
Huawei	Nova 3i	Motorola	moto g^{7} play	Oppo	Find X2	Samsung	Galaxy A20s
Huawei	Nova 4	Motorola	moto g^{8}	Oppo	Find X2 Pro	Samsung	Galaxy A20e
Huawei	P20	Motorola	moto g^{8} play	Oppo	Find X3 Pro	Samsung	Galaxy A30
Huawei	P20 Pro	Motorola	moto g^{8} plus	Oppo	K3	Samsung	Galaxy A30s
Huawei	P30	Motorola	moto g^{8} power	Oppo	K5	Samsung	Galaxy A31
Huawei	P30 Pro	Motorola	moto g^{8} power lite	Oppo	R17 Pro	Samsung	Galaxy A32
Huawei	Porsche Design Mate RS	Motorola	moto g^{9} play	Oppo	Reno	Samsung	Galaxy A32 5G

Figure 55: Supported devices to work with ARCore. Listed extracted from the ARCore website **[73]**.

Annex F. 2D plan of the ULB lab

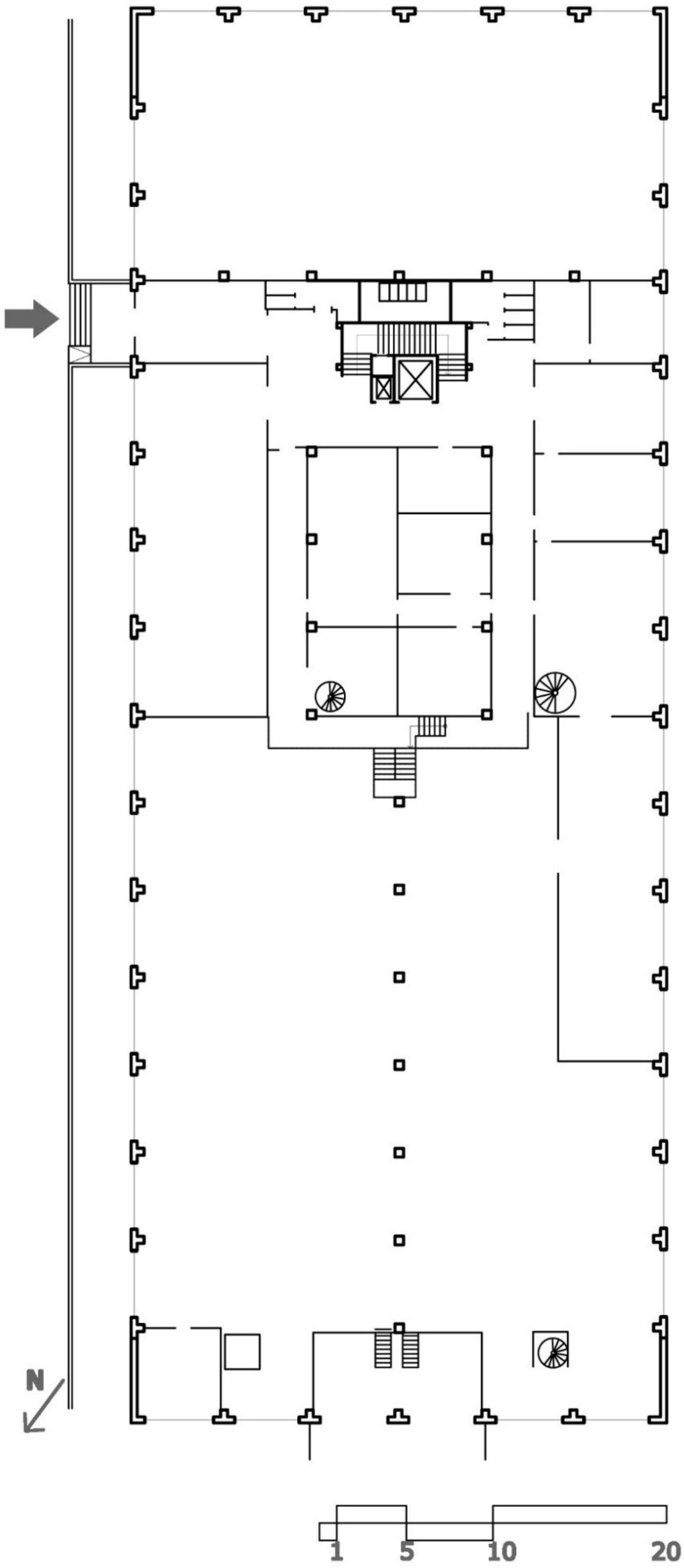


Figure 56: 2D plan of the laboratory of Civil Engineering located in building C of the ULB Solbosch campus.

