# POLITECNICO DI MILANO

## Master in

Building Information Modelling

BIM A+ European Master in Building Information Modelling

# Gamification in Construction

## principles, methods, and applications to construction simulation


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# ERRATA

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# STATEMENT OF INTEGRITY

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# SOMMARIO


Negli ultimi due decenni, in seguito alla diffusione del BIM, delle simulazioni digitali e della realtà virtuale nel campo AECO, così come ai loro sviluppi polivalenti, l'industria delle costruzioni ha mostrato un crescente interesse per gli approcci digitali basati sulla gamification e/o sull'uso di motori di gioco come ambienti di simulazione. All'inizio, le tecnologie basate sui videogiochi sono state essenzialmente utilizzate in questo campo come un modo alternativo e immersivo di comunicare la progettazione ai clienti, ai futuri utenti o, in alcuni casi, come un modo intelligente per formare i lavoratori nei cantieri.

La crescente interoperabilità dei motori di gioco (come Unity 3D) con le comuni piattaforme BIM ha anche favorito lo spostamento verso approcci ibridi tra i videogiochi e l'industria delle costruzioni, con l'intenzione di fornire ambienti di sviluppo per gemelli digitali. Di conseguenza, i motori di gioco sono oggi considerati una componente emergente dell'ecosistema della costruzione digitale, e molte applicazioni orientate alla costruzione sono disponibili sia nella ricerca che nella pratica.

In questo contesto è stato indagato l’attuale stato dell'arte per quanto riguarda la ludificazione digitale nelle costruzioni, ripercorrendo le classificazioni delle applicazioni di ricerca esistenti nel dominio delle costruzioni, con attenzione particolare ai fini del loro riutilizzo nella pratica quotidiana di cantiere.

Quindi è seguito lo studio e l’implementazione di approcci alla ludificazione strutturati per la simulazione delle operazioni di costruzione, finalizzate alla formazione ed all’addestramento del Preposto in qualità di nuovo protagonista assoluto dell’aggiornamento di aprile del D.Lgs. 81/08.

In termini applicativi, si è infine portata attenione a tematiche quali 1) strutturazione dei requisiti formativi 2) produzione di storylines adeguate al contesto ed in linea con i requisiti 3) interfaccia con i dispositivi di realtà virtuale immersiva.

Come parte finale del lavoro, l’applicazione dei requisiti strutturati nel flusso di lavoro al caso di studio ipotizzato per la formazione.


**Parole chiave:** (Modellazione Ergotecnica, Gamification, Interoperabilità, Simulazione digitale, Unity3D)

# ABSTRACT

The construction industry has shown a growing interest in digital approaches based on gamification and/or the use of game engines as simulation environments over the past two decades, following the spread of BIM, digital simulations, and virtual reality in the AECO field, as well as their multi-purpose development. Initially, game-based technologies were primarily employed in this industry as an alternate and immersive method of expressing design to clients, future users, and, in certain instances, as a clever method of training construction workers.

The increased interoperability of gaming engines (such as Unity 3D) with prevalent BIM platforms has also spurred a trend towards hybrid approaches between the video game industry and the construction industry, with the aim of creating development environments for digital twins. As a result, game engines are currently seen as an emergent component of the digital building ecosystem, and numerous construction-oriented applications are accessible for both research and practise.

In this context, the current stage of digital gamification in construction was examined by tracing the categories of existing research applications in the construction sector, with an emphasis on their reuse in ordinary building practise.

This was followed by the study and implementation of structured gamification approaches for the simulation of construction processes, with the goal of educating and training the new protagonist of the April update to Legislative Decree 81/08.

A portion of the effort entailed concentrating on challenges such as 1) organising training needs; 2) generating narratives that are suited to the setting and meet the needs; 3) interacting with equipment for immersive virtual reality.

The work concludes with the application of the workflow-structured requirements to the hypothesised training case study.

**Keywords:** (Construction site Information Modelling, Digital simulation, Gamification, Interoperability, Unity3D)

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# 1. PREFACE

In order to clarify what the actual North of this work is, it is necessary to first provide a basic overview of the state of the art as well as an introduction. This is because in order to grasp where we want to go, we must first comprehend where we have been and what we want.

Gamification in Construction: Principles, Methods, and Applications to Construction Simulation aims to examine the realm of gamification applied to the construction industry**.** In this section, I propose to present the structure of the thesis by briefly describing the topics that will be covered in subsequent chapters. See **Figure 1**.

In the subsequent chapters, it will be demonstrated that gamification has a wide range of applications, each of which will be described in detail. This thesis seeks to identify a potential application based on its reusability in daily practise by attempting to explain its integration with an existing information flow procedure. Preliminary investigations and a literature review, the presentation of game engines, and the case study are the three primary sections of the structure. Each of these three sections is further elaborated by a substructure designed to elucidate the aforementioned concepts: in the case of the literature review, an overview of the various definitions of gamification will be presented, along with an analogy that clarifies what is meant by this. In the second section of the thesis, game engines will be discussed in terms of their construction and capabilities. Last but not least, the application case will discuss the regulatory requirements that compelled us to develop this solution, as well as the useful tools and apps.

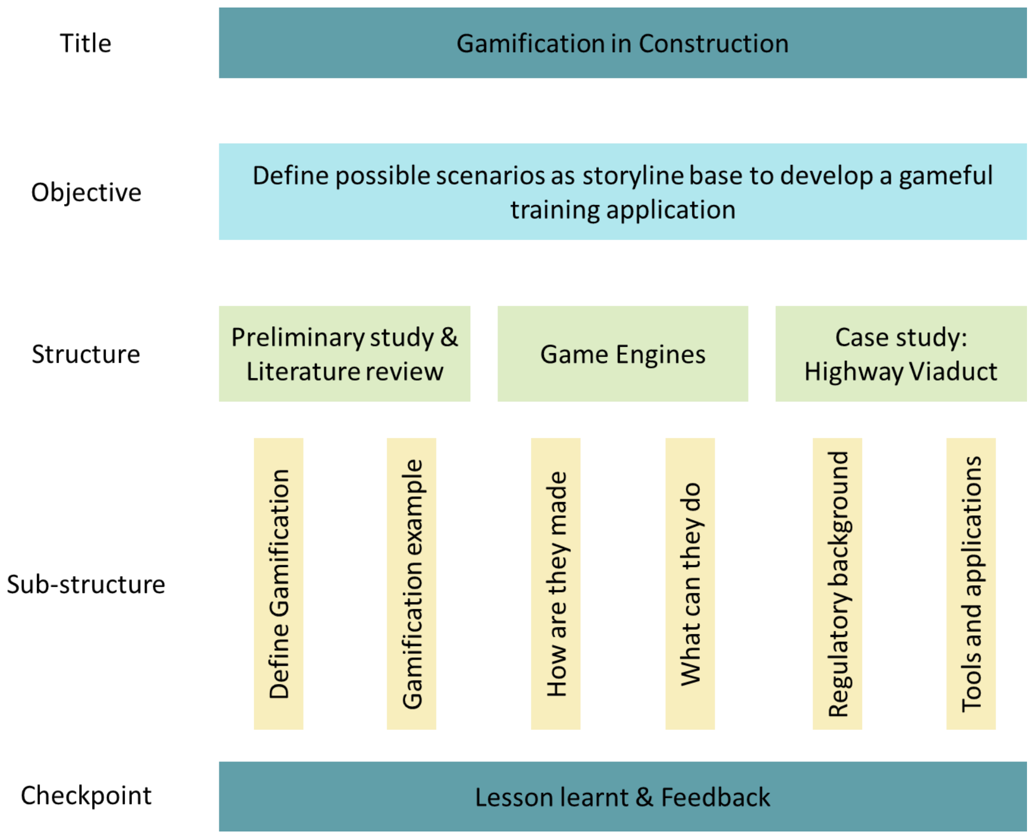


**Figure 1 – Thesis structure**

The purpose of this thesis is to investigate possible scenarios that can be developed as training with the support of gamification logics that have proven to be useful in terms of engagement and return on learning (Zainuddin et al., 2020). Specifically, the goal of this investigation is to determine whether or not a particular scenario can be developed as training (Lin et al., 2019). It is not within the purview of this work to produce a finished product, as that falls under the purview of game developers; rather, the emphasis will be placed on the definition of workflows that can be applied, according to specific requirements, in Operation & Construction. It is relevant to mention the scalability of this work; it could be applied to other fields, e.g. Facility Management, with the due considerations over the expected outcomes.

Specifically, in the Operation & Construction circumstance, that has been stated above, it is possible to design training scenarios for highly competent operators who have been given difficult duties that require a greater level of coordination as well as training. AECOM is one of the numerous industries that is looking into gamification and serious games as a novel and cutting-edge method of training that is also more immersive (Feng et al., 2022). As other relevant examples, it is worth to mention the applications that virtual reality surgery training is having on the market right now (Kyle Melnick, 2022), or the sophisticated enhancements that can be obtained for the aviation business (Torğul et al., 2022).

Keeping this key premise in mind, let us now analyse the questions that this thesis seeks to solve. Long training sessions are frequently inefficient, particularly in terms of employee involvement. As a result, these training periods result in downtime costs for employees, who wish to avoid them if possible. The days spent in training that require the employment of specialists for face-to-face training courses can be long and tedious. One potential advantage of serious games could be the ability to create reproducible content that is more in line with practical reality (Ren et al., 2022). This would allow the learner to practise in a protected virtual environment while also allowing different aspects such as sources of risk to be addressed (Silva et al., 2013).

Another important function of these tools is that they can be utilised to educate those who are responsible for maintenance. If they were provided with virtual or augmented reality visors that allowed them to interact directly with their surroundings while also obtaining data remotely, it is possible that their task could be significantly aided in terms of learning as well. The incorporation of information editing capabilities during the operation phase is a potential alternative that can be considered. If this activity was carried out locally rather than from a remote location in the office, the results would be significantly more accurate and fruitful. This would mean that the data could be double-checked on-site, ensuring its accuracy and reducing the bother of having to travel back and obtain the data. This would be a positive development.

This work intends to pay particular attention to those application cases related to the information modelling of works requiring a highly complex work schedule where coordination between the design and operational parties plays a fundamental role in the success of the project. The specific training and preparation that is hypothesised, is intended to be a digital improvement tool that is linked to a gameful approach in order to captivate it. This is done in order to guarantee a result that is in line with the expectations while also ensuring that production efficiency is maintained.

The objective of this, is to provide examples that can be used as a basis for the construction of specialised training applications by demonstrating the benefits of the data and the possible integrations that can be made with them. The purpose of the research is to define workflows on how to structure scenarios by providing some practical examples beginning with an evaluation of the current state of the art regarding the incorporation of virtual or augmented reality tools with training, regardless of whether it is for the construction phase or the maintenance phase.