Annex G. Plan details of the construction simulation in Revit

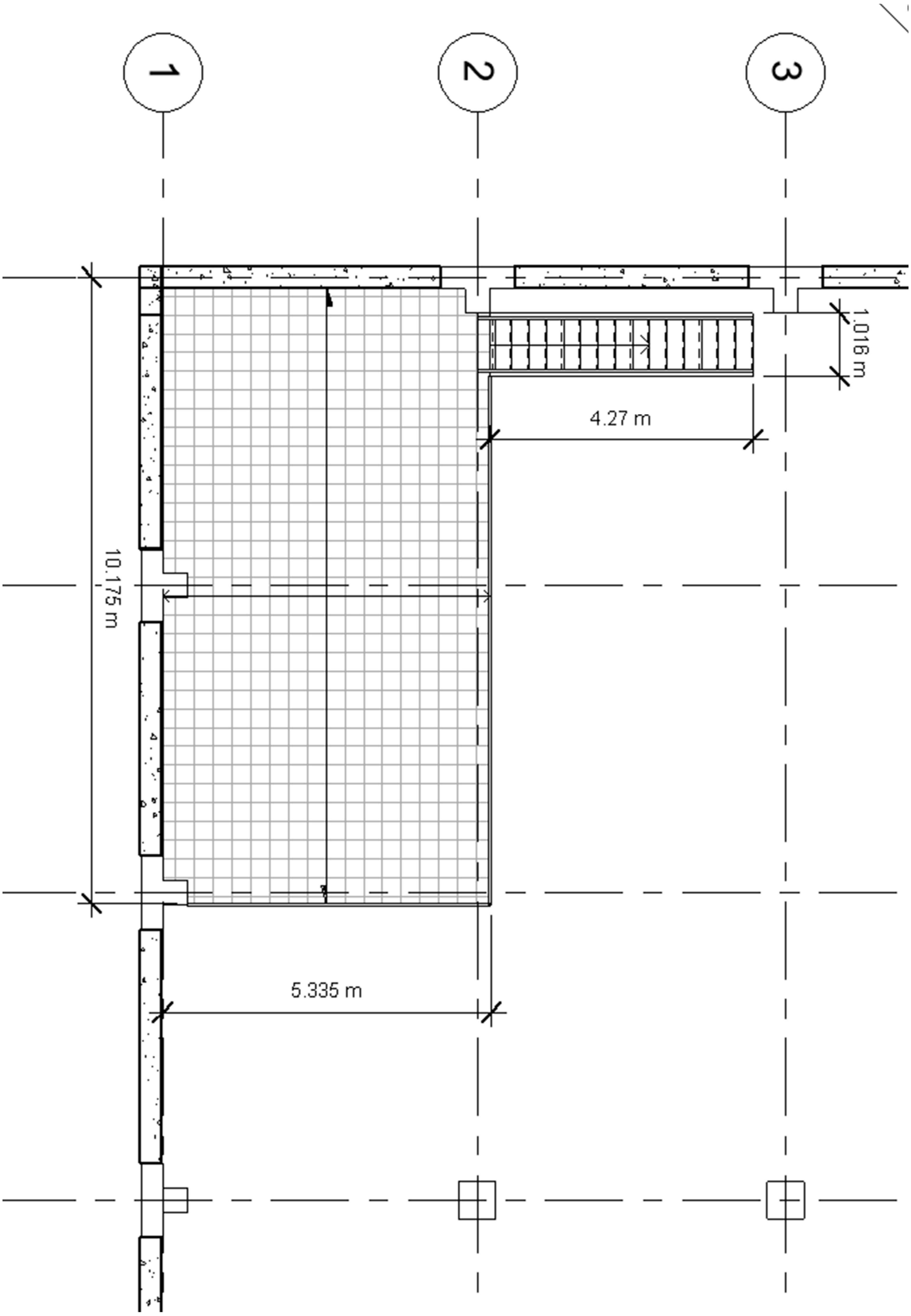


Figure 57: Plan of the construction