This introduction will be used to structure the body of this work, which will provide an overview of the current state of the art. This overview will cover topics such as the psychological reasons that justify taking a gameful approach to training, game engines, and the logic that lies beneath them. It will then proceed with the structuring of the workflow that is applicable to the context that was described above, highlighting the important features, and it will conclude with what results are expected from the implementation of the proposed scientific framework as well as possible future implementations.

The following Figure 2 illustrates a comprehensive SWOT analysis performed on the comparison of current scientific publications. A gamified method results in a highly engaging activity and safer training, yet at the same time lacking large-scale trust despite being technically and technologically superior to the current state of the art. However, it offers a unique chance to save training expenses because it may be reused several times if deployed as an internal solution. Threatening this process is the potential length of time required to design the application, the application's specificity, and its limited reusability if not created intelligently.

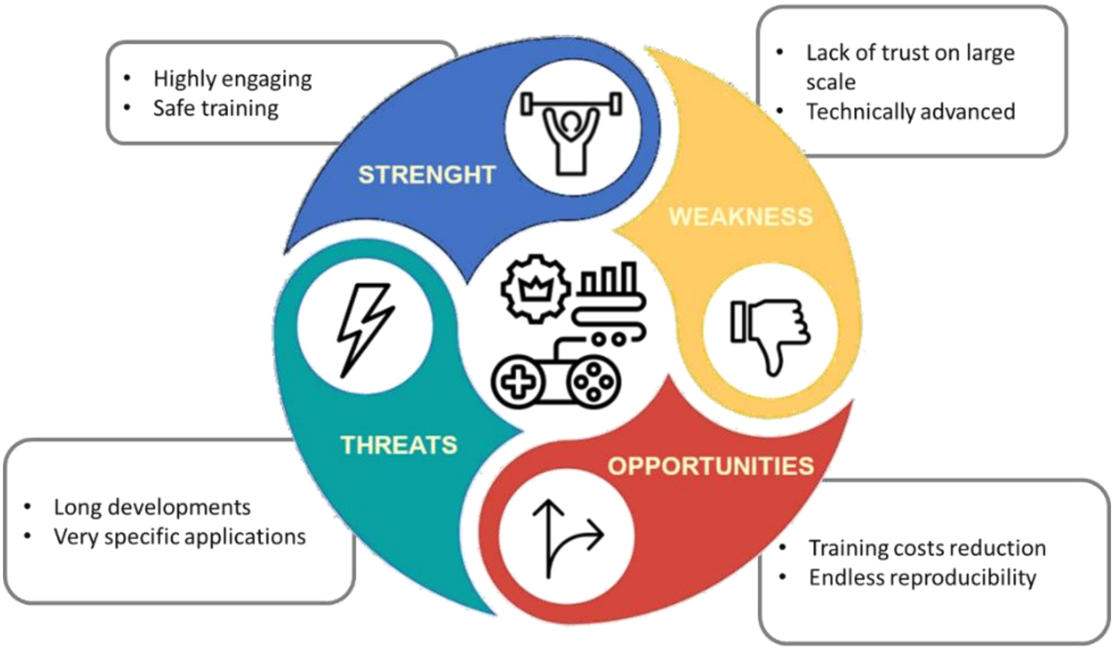


Figure 2 – Gamification SWOT Analysis

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# 2. LITERATURE REVIEW

This chapter's objective is to introduce and explain the various applications of gamification that are theoretically possible by making use of concrete examples. Not only will cases relating to architecture, engineering, construction, operations, and management be given, but also cases relating to cross-disciplinary applications to other scientific fields.

We will make an effort to provide answers to questions such as, "What is the definition of gamification?" Which areas does this pertain to specifically? What are some particularly noteworthy examples? How can we interact? In order to respond to these questions, we will construct a discourse that first offers the reader a series of definitions of gamification, distinguishing it from serious games, and then outlines the most typical experiences that may be achieved via the use of gamification.

Talking about gamification implies to have a basic knowledge of what the process of learning is. In order to build a resilient and reliable knowledge it is relevant to acknowledge the stages occurring in this process. The purpose of presenting the Data, Information, Knowledge, and Wisdom pyramid (DIKW), Figure 3, absolve this aim; it is an important tool that will be used in the succeeding paragraphs of this work to define the reasoning that was utilised. The reason underlying the presentation of this inverted pyramid, compared to its typical arrangement, is to draw attention to the increasingly disruptive effect that each successive layer has on the previous one. In point of fact, the contribution made by each layer rises progressively as one moves from the stage of data gathering to the stage of wisdom construction. In the beginning, the data is collected and organised in order to structure the information; this process traces the practise already in use in current design with authoring software; the input that this information provides leads to knowledge of the project or practise to be learned, which ultimately leads to wisdom. The level with the most comprehensive and unpredictable input is the one that produces the largest amount of insight.

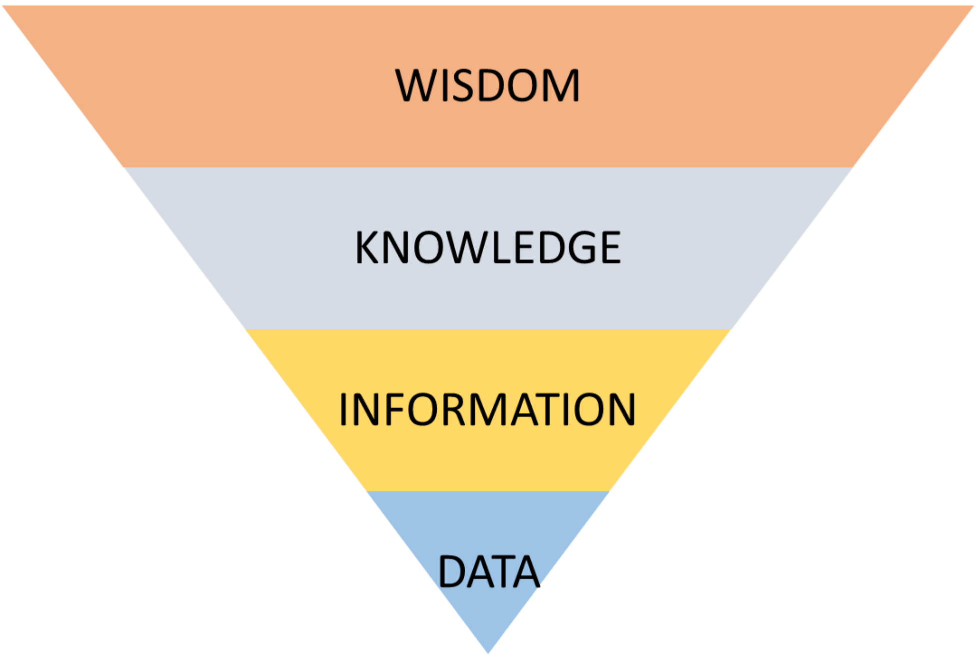


**Figure 3 – DIKW inverted pyramid**

## 2.1. What is gamification

The scientific community appears to have adopted the term gamification from British programmer Nick Pelling (Csaba et al., 2017), (Michał Jakubowski, 2014), (Kamasheva et al., 2015), who in 2002 first referred to playful applications unrelated to pure entertainment. Even though there is a great deal of literature about this event, all references to it link back to a page on Pelling's website where he attributes the phrase to himself (Nick Pelling, 2011).

In addition to its first chronological emergence, the distinction between Gamification and Serious Games must be clarified in order to comprehend its significance, as they are complementary but distinct concepts. Despite the continued use of the term 'gamification,' alternative, more purpose-specific meanings have evolved. It is not uncommon to encounter phrases like 'productivity games' (McDonald et al., 2008) rather than 'playful design' (Ferrara, 2012) , but 'gamification' has arguably institutionalised itself as a household term. Also, as a result of this, the word is a focal point of debate: applications, simplifications, and interpretations drive the majority of the conversation.

The idea of the author of this thesis work is that considering the engagement that video games have for users, in terms of time of use, dedication and involvement, the term 'serious game' describes the design of complete games for non-entertainment purposes, 'gamified' applications simply incorporate game elements.

It is worth to spend few words over the revisited compass in Figure 4 adapted from (Deterding et al., 2011) as it properly explains the relation between whole/parts and gaming/playing identifying where gamification and serious games fit. According to the authors of the aforementioned publication, "gamification" does indeed define a distinct but previously unspecified group of phenomena, namely the gameful interaction, complex of gamefulness, and gameful design, which are distinct from the more established concepts of playfulness, playful interaction, and design for playfulness. Using this observation as justification, they offer the following definition: "*Gamification is the use of game design elements in non-game contexts*". Nevertheless, the current use of the "gamification" term range between two related ideas. The first trend is the increasing normalisation, legitimization, and pervasiveness of (video) games in day-to-day life (Chatfield, 2005), (Helagason D., 2010). The second, more specific idea is that given that video games are designed primarily for entertainment and have the ability to motivate players to engage with them on a level of unprecedented depth and for an extended period of time, game mechanics ought to be able to make non-game products and services more enjoyable and attention-grabbing (Zichermann and Cunningham, 2011). It is common practise for vendors and consultants to describe "gamification" in terms of its application and the benefits it provides to clients. For example, "gamification" can be defined as the use of game technology and game design methods in contexts other than the video game industry (Helagason David, 2010), or it can be defined as the process of employing game thinking and game mechanics in order to solve problems and engage users (Ziecherman, 2011).

To summarise the difference between the Figure 4 concepts, we may refer to toys as those full-sized items with which we can play. However, it is also possible to play with the individual pieces that make up toys, which is referred to as a playful design. Analogously, on the gaming side, it is feasible to distinguish a gameful design, also known as gamification, as the use of portions of the required gaming elements to form a complete game. To offer a clear contrast between the words mentioned, it is useful to consider the following analogy. The Millennium Falcon is a full product intended to be played as a whole item, although its component pieces can be assembled in a manner distinct from the overall product and played as separate components. Similarly, on the digital side, in our case, of gaming, it is possible to imagine the parts (or rather, the features) constituting the game as assembleable elements that make it possible to obtain a finished product, such as the microgame pre-installed in Unity that allows learning to use the software through gamification experiences.

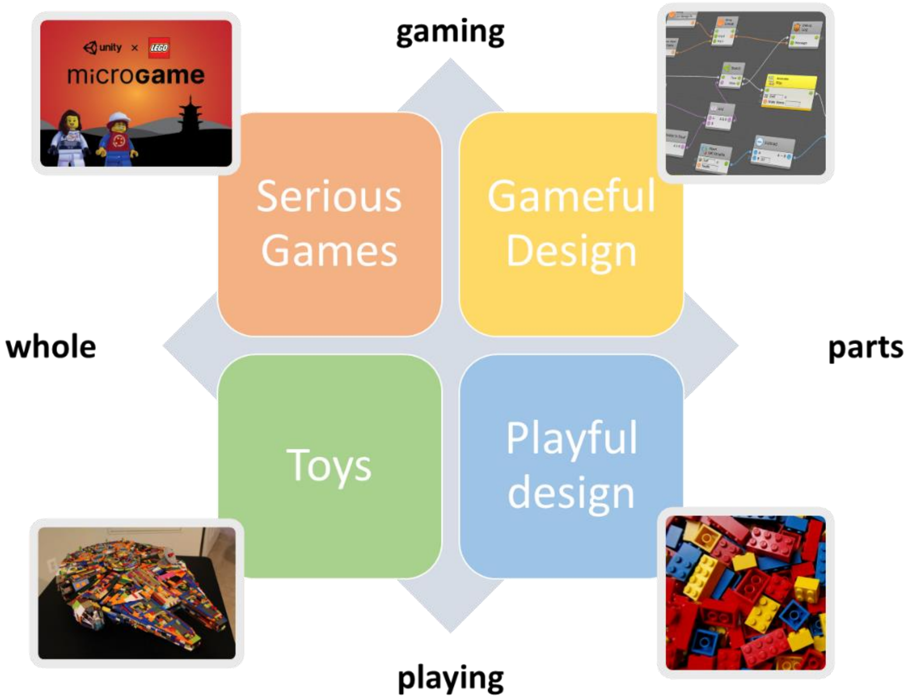


**Figure 4 –Compass to navigate SGs and Gamification**

According to the definition adopted by the author within this thesis, gamification is the incorporation of game elements and principles to non-game environments to improve user experience, engagement, and results. Gamification is a design strategy used to incorporate game-based concepts into settings, activities, and tasks, as opposed to completely replacing them with video games. Consequently, gamification is relevant to non-digital environments, such as classroom-teaching activities that utilise gamified quizzes with points, leaderboards, and awards. Regarding SGs, they are often digital games designed to fulfil objectives other than enjoyment. Specifically, an SG is a self-contained digital application that accomplishes intended goals, which is distinct from gamification.

To comprehend the current possibilities of gamification, one needs to examine Gartner's yearly Hype Cycle. Gartner Inc. has studied gamification for a number of years, beginning in 2011 and concluding in 2014, but not until 2015 (Gartner Inc, 2014). Gamification passed through two of the 5 cycles between 2011 and 2014, when it entered its third phase. The graph produced annually by Gartner Inc. depicts the most cutting-edge technologies and provides adoption projections based on the fact that each inventive process encompasses five well-defined phases.

The y-axis represents an objective examination of the surrounding expectations, while the x-axis represents the innovation's demonstrated value through time. Then, moving from left to right, it traces the progression of the idea through five predictable phases. The first phase is the innovation trigger, which occurs when a technology breakthrough or product launch gets people talking, when start-ups emerge as capital investment climbs, and when first-mover corporations begin launching trials. The second phase is the peak of inflated expectations, when the excitement attracts additional providers and consumers. There is a great deal of media coverage, but there is little evidence that the innovation can provide what is required. The third phase is the slope of disillusionment, which occurs after the initial enthusiasm subsides and early adopters observe predictable performance issues and little return on investment. In phase four, the slope of enlightenment, early adopters begin to realise first benefits and others begin to comprehend how to adjust their organisations to the innovation. We have finally reached phase 5, the productivity plateau. At this time, more users are experiencing tangible benefits, and the invention enters the mainstream. Typically, it takes between three and five years for an innovation to progress through the five phases, although the pace might vary.

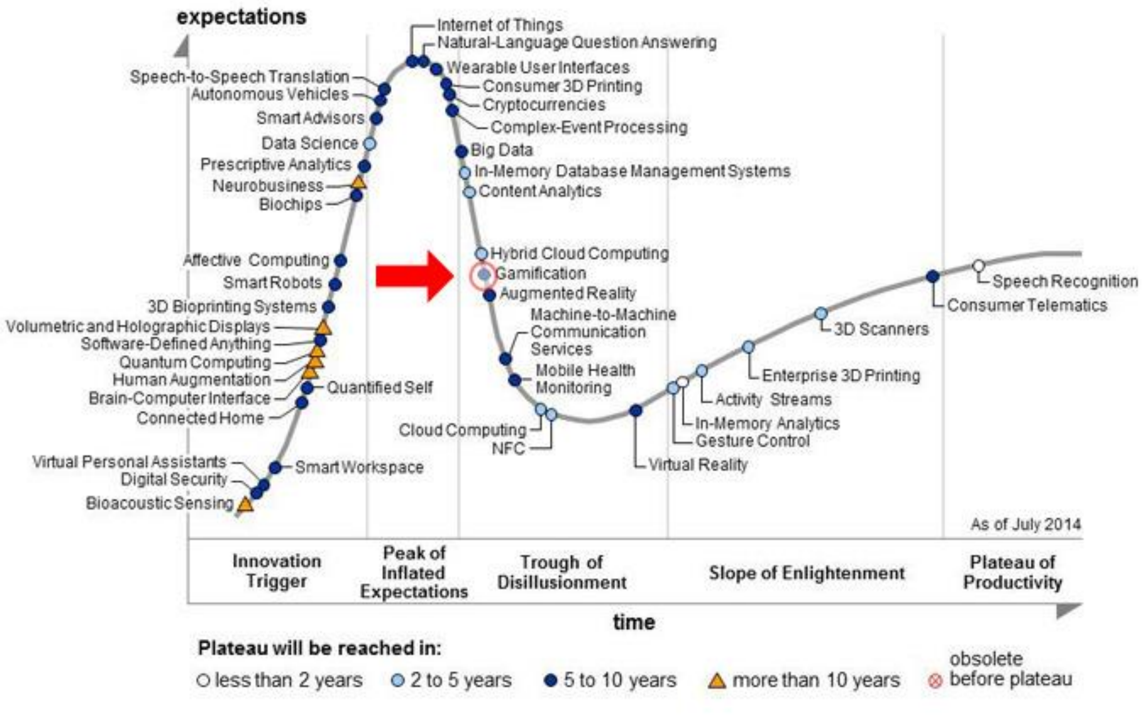


**Figure 5 –Gartner's Hype Cycle 2014**

As it can be seen in Figure 5, it was predicted that Gamification, an innovative technical solution, would reach its peak within two to five years. Even though gamification was no longer present as of 2015, it is reasonable to assume that it has reached at least the fourth phase of the Slope of Enlightenment, as numerous companies offering a variety of services based on the various application fields are promoting numerous applications based on a gameful approach.

## 2.2. Multisensory systematisation of knowledge

How therefore do we connect gamification and serious games to the purpose of this thesis? What is the scientific basis allowing us to connect gamification to a training session? We have to identify the region we are interested in and analysing it explicitly. As stated in the previous section of this work, the DIKW pyramid is a representation of the cognitive process and learning that places four elements in a hierarchical relationship: data, information, knowledge, and wisdom. To further extend the notion, the following picture, Figure 6, illustrates the parallelism between the gameful application development process and the corresponding DIKW levels. As other schemas, also this one has some limitations; it is a model of hierarchical knowledge management that tends to oversimplify complicated scenarios, such as logical gamification design in which aspects are intricately interrelated and challenging to handle independently. Nevertheless, the levels of the DIKW pyramid and the progression that is expected to take place within a serious game logic could be sufficiently and adequately presented.

In Figure 6, the pyramid on the left provides a comprehensive illustration of the developing stages, beginning with a raw collection of data obtained from the context research and culminating in an improved outcome. On the right-hand side of the image, the inverted DIKW graphically depicts how the impact of each layer on the one that comes after it gradually increases over time. The purpose of the following list is to emphasise and match a succinct explanation of the knowledge hierarchy management pathway with the stages required for the creation, organisation, and characterization of a serious game experience. Moving from the base to the top those layers can be related as it follows:

- Data: Acquire the data pertaining to the building site, as well as the regulations, in order to develop a database of information that may be used in the subsequent stage.

- Information: Organize and structure the data that was obtained in order to construct the key performance indexes (KPIs) and the metrics that will be used to measure improvement while the training is being conducted.

- Knowledge: In order to construct the serious game that is required for the intended usage, the combination of the relevant information within the game engine design, is required.

- Wisdom: Having a broader understanding of the lessons that were learned and being able to produce a better result on duty.

Moving on, it is now relevant to describe how to engage with the game. Despite the fact that our interactions with the world are multisensory, learning research frequently focuses on unisensory experiences. Providing a person with various sensory signals ought to aid representation; hence, several educational programmes have emphasised the advantages of mutually supporting multisensory knowledge. In recent decades, psychologists and neurologists have expanded the study of multisensory perception. Research has revealed that multisensory stimuli combinations facilitate information processing much more than within-modal stimulus combinations (Gingras et al., 2009). Memory, perceptual and implicit learning, and training results are facilitated by multisensory processes (Murray et al., 2004), (Alais and Cass, 2010).

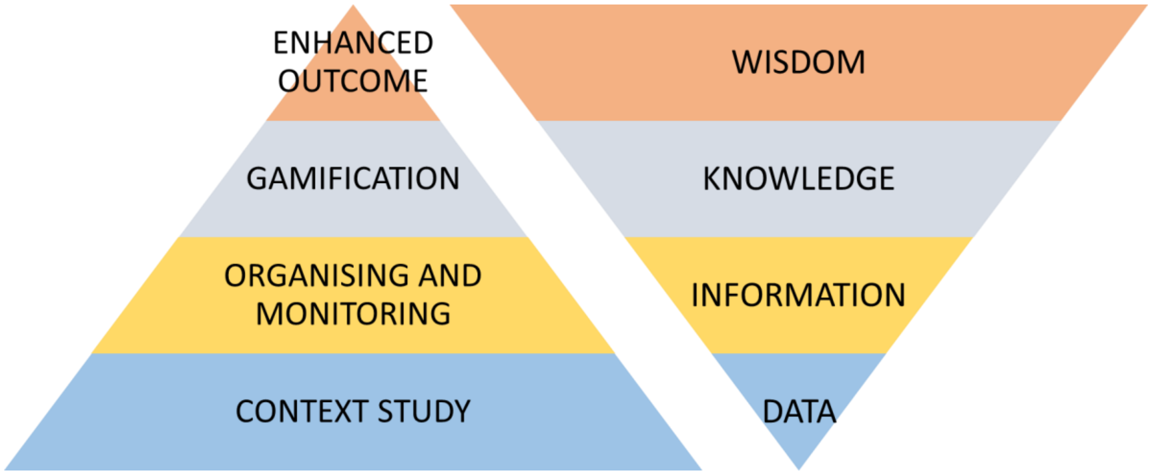


**Figure 6 –Developping stages corresponding to DIKW layers**

The benefit of multimodal information extends to adult paired associative learning (Crewther et al., 2013). The authors of (Hancock et al., 2013) demonstrate that multimodal audio/tactile cueing enhances the performance (speed and accuracy) of visual search and decreases mental effort. Currently, the majority of digital information exchanges are characterised by a poor use of sensorimotor skills (Caon et al., 2016). Although the change from desktop to mobile interfaces, VRi, AR, XR has enhanced many parts of the user experience, those more recent interfaces continue to rely heavily on vision, hearing, and rudimentary tactile feedback, while other senses remain underexplored. Nevertheless, determining the proper multimodal signals for certain scenarios is still a trial-and-error process, with numerous unanswered questions about the design and measurement of these cues (Kruijff et al., 2017).