simulation located in the lab.

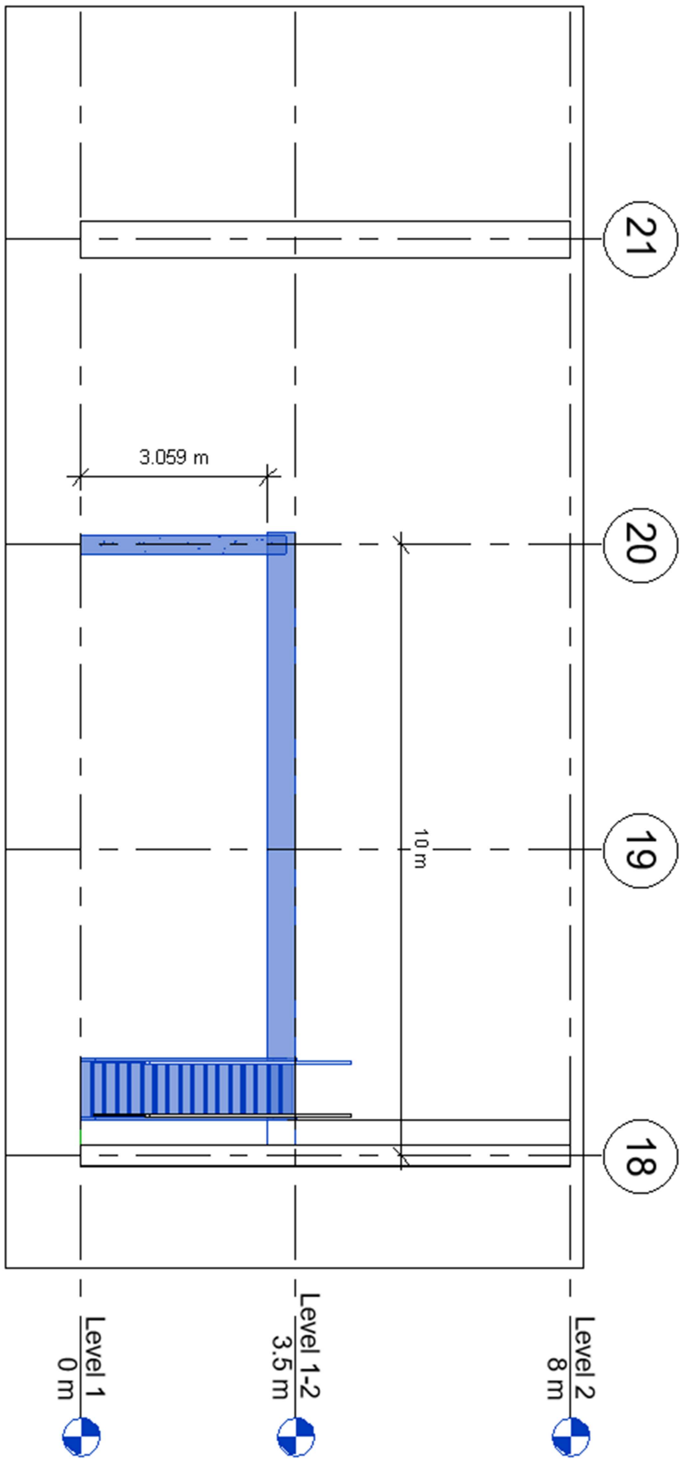


Figure 58: Cross section of the construction simulation located in the lab.

Annex H. Code of the 3D model placement

```
namespace GoogleARCore.Examples.ObjectManipulation
{
    using GoogleARCore;
    using UnityEngine;

    /// <summary>
    /// Controls the placement of objects via a tap gesture.
    /// </summary>
    public class PawnManipulator : Manipulator
    {
        /// <summary>
        /// The first-person camera being used to render the passthrough camera
image (i.e. AR
        /// background).
        /// </summary>
        public Camera FirstPersonCamera;

        /// <summary>
        /// A prefab to place when a raycast from a user touch hits a plane.
        /// </summary>
        public GameObject PawnPrefab;

        /// <summary>
        /// Manipulator prefab to attach placed objects to.
        /// </summary>
        public GameObject ManipulatorPrefab;

        /// <summary>
        /// Returns true if the manipulation can be started for the given
gesture.
        /// </summary>
        /// <param name="gesture">The current gesture.</param>
        /// <returns>True if the manipulation can be started.</returns>
        protected override bool CanStartManipulationForGesture(TapGesture
gesture)
        {
            if (gesture.TargetObject == null)
            {
                return true;
            }

            return false;
        }

        /// <summary>
        /// Function called when the manipulation is ended.
        /// </summary>
        /// <param name="gesture">The current gesture.</param>
        protected override void OnEndManipulation(TapGesture gesture)
        {
            if (gesture.WasCancelled)
            {
                return;
            }

            // If gesture is targeting an existing object we are done.
            if (gesture.TargetObject != null)
            {
                return;
            }
```

```
            // Raycast against the location the player touched to search for
planes.
            TrackableHit hit;
            TrackableHitFlags raycastFilter =
TrackableHitFlags.PlaneWithinPolygon;

            if (Frame.Raycast(
                gesture.StartPosition.x, gesture.StartPosition.y, raycastFilter,
out hit))
            {
                // Use hit pose and camera pose to check if hittest is from the
                // back of the plane, if it is, no need to create the anchor.
                if ((hit.Trackable is DetectedPlane) &&
                    Vector3.Dot(FirstPersonCamera.transform.position -
hit.Pose.position,
                        hit.Pose.rotation * Vector3.up) < 0)
                {
                    Debug.Log("Hit at back of the current DetectedPlane");
                }
                else
                {
                    // Instantiate game object at the hit pose.
                    var gameObject = Instantiate(PawnPrefab, hit.Pose.position,
hit.Pose.rotation);

                    // Instantiate manipulator.
                    var manipulator =
                        Instantiate(ManipulatorPrefab, hit.Pose.position,
hit.Pose.rotation);

                    // Make game object a child of the manipulator.
                    gameObject.transform.parent = manipulator.transform;

                    // Create an anchor to allow ARCore to track the hitpoint as
understanding of
                    // the physical world evolves.
                    var anchor = hit.Trackable.CreateAnchor(hit.Pose);

                    // Make manipulator a child of the anchor.
                    manipulator.transform.parent = anchor.transform;

                    // Select the placed object.
                    manipulator.GetComponent<Manipulator>().Select();
                }
            }
        }
    }
}
```