In Figure 7 is possible to quickly understand the current state of art on which senses can be trained through contemporary tools (Covaci et al., 2018). At the moment is still not possible, nor the author sees the utility, to implement in the learning process smell or taste. On one hand, it is acknowledged that it is preferable not to have any real-world experiences connected to taste or smell on-site; let us consider the numerous hazards to which we would expose if any building substance or object were eaten or sniffed; attempting to taste or smell concrete formwork release oil is not a good idea. On the other hand, it has already been proven the utility with factual applications of hearing, sight, and touch in the training scenarios, as those are the senses involved during a common VRi training session using a head-mounted display.  Regarding those mentioned senses, they evoke suggestions in all the readers; memories of site experience are directly related to those ones: the noise of an excavator, the sight of it and the feeling of obnoxious heat during summer inspections. Leveraging on those impressions it is possible to easily acquire good habits and practices.

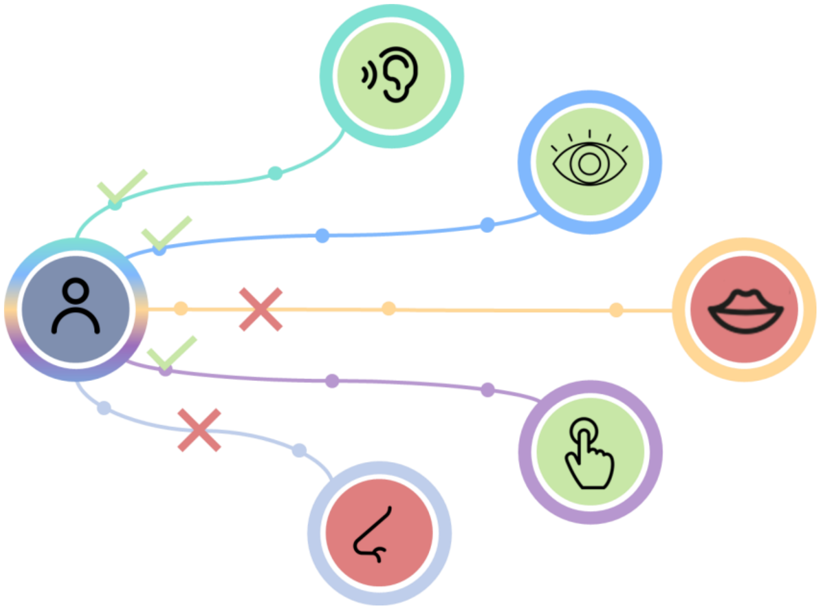

**Figure 7 –Training senses in the AECOM**

### 2.2.1. Learning workflow

Now, let's talk about why the process of learning is so important, as well as how it evolves through time. What distinguishes learning through the use of gamification as a tool from other methods of education? This question will be answered in the following paragraph. At the present stage of the thesis, it is important to illustrate how the source of the training need is clearly identifiable. The need for the training arises from a deficiency in the performance of a particular task. If one follows this line of reasoning, it is possible to close the knowledge gap by formal or informal learning, as illustrated in

Figure 8 is adapted from the study by (Cerovšek et al., 2010). If the following approach is adopted, the knowledge gap will be closed. Being able to start this process is a critical phase for the development of skills that may be applied to specific situations, as those are meant to help gaining experience and improving the learning process bearing in mind to close the circle by applying the lessons learnt.

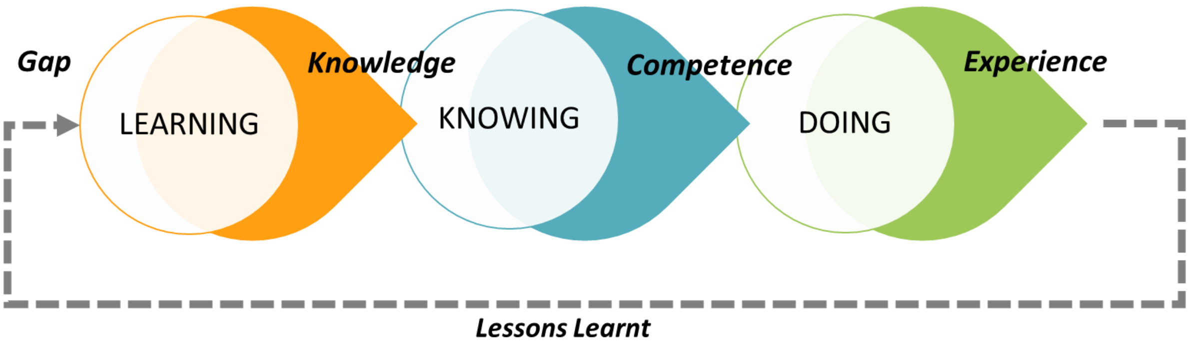


Figure 8 – Training workflow

In recent years, a rising number of evidence, such as comparisons between SGs and traditional education techniques in the areas of construction health and safety training and skills development, have been presented. Global studies have revealed the empirical evidence that SGs are more successful than standard training approaches. (Albers et al., 1997; Lin et al., 2011).

### 2.2.2. Elements of gamification

In light of what was anticipated in the preceding part, the objective of this section is to define what gamification features are and how they are utilised in the learning process as opposed to other procedures with the same intent. Several factors, as seen in Figure 9, elaborated from (Hagene, 2018), are necessary to adopt a game-like attitude. In direct comparison to toys and games as seen previously in Figure 4, it is essential to engage the user. In reality, user involvement is the linchpin that, if correctly constructed, ensures the success of the learning process. Ultimately, you will get the most out of it if you can create a strategy that engages the participant of their own free will as opposed to forcing them to undertake any activity. Another key aspect for the success of the gamified activity is the sense of rivalry or challenge that develops naturally if the user engagement is properly ensured. Competition is the attitude that emerges in response to a challenge; it can be directed either towards oneself or other players/colleagues. Attempting to improve oneself each time might ultimately be one of the forces that propels an activity to success. However, the competition produced must be correctly recognised and rewarded, thus it is vital to specify what the successes are in connection to the set goals, so that they can be readily identified upon attainment and the right awards can be provided.

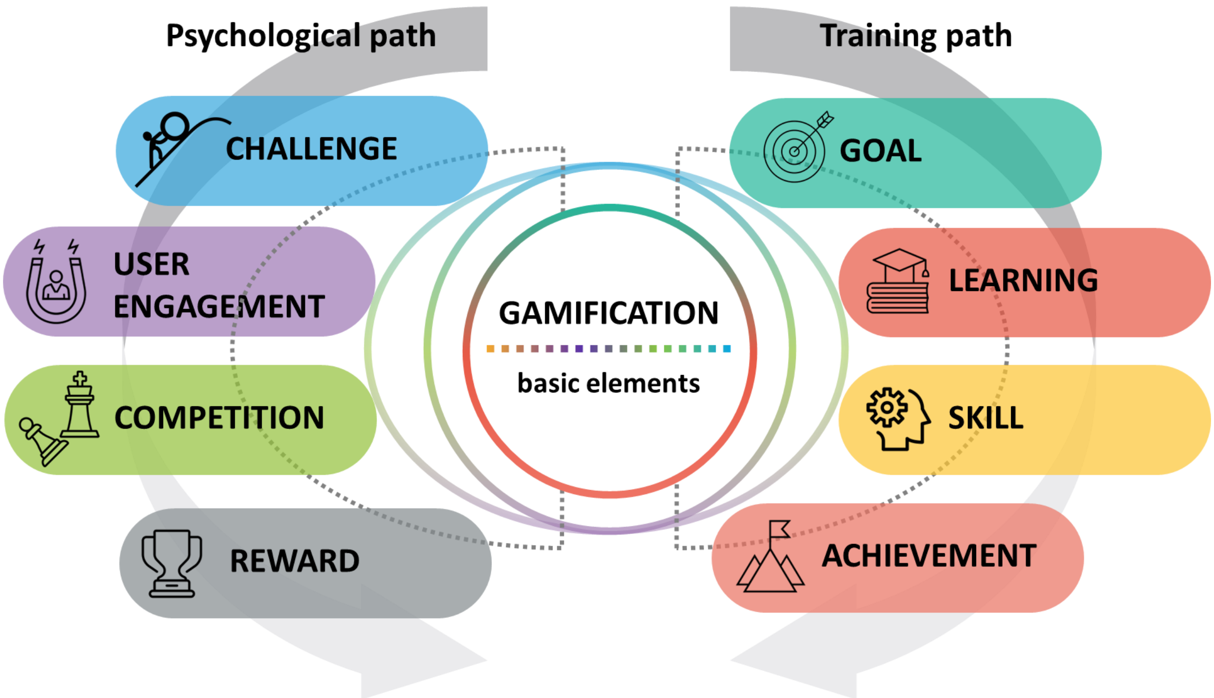


**Figure 9 – Gamification basic elements**

How can the relationship between the computer and the human be optimally utilised? A concise description of Human-Computer Interaction must be provided (HCI).

Human Computer Interaction (HCI) often refers to the study of the design, assessment, and implementation of interactive computing systems for human use, as well as the key phenomena surrounding them. It is essential to emphasise that even the most complex machines are useless if men cannot operate them effectively. In order for the HCI to be successfully utilised, utility and usability must be addressed in its design.(Sinha et al., 2010)

A system's functionality is defined by the activities or services it offers to its users. However, functionality's worth becomes apparent only when it can be employed effectively by the user.

Usability of a system refers to the range and extent to which the system may be utilised efficiently and effectively to achieve specific goals for specific users. The real efficacy of a system is attained when the system's functionality and usability are properly balanced.

To effectively enable the above mentioned HCI, (Feng et al., 2022) sets the items needed for the process. The interaction between users and SGs can be identified in the following seven items, Figure 10. The navigation implies how a user can navigate or make movement in the virtual environment of a SGs while the storytelling refers to the way a story is presented to users enabling them to follow and complete the storyline. Inevitably, consequences are expected if in the simulation of the SGs some actions are taken hence the necessity and severity of those depend on the intended outcome. Feedback is the information that is presented through reports or textual messages to the user informing about the progress and the performance attained so far. The way to convey knowledge and messages to users is called instructional approaches and is meant to achieve pedagogical outcomes; to deliver the pedagogical insight some behaviours have to be induced, hence designing the conditions that would imply a behavioural outcome is necessary. Lastly, keeping track and record through KPI provides users' performance history for further analysis.


**Figure 10 – Interaction between users and SGs**

### 2.2.3. Game Engines relevant features

A game engine is a programming environment that is frequently employed for the design of computer games. This industry expression is also known as game architecture, game framework, as well as game frame. Among the most frequent aspects of game engines there are 2D and 3D graphics rendering, physics engine, animation, artificial intelligence, sound, and networking. As noted, this is a platform used to develop a myriad of various games utilising several programming languages. It is equivalent to any other integrated development environment, with the inclusion of characteristics and choices that aid game design. (n.d., 2021, 2016)

Rendering Engine (RE)

Rendering engines (RE), also known as graphic engines one of the many parts of a game engine. It focuses on the game's 2D and 3D graphics rendering. It is a fundamental requirement for a game engine to be provided with a RE, furthermore it has to be compatible with multiple import formats. Whether a game is 2D or 3D, a visual component that compliments the aesthetics is vital. This essential component is showed to have different outcomes according to the software solution adopted, see Figure 11 from (Squarespace, n.d.) to grasp the differences achievable in the below mentioned render engines and the time elapsed to reach the same amount of rendered objects.


**Figure 11 – Render engines comparison, from** (Squarespace, n.d.)

Artificial Intelligence (AI)

Artificial Intelligence (AI) is a complex of diverse technologies that combine to enable computers to perceive, comprehend, act and learn with human-like levels of intelligence. It has a huge influence on the overall performance and logic of a game. When building a game, the AI engine provides recommendations depending on the player's in-game activities. A hero in a multiplayer battle arena game, for instance, approaches an opponent tower. When within range, the tower will immediately assault the hero. Consequently, the tower's attack causes the hero to lose some health. These logics are implemented by scripts developed and built by AI software engineers with substantial expertise. We may say that the scripts respond based on the overall game behaviour.

Physics Engine (PE)

A Physics Engine (PE) is a crucial component of software, especially for simulation games. This is a subcomponent involving the construction and development of simulations of actual activities, movements, and reactions. Among them are velocity, acceleration, fluidity, and projectile motions. The bulk of games that incorporate physics engines feature real-time actions and reactions. Grand Theft Auto is an amazing example of a gaming engine that employs physics. The collisions of automobiles and gravity when descending create a visual picture of genuine action-reaction scenarios. Beside the application of GTA videogame, there are several applications that can be obtained relying on the setting of the Particle System such as in Figure 12 from (Unity, n.d.).

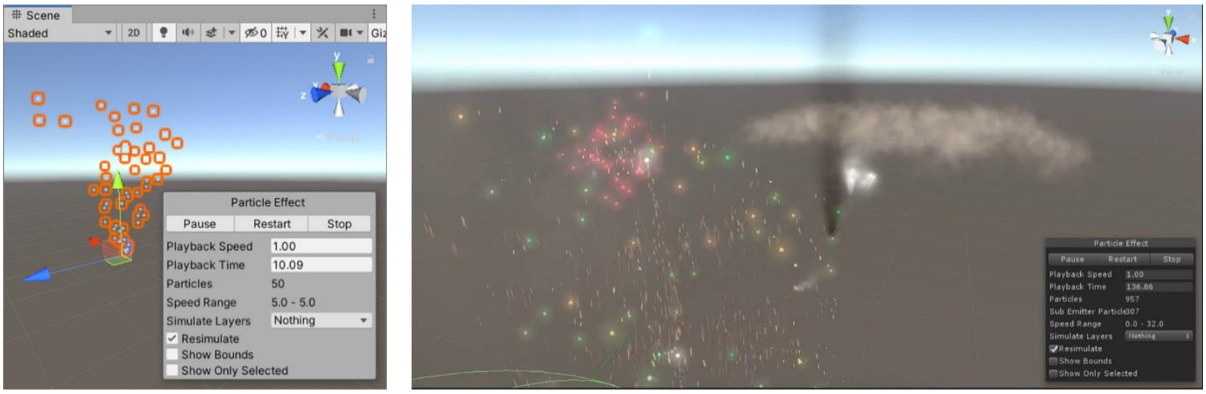


**Figure 12 – Particle System settings and results, from** (Unity, n.d.)

Audio System (AS)

The Audio System (AS) also known as sound engine is used to operate effects when assets interact inside the game. Practically, it consists of audio files which have been integrated in the designed game. This loads, optimises, and plays the sound files associated with each game action.

Networking

The development of the Internet made remote collaboration possible, hence facilitating a more interactive gaming experience. The network engine allows multiplayer or social gaming, allowing you to play with other users. These engines collaborate to provide each user with properly working solution. Depending on the game's growth, one or two of these may not be essential. Regardless, this software package is intended for utilisation by organisations and programmers.

### 2.2.4. Examples of game engines

The number of game engines available on the market is considerable, so in order to study how to adopt a solution that would meet our requirements, it was necessary to delve into some of the most common engines available and make a choice. The first step was to examine the availability of free web materials. GitHub is a web-hosting platform created to host software projects and based on the open-source software Git; for this reason, and in view of what has been said previously about the implementations that game engines offer in terms of programming, GitHub was considered as a valid tool to measure the opensource resources available online. By doing out study for some of the game engines, data was obtained on Repositories, Code, Commits, Issues, Discussion. Furthermore, in order to assist the option for an application development of this project, the subscription plans for the same software were also evaluated.

The option consequently settled on Unity3D since it has the highest number of resources on GitHub and is free for the Personal edition featuring Core Unity real-time programming platform with Bolt visual scripting, Advanced Cloud Diagnostics, An instructional version for pupils is also available.

**Table 1 – Game engines comparison**

| | Subscription typologies | | GitHub Presence | | | | |
|---|---|---|---|---|---|---|---|
| | *License* | *Costs* | *Repositories* | *Code* | *Commits* | *Issues* | *Discussions* |
| **Unreal** | Standard | Free | 2.70E+04 | 3.00E+06 | 3.00E+06 | 1.63E+05 | 4.61E+02 |
| | Enterprise | 1500 $ ps/yr | | | | | |
| | Custom | Custom | | | | | |
| **Lumberyard** | Standard | Free | 1.45E+02 | 1.45E+02 | 5.20E+04 | 3.00E+03 | 3.00E+01 |
| **GameMaker Studio** | Free | Free | 7.78E+02 | 5.16E+05 | 2.88E+02 | 7.62E+02 | 1.80E+01 |
| | Creator | 49,99 $/yr | | | | | |
| | Indie | 99,99 $/yr | | | | | |
| | Enterprise | 799,99 $/yr | | | | | |
| **Unity3D** | Personal | Free | 2.57E+05 | 1.62E+08 | 4.12E+05 | 2.31E+05 | 1.00E+03 |
| | Plus | 399 $ ps/yr | | | | | |
| | Pro | 1800 $ ps/yr | | | | | |
| | Enterprise | custom | | | | | |
| **Cryengine** | Standard | 5% royalty | 3.19E+02 | 8.60E+04 | 1.00E+03 | 1.00E+03 | 1.30E+01 |
| **Gamebryo** | N.A. | N.A. | 2.20E+01 | 2.00E+04 | 4.04E+02 | 1.00E+03 | 1.00E+00 |
| **Hero Engine** | Starter | 99,95 $/yr | 2.19E+02 | 1.00E+06 | 3.00E+03 | 6.00E+03 | 5.30E+01 |
| | Basic | 149,95 $/yr | | | | | |
| | Standard | 299,95 $/yr | | | | | |
| | Premium | 749,95 $/yr | | | | | |
| | Professional | 599,95 $/yr | | | | | |

### 2.2.5. Examples of gamification

The majority of games have aspects such as rules, objectives, interaction, feedback, problem solving, competition, narrative, and fun (Vandercruysse et al., 2012). According to the pedagogical function that these game components have in this sector, it is conceivable to claim that not all of the elements are required to properly gamify a training activity; instead, it is useful to carefully pick those aspects that satisfy the course's training objectives. The educational benefit of game elements commonly linked with gamification is examined in the next section.

Certain characteristics of training settings can boost trainee engagement and motivation. Similar to traditional grading schemes, gaming point or experience (XP) systems reward learners for completing certain activities, assignments, or examinations. Game or XP points can provide training settings with important affordances. When a trainee reaches a specific point level, the firm may provide him or her with an additional paid day off or other incentives.

Elements of the game upon which this reasoning must rely might include:

**Badges:** Digital badges are a means to recognise trainee effort. For instance, the employee may earn a badge if they accomplish a given degree of task success or if they pay extra attention, such as by identifying ignored key aspects. These badges may be shown in a ranking list to inspire other trainees to improve or to highlight the range of badges that may be obtained.

**Leaderboards:** Leaderboards that display the distribution of point totals that trainees have collected via various training activities can be used to inspire trainees through competition. However, care must be given when designing leaderboards, as presenting all trainees in descending order of their point totals might be discouraging for trainees at the bottom. Consider employing a method in which trainees only see the two trainees directly above and below them in order to promote healthy competition without discouraging learners who are performing poorly.

In the context of providing gamification examples not solely limited to learning, training or other serious applications, a handy list of examples is now delivered:

**Duolingo** – Gamifying language learning by requiring students to perform drill-and-kill grammar and vocabulary activities in exchange for experience points and access to more challenging exercises.

**Minecraft** – A popular game that has been modified for educational settings by providing students with a sandbox to create their own virtual worlds.

**Coursera** – A platform that offers free educational classes to anybody who is interested, but implements badges and other reward systems for participants to encourage participation and retention.

**NikeFuel** – Nike introduced gamification to exercise in order to boost user engagement with the product. A major reason for this is because games encourage their audience to pay attention and participate.

**Starbucks** – "My Starbucks Rewards" aim to Customers improve their degree of loyalty based on the quantity of things they purchase in order to receive further benefits.

**Foursquare** – Foursquare is an implementation of a location-based social network, which are mobile applications that allow users to create social networks and share their position with peers. It is supposed to "transform life into a game" by awarding users with mayorships and badges for visiting actual sites, in contrast to previous products of its kind. Foursquare is aimed to influence user behaviour by incorporating digital game aspects into real-world locations. Foursquare is distinct from its rivals because its game aspects encourage users to participate in non-gaming activities, such as visiting bars and historical places, rather than standard gaming behaviours, such as object hunting and player conflict.

## 2.3. Gamification applied in AECOM

How and why should we consider the possibility of applying gamification to the AECOM industry, which encompasses architectural, engineering, construction, and operations and maintenance? Without a doubt, the setting to which we are referring is that of Industry 4.0, a never-ending process of which we are a part and in which we have the power to decide the laws of the foreseeable future.