Annex I. Script of the Model Manipulation

```
namespace GoogleARCore.ObjectManipulation
{
    using UnityEngine;

    /// <summary>
    /// Manipulation system allows the user to manipulate virtual objects
(select, translate,
    /// rotate, scale and elevate) through gestures (tap, drag, twist, swipe).
    /// Manipulation system also handles the current selected object and its
visualization.
    ///
    /// To enable it add one ManipulationSystem to your scene and one Manipulator
as parent of each
    /// of your virtual objects.
    /// </summary>
    public class ManipulationSystem : MonoBehaviour
    {
        private static ManipulationSystem s_Instance = null;

        private DragGestureRecognizer m_DragGestureRecognizer = new
DragGestureRecognizer();

        private PinchGestureRecognizer m_PinchGestureRecognizer = new
PinchGestureRecognizer();

        private TwoFingerDragGestureRecognizer m_TwoFingerDragGestureRecognizer =
            new TwoFingerDragGestureRecognizer();

        private TapGestureRecognizer m_TapGestureRecognizer = new
TapGestureRecognizer();

        private TwistGestureRecognizer m_TwistGestureRecognizer = new
TwistGestureRecognizer();

        /// <summary>
        /// Gets the ManipulationSystem instance.
        /// </summary>
        public static ManipulationSystem Instance
        {
            get
            {
                if (s_Instance == null)
                {
                    var manipulationSystems =
FindObjectsOfType<ManipulationSystem>();
                    if (manipulationSystems.Length > 0)
                    {
                        s_Instance = manipulationSystems[0];
                    }
                    else
                    {
                        Debug.LogError("No instance of ManipulationSystem exists
in the scene.");
                    }
                }

                return s_Instance;
            }
        }
```

```
/// <summary>
/// Gets the Drag gesture recognizer.
/// </summary>
public DragGestureRecognizer DragGestureRecognizer
{
    get
    {
        return m_DragGestureRecognizer;
    }
}

/// <summary>
/// Gets the Pinch gesture recognizer.
/// </summary>
public PinchGestureRecognizer PinchGestureRecognizer
{
    get
    {
        return m_PinchGestureRecognizer;
    }
}

/// <summary>
/// Gets the two finger drag gesture recognizer.
/// </summary>
public TwoFingerDragGestureRecognizer TwoFingerDragGestureRecognizer
{
    get
    {
        return m_TwoFingerDragGestureRecognizer;
    }
}

/// <summary>
/// Gets the Tap gesture recognizer.
/// </summary>
public TapGestureRecognizer TapGestureRecognizer
{
    get
    {
        return m_TapGestureRecognizer;
    }
}

/// <summary>
/// Gets the Twist gesture recognizer.
/// </summary>
public TwistGestureRecognizer TwistGestureRecognizer
{
    get
    {
        return m_TwistGestureRecognizer;
    }
}

/// <summary>
/// Gets the current selected object.
/// </summary>
public GameObject SelectedObject { get; private set;  }

/// <summary>
/// The Unity Awake() method.
```

```
        /// </summary>
        public void Awake()
        {
            if (Instance != this)
            {
                Debug.LogWarning("Multiple instances of ManipulationSystem
detected in the scene." +
                                 " Only one instance can exist at a time. The
duplicate instances" +
                                 " will be destroyed.");
                DestroyImmediate(gameObject);
                return;
            }

            DontDestroyOnLoad(gameObject);
        }

        /// <summary>
        /// The Unity Update() method.
        /// </summary>
        public void Update()
        {
            DragGestureRecognizer.Update();
            PinchGestureRecognizer.Update();
            TwoFingerDragGestureRecognizer.Update();
            TapGestureRecognizer.Update();
            TwistGestureRecognizer.Update();
        }

        /// <summary>
        /// Deselects the selected object if any.
        /// </summary>
        internal void Deselect()
        {
            SelectedObject = null;
        }

        /// <summary>
        /// Select an object.
        /// </summary>
        /// <param name="target">The object to select.</param>
        internal void Select(GameObject target)
        {
            if (SelectedObject == target)
            {
                return;
            }

            Deselect();
            SelectedObject = target;
        }
    }
}
```