The rapid evolution of visualisation technologies, such as virtual reality (VR), augmented reality (AR), and mixed reality (MR), has numerous consequences for the AECOM industry. These visualisation tools are facilitating new channels of communication and collaboration among stakeholders, hence facilitating the transition of AECOM. In addition, the incorporation of gamification with visualisation technologies has led to the emergence of new applications and effects, such as skills teaching, health and safety training, and behavioural investigations. These gamified applications resemble the fundamental structure of SGs (Feng et al., 2022), Figure 13.

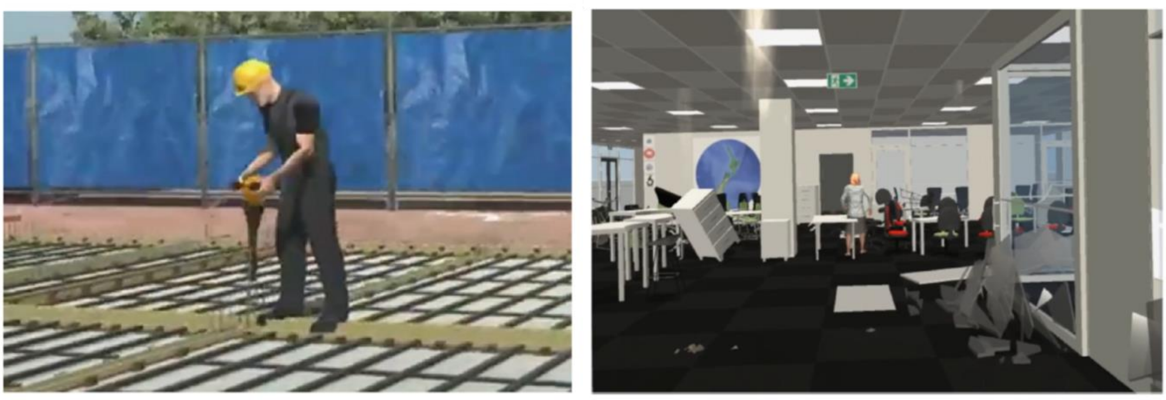

**Figure 13 – Virtual environments for AECO, from** (Feng et al., 2022)

A virtual world used for serious games is usually a regulated environment where in-world occurrences are managed by pre-set training or gaming situations (Liu et al., 2011). SGs have been characterised as video games with serious aims, such as education, training, and analysis, as opposed to simply enjoyment. Interaction between humans and computers is anticipated to have varied effects based on SGs principles. The interplay of SGs with computer simulations in diverse fields, such as education, emergency management, engineering, training, and healthcare, engages and motivates people. The similarity between these two concepts is in their game-like designs, or the application of game components and rules. Visualization applications (such as VR or AR applications) are fundamentally digital applications. When gamification is applied to them, they become SGs with sophisticated visualisation technologies, mimicking the characteristics of SGs typically seen on other forms of visualisation media (such as tablets and desktop screens).

In recent years, an increasing number of evidence, such as comparisons between SGs and traditional education methodologies in construction health and safety training and skill development, have been given. Global research has found empirical evidence that SGs are more effective than conventional training methods. (Albers et al., 1997; Lin et al., 2011). Ergonomic awareness programmes assist users in developing an understanding of the dangers of ergonomic hazards in the workplace and in acquiring the information required to safeguard their backs, necks, shoulders, hands, wrists, elbows, and knees (Albers et al., 1997).

Some of the following examples are intended to introduce the reader to the variety of possibilities this approach provides in terms of usability and applicability.

### 2.3.1. Digital heritage and tourism

The use of gamification can be applied to digital heritage and tourism, it can enhance the experience of a museum or a heritage site of different scale. (Paliokas et al., 2020) refers to small to medium real-world museum as AR application design experience. It could be used to virtually access remote or destroyed areas of the site as mean of convoy of digital 3D models; as an example, users could navigate simulations which have taken place long time ago in history Figure 14.


**Figure 14 – Physical setting and e-tracer, from** (Paliokas et al., 2020)

### 2.3.2. Artificial intelligence

Artificial Intelligence (AI) can be defined as the activity intended to provide machines instructions as to be perceived intelligent. Intelligence also implies the function to properly foresee environment situations and this aspect can be applied in AECOM as a mean to forecast construction output through Artificial Neural Network (ANN) (Nilsson, 2011); likewise, it can be used to improve decision-making in the bidding process with Machine Learning (ML) (Sonmez and Sözgen, 2017). Another application is the simulation of human behaviour in buildings providing information about occurrences while Actors are involved (Simeone and Kalay, 2012). Another very interesting application can be the predictive maintenance using Recurrent Neural Network (RNN) (Rivas et al., 2020). All those applications require a consistent knowledge of programming languages such as Pyton or C++ in order to develop useful applications disconnected from market vendors.

### 2.3.3. Hazard identification

It is broadly known that SGs are found to be suitable in hazard identification training modules (Mohd et al., 2019); some of them are based on Input-Process-Outcome (IPO) model which intend to design hazard identification specifically for construction workers leveraging on safer environments, visual training and hands-on-experience even for those situations potentially endangering (Ren et al., 2022). Evacuation training could be conducted to understand the falls of critical made decisions (Silva et al., 2013) as well as evaluation on navigation in complex and unfamiliar buildings (van Shaik et al., 2015).

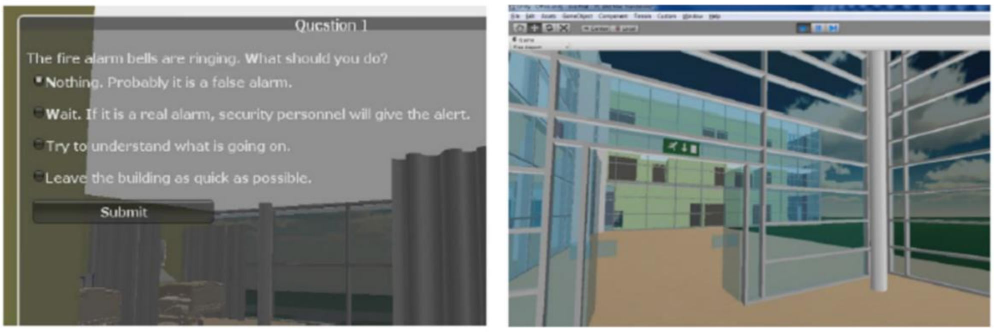


**Figure 15 – Game progression: question and ending, from** (Silva et al., 2013)

### 2.3.4. Training

The training use of the gamification is, according to the author, the most promising and the most researched one. Even if currently is the most explored it is still worth to dive in as there is no application on the Italian market concerning health and safety topic. Several examples were set by the international academics such as programs on machinery operation to instruct the safe use of construction equipment (Carozza et al., 2015). Likewise, it has been shown that hearing protection programmes stress the detrimental effects of noise on hearing and encourage the use of hearing protection equipment (Seixas et al., 2011).

First-aid programmes instruct participants on how to administer appropriate first-aid treatment in the case of accidents or unexpected sickness (Lingard, 2002). Another case is related to fall prevention programmes to instruct users in ladder usage, leading-edge work, truss setup, and scaffolding usage fall prevention procedures (Evanoff et al., 2016). Electricity safety programmes are meant to assist users in comprehending the possible dangers posed by electricity in the workplace (Zhao and Lucas, 2015). Trench safety initiatives encourage self-protection against trench collapse (Dickinson et al., 2011). Scaffolding safety programmes identify hazardous situations associated with inappropriate scaffolding usage, such as inadequate overlaps between planks (Le and Park, 2012). PPE programmes include instruction on the correct use of PPE, such as wearing welding gloves when welding (Li et al., 2012).

**Figure 16 – Possible interaction in the virtual environment, from** (Carozza et al., 2015)

## 2.4. Adoption

Unity is a game engine for several platforms created by Unity Technologies. The engine was enhanced to accommodate several platforms. The engine may be used to construct three-dimensional, two-dimensional, virtual reality, augmented reality, and other games and simulations. As it can be seen in Figure 17, Games, Digital Twins, Automotive, Transportation & Manufacturing, Film, Animation & Cinematics, Architecture, Engineering & Construction, Gambling, and Accelerate Solutions are among the solutions offered. Unity allows users to develop both 2D and 3D games and experiences, and the engine provides a core scripting API in C# with Visual Studio integration. Unity also offers JavaScript as a scripting language and MonoDevelop as an Integrated Development Environment (IDE) to those seeking an alternative to Visual Studio. (Unity, 2022a, 2022b)

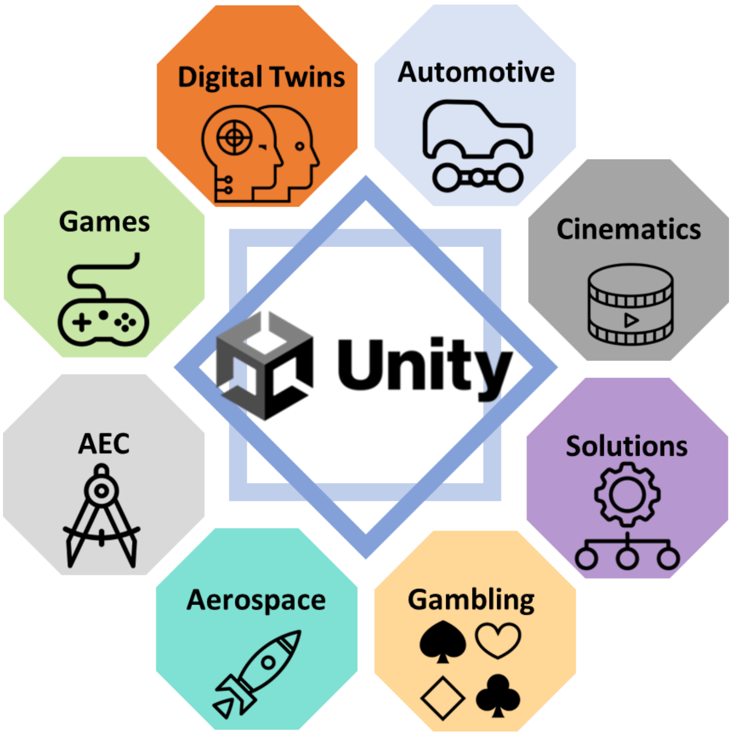


**Figure 17 – Unity solutions**

Unity 3D has a multitude of professional tools for programmers and artists. Unity offers a work environment that blends artist-friendly tools with a component-driven design to make game creation incredibly straightforward. Unity employs a prefab-centred component-based approach to game development. Using prefabs, game designers may construct objects and environments more quickly and effectively. With its advanced shaders, physics-based materials, post-processing, and high-resolution lighting systems, Unity is capable of delivering excellent visuals in all areas. Unity excels in cross-platform deployment, which is a big lure for modern developers. With compatibility for all major consoles and operating systems, Unity games may be delivered to any and all platforms (Unity, 2022c).

With Unity's editing capabilities, you can manage inputs from mouse, keyboards, and gaming controllers concurrently. There is also rather robust support for cloud-based solutions for multiplayer games, including server hosting and scalable matchmaking, making it a one-stop option for multiplier experiences. In more recent versions of Unity, teamwork has been significantly enhanced. Built-in version control and cloud integration could facilitate collaboration.(Unity, 2022d)

## 2.5. Implementing Unity

Beyond the more obvious modes, such as 3D design, it is possible to acquire and import digital assets that already exist in the digital world, and therefore also within Unity (or other game engines). It is feasible to conduct surveys in this instance using laser scanners, unmanned aerial vehicles (UAVs), or 360-degree cameras. Figure 18, adapted from (Feng et al., 2022), demonstrates that although the usage of these tools have been extensively addressed in the literature, there is no automation to assist the conversion of this information. For instance, if we consider the LiDAR (Light Detection and Ranging) survey, we are well aware of how accurate, detailed, and desirable it can be (assuming we have a free field and do not have to deal with obstructions inside or objects of street furniture outside such as trees or lampposts), but the accessibility and correct use of this information for the purpose we are discussing is not widespread. Automated conversion from a point cloud to an equally exact solid model is still a subject of research and development due to its complexity.

The practise of exporting geometry to virtual game environments in a manner that is relatively simple and straightforward has been well-established, according to an analysis of the current state of the art (Bille et al., 2014). Although certain expedients can be taken to improve the transfer of geometric data, even a simple and conventional approach yields good results with minimal effort (Vincke et al., 2019). The current obstacle is to be able to incorporate, during the export phase of a BIM project, both geometries with a topology (polygonal subdivision of the mesh) consistent with the requirements of virtual usability as well as the preservation and transposition of the information and metadata in the model, so that it can be used during the simulation phase. This is a challenge because it is currently difficult to do both of these things. This is exactly the component that is lacking in the workflows that are currently being implemented by vendors. We are now capable of exporting and making a 3D model interactive with just a few clicks; this includes photorealistic three-dimensional assets, simulative materials, and realistic lighting; but, we are not currently in a position to provide comparable benefits in terms of data.

One of the uses that may be possible for the sensing technologies that are used in virtual simulation settings is integration with the emergency training methods used by the police, fire department (Engelbrecht et al., 2019), and Red Cross. It is vital to have a comprehensive understanding of the environmental conditions in which emergency response resources will operate in order to be able to calibrate and coordinate those resources effectively. Stressful decision-making environments are fundamental to be understood before taking action, (Clifford et al., 2019). Small sensor equipment could be used to map and detect the environment in complicated settings, such as sites that are difficult to access, by inserting small cameras via holes, which are easier to produce than openings. This would allow for the mapping and detection of the environment. It is possible to select the most appropriate method and reproduce its operations while operational teams open and secure passages if an assessment of the intervention region is performed first. This would make it possible. When evaluating restricted areas, virtual simulations, as opposed to video inspections, would be preferable to the existing technique of evaluation, which uses video inspections.

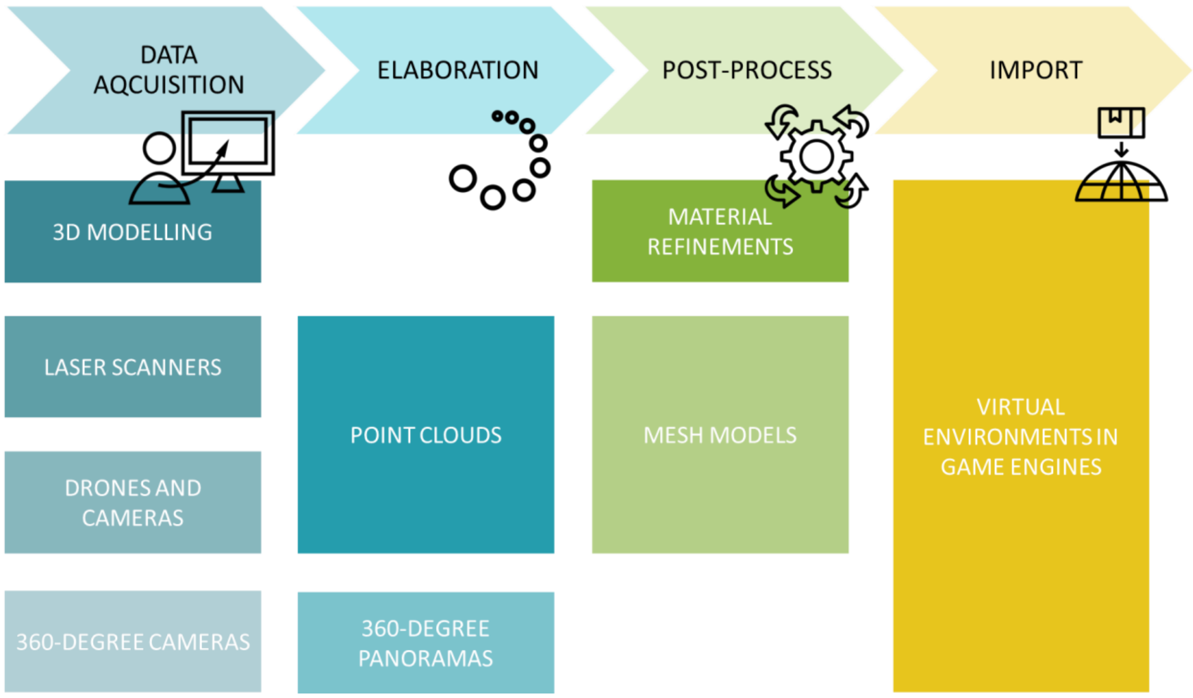


**Figure 18 – From virtual environments to game engines**

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# 3. IMPLEMENTATION OPPORTUNITIES

This section provides an introduction to a framework that was developed to be used as a reference for further applications of training to expose the possible benefits and focusing points for real-world challenges that arise during the execution phase of projects. A training framework for Appointed Work Supervisor (AWS) will be presented using the most appropriate literature references applied to the long-term experience developed on field with the goal of suggesting a valid, applicable, and effective workflow detecting barriers of implementing such applications.

The purpose of the case study that is described in this chapter is to demonstrate a possible application of training that is related to construction practise. In particular, it is interesting to examine how certain new obligations introduced by the April update to the Consolidated Safety Act, Legislative Decree 81/2008, relate to the subject of this thesis. It is essential to identify to whom this work refers and how it will serve to the scope presented. Following the implementation of the most recent set of regulatory changes, this issue was chosen because the AWS now has extra tasks to fulfil. To put it more succinctly, the ASS will take on the role of the absolute protagonist in the new Safety Management Plan (SMP).

## 3.1. Legislative background

The work on the periphery of the supervisor's responsibilities started with a comparative reading of the current Safety Act and an earlier version that dated back to January 2020 before the breakout of the SARS-CoV-2 pandemic. By first examining the similarities and differences between the contents of Articles 18, 19, 20, 36, and 37. The primary things that come to light are the new responsibilities that will be assumed by the AWS, as well as the training requirements. It is now the responsibility of both the manager and the employer to determine who will serve as the AWS for the actions related to supervision that are detailed in the following pages. In the day-to-day operations of the construction site, this person takes on new responsibilities. Actually, in accordance with the provisions of Article 19, it is the duty of the supervisor to temporarily halt the activity in the event that he identifies potentially hazardous conditions while performing his supervisory duties. In addition, Article 37(5), which elucidates the goals of the training, has had its description expanded to include more specifics. It consists of a practical test for the correct and safe use of equipment, machines, plants, substances, and gadgets, including personal protective equipment (PPE); it also consists of applied instruction for safe working methods. The activities of training that are practical in nature, are carried out and are required to be recorded in a certain register, which must also be maintained in a computerised format.

### 3.1.1. Obligations of the employer and manager

Among the various requirements relating to the updating of Legislative Decree no.81/2008, which will not be discussed in this text, there is a relevant shift in Article 18 as it relates to the employer and the manager. Those two pivotal roles are required to identify a AWS in a number that is coherent with the duties required and for the performance of the supervisory activities referred to in Article 19 relating to the obligations of the AWS.

It is specified that according to the new acquired roles it is possible that the owed remuneration to the supervisor for carrying out the duties that were mentioned in the previous line will be established by collective labour contracts and agreements. Furthermore, as a safeguard measure to the prominent role of the AWS, the regulation specifies that it is not permissible for the supervisor to experience any kind of disadvantage as a direct result of the actions that they are responsible for. Those enhanced provisions were made subject as to the alternative punishment of serving time in jail in addition to paying a fine.

### 3.1.2. Obligations of the Appointed Work Supervisor

Since Article 19 specifies the obligations of the supervisor, it is important to devote a few more words to the major topic of this job, which justifies and elaborates on the complexity and significance of the position to which the designated employee is called.

In the performance of his duties, the AWS is responsible for supervising and monitoring the compliance of individual workers with their legal requirements, as well as the company's health and safety regulations and the usage of collective and individual protective measures. Examining the first paragraph alone immediately reveals the complexity of the figure being analysed; furthermore, it is always his obligation, care, and responsibility to intervene to change the non-compliant behaviour of his subordinate workers by providing the necessary safety instructions, demonstrating the need for training and instruction in the recognition of incorrect behaviour. His work of vigilance is not merely theoretical, but can be supported by tangible measures, such as informing his immediate supervisors of the worker's activities and interrupting his work.

His actions consist of commitments to others and to himself. It is his responsibility to adjust behaviour that does not conform to the Safety Management Plan (SMP) and Safety Coordination Plan for execution phase (SCP-e) and to provide safety advice. It is always his responsibility to ensure that only authorised workers have access to work areas; it is his responsibility to demand compliance with safety measures. In addition, he must monitor the ongoing operations so that he can tell workers who are at risk of the danger they face, and he must avoid from requesting the same people to perform dangerous tasks unless properly warranted. In order to fulfil all of these complex responsibilities, Article 19 requires the AWS to provide training courses as described in Article 37.

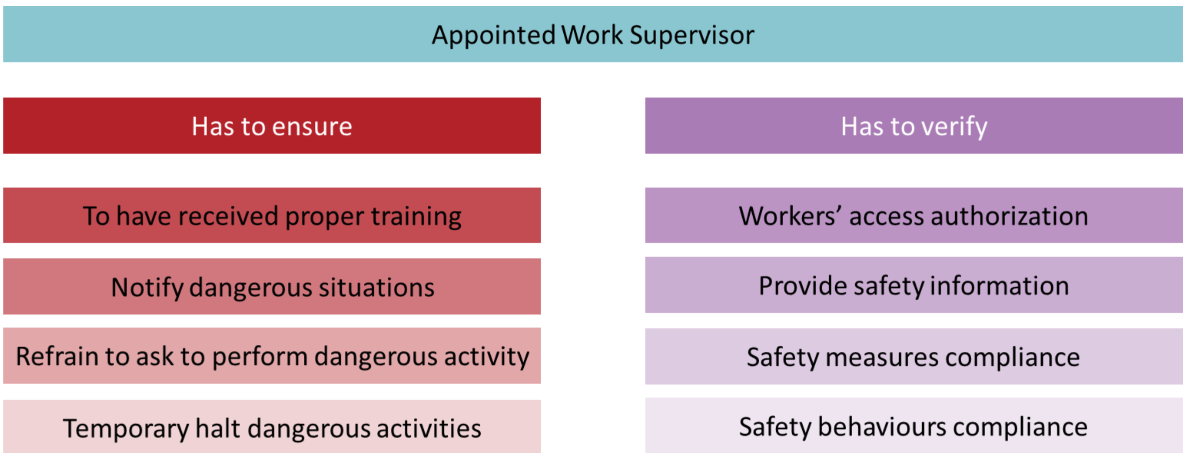



**Figure 19 – Appointed Work Supervisor skillset**

### 3.1.3. Obligations of the employee

Third, in no particular sequence, is Article 20 regarding the obligations of workers. In light of the general requirement that every worker must take care of his or her own health and safety, as well as that of others present in the workplace, on whom the effects of his or her actions or omissions fall, the worker is required to observe the provisions and instructions given by the employer, managers, and ultimately the AWS, the most influential of the aforementioned, to whom he or she can direct questions.

## 3.2. From regulation to training through CoSIM

On the applicability of these concepts introduced by the legislative update, the research then investigated the functionalities available on the market identifying as a promising opportunity the immersive Virtual Reality (VRi). Its appealing and innovative application to ergotechnical modelling surely could engage the trainee; furthermore, it could be applied as a tool for both the client's and the construction company's point of view.

Regarding its application throughout the building lifecycle some considerations have emerged in relation to the health and safety on site. It is worth to briefly mention the Construction Site Information Management (CoSIM). This concept roots in Italy where refers as a possible BIM use aiming to improve and detail the constructability pre-design and design. Leaving it to the reader to investigate further, we refer to the following sources to retrieve its structure and scope (Trani et al., 2015); other applications and case studies are in (Trani et al., 2018; Trani and Cassano, 2018).

### 3.2.1. Design stage

At the design stage, Construction Site Information Management (CoSIM) is characterised by an eminently performance-based approach intended to assess the overall ergotechnical behavioural aspects of the site system; For this reason, the availability of a specific BIM authoring software (such as CerTus HS-BIM), once fitted with an extensive library of fixtures and equipment is considered to be a good starting point. Moreover, if the families would be appropriately parameterised in relation to their possible operational configurations, it could enhance the uses and boost the applicative case studies. It could give the possibility of parcelling out the intervention model into construction phases, thus allowing a better understanding of the activities and related risks. As a more effective way of communicating, it is possible to animate with a real time rendering the previously defined construction site elements, this is considered more than sufficient for the building production, health and safety analyses of workers today (and reasonably in the future) required by law. All this considered, at this stage of the process, it is deemed unnecessary to equip the ergotechnical designer (i.e. the Safety Coordinator for the Design) with a VRi tool to serve his activity (i.e. the safety and coordination plan).

In the current and medium-term historical moment, the software described, could be paired with sufficiently adequate monitors (in terms of size and resolution) to be connected to a high-performance machine; it represents in author’s opinion, a hardware-software endowment that is more than sufficient and, above all, economically sustainable for the transition to digital ergotechnical design. For a long-term view it could be interesting to investigate and bridging existing isolated applications to the CoSIM design and coordination.

### 3.2.2. Execution phase

Subsequent and likewise to the design phase, comes the execution phase. At this stage, it has been posed the problem of the viability and efficiency of VRi methods applied to ergotechnical design both from the point of view of the client (i.e., the Safety Coordinator for Execution) and of the contractor and/or executor.

At this stage, the *consecutio temporum* travels in reverse, the responsability of ergotechnical planning (safety planning) being borne by the contracting company and the burden of control being borne by the commissioning structure. The availability of a CoSIM model issued at the tender stage greatly simplifies the preparation of production and safety plans by companies. In fact, it is possible to represent to the workers and supervisors, on tables or site monitors, the fittings and equipment actually (and no longer only plausibly) adopted in a given phase of the work, as well as the exact location of the workers in a given job, highlighting useful information for the achievement of quality and safety in their work. This consideration is expected to be more readily realisable and consequently relevant in the near future.

As CoSIM at the production stage is necessarily produced on-the-go, it can be said that the responsibility for the design and management of a workplace and its associated workstations nevertheless implies the need for a direct prior, on-site assessment of its environmental, boundary, access, usability and equipment conditions by the person in charge. As these boundary conditions are extremely changeable over time in the context of a temporary or mobile construction sites, a preventive inspection activity is therefore considered essential, which cannot be replaced by a “virtual tour” at a “distance” (off-site), especially in view of the aims of protecting the health and safety of workers in this activity. In any case, it is undeniable that the availability of a model that can be navigated/visited with VRi tools allows the company’s ergotechnical designer to refine it at the desk with what is found in the field, using software such as the one introduced before and discussed below.

### 3.2.3. On-site training

In this way, the production of safety operating procedures (compulsory at the current state of the law) accompanied by sheets, digital views, or real time renderings deduced from the ergotechnical model at the production stage, facilitates their approval (i.e. the judgement of suitability of the SMP) by the commissioning structure, given their extreme usefulness in terms of informing the workers, thus fluidifying the progress of a construction site.

However, it is not evident the usefulness of a VRi tool for the safety coordinator for execution, since it remains essential, in the current state of jurisprudence, his preventive activity of on-site inspection aimed at the subsequent assessment of the suitability of the procedures proposed by the contractors that have to be approved.

#### 3.2.3.1. Extending the training to other workers

Recalling the well-known distinction between information (on-site, at the worksite) and training (off-site, at the task), assuming the ordinary logistical organisation of a worksite, even if advanced, it is considered that the availability of VRi navigation equipment of an ergotechnical model is not feasible, at least in the medium term, in terms of efficiency, as it is extremely complex to inform an entire working team on the safety procedures that have to be implemented in the different worksite phases.

On the other hand, the considerable usefulness of gathering the same team around a ‘generously sized’ site monitor, piloting to their advantage a virtual ‘tour’ of the places and workstations that will be assigned to them and the operations they will have to perform with the equipment identifiable in the model. The same model, moreover, may be navigable again, if necessary, by individuals or their supervisors by means of portable devices, thus implementing an information ‘redundancy’ that can only benefit the quality of the work performed and the safety of those who perform it.

### 3.2.4. Off-site training

Regarding the off-site training and instruction for workers, the use of VRi systems leads to different considerations. It has been presented in 2.2.2 Elements of gamification, that the outcomes related to a traditional classroom training are extremely less effective as they depend on a multiplicity of critical factors. Those are related to the ability of the teachers to grasp learners’ attention and also to the variety of addressed topics which are often repeated being unfortunately also quite detached from the daily experienced reality of the workers. In the case of training, the immersive virtual reality experience is undoubtedly very engaging and destined to remain in the learner’s imagination for a longer time; let us consider the event of virtually falling from a ten-metre high scaffolding due to the lack of a guardrail, that situation will definitely constitute a memory remaining extremely alive in the subconscious thus leading to the unquestionably help to identify such a danger in the reality of the construction site.

It is therefore considered extremely useful to implement such a training methodology, developing specific storyboards in an immersive virtual environment to be experienced first-hand by workers in training. Application examples are not lacking, but it is considered necessary to proceed with a structured approach, progressively developing specific paths for the different tasks present on a construction site. The objective to be set, therefore, for a company with an organised site, is the identification of a ‘training room’ (which in the most structured cases could also be a Cave automatic virtual environment) which, far from being a classroom, is instead a space equipped with VRi hardware and software dedicated to training.

To exemplify, it is believed that a three-hour classroom training for a group of nine workers can be replaced, with incomparable effectiveness, by twenty minutes of immersive virtual reality appropriately designed for each of them, thus gaining the company more trained workers and reducing the ‘loss of productivity’ often attributed by construction companies to the time spent training their workers.

The training of workers in specific tasks or in the use of particular facilities, equipment or machinery is a different matter. In the current state of the art, in fact, it is provided that the training is carried out by an experienced person and at the workplace. The training consists of a practical test, for the correct and safe use of equipment, machinery, plants, substances, devices, including personal protective equipment; the training also consists of an applied exercise, for safe working procedures' (Legislative Decree No. 81/2008, Article 37). Without prevent the unavoidable need for the worker to have a hands-on experience on the specific equipment (aimed to have him familiarise with it in a real working environment) some sort of ergotechnical modelling based on simulation cannot be excluded, indeed it is desirable. Experiences of this type already exist for some tower cranes and earth-moving machines. Analogously, it is considered appropriate to create storyboards containing dangerous situations, even the occurrence of damaging events (generated and suffered) in order to imprint unforgettable experiences in the worker, to be recalled in the daily use of the equipment.

# 4. TRAINING FRAMEWORK AS CASE STUDY

## 4.1. Methodology

Having in mind the scope of application of this process and having highlighted the reasons why the development of this topic is necessary, two macro-areas were identified in the course of the maturation of the reasoning. There are two macro-areas identified to serve this purpose. The contents of the swim lanes contain information on the development of the application in natural language. The first relates to the logic of the game and is distinguished for containing within it an event, a criticality and a required action. The other macro-area pertains to the design of the game application, this in fact being a more conceptual grouping being identified by a description and collation of learning objectives. The relationships between the playful macro-area and the design macro-area are at the level of event/description and required action/learning objective. To support this explanation, please refer to Figure 20. In the figure shown there are the two swim lanes of game and design that schematise the relationships between the above parts. Within the game application, each event is characterised by a description of the context useful for representing to the learner or programmer the points on which attention must be directed; each event is developed in such a way as to trigger cause or highlight a criticality.

Figure 21 provides a concrete illustration of the relationship between the design and the development of the game and its components. The components of the diagram are, in logical order: (1) description, (2) event, (3) criticality, (4) necessary action, and (5) learning objective. The purpose of the following paragraphs is to provide better understanding regarding the integrative contribution that this method facilitates in relation to Figure 23.

### 4.1.1. Description

The initial phase in the design industry is description. As stated previously, this is a normal language description and not a machine language description. The purpose of the description is to provide information to the developer and highlight, in connection to the process, the events that must be supported by the application. The objective is to offer indicators that enable the programmer to trigger the scene and level, hence initiating the event. The relationship between the description and the events is 1 to 1. For each event, a description must be provided to assist computer production work by elucidating the manner in which the occurrences are to unfold.

### 4.1.2. Event

The second part of the process translates the trigger in the game's description and references to the macro region of the game. This phase denotes the start of each scenario and level that will be encountered within the programme. The trainee, the AWS, sees many characters appear and then, in accordance with the functions that are expected of them, those characters immediately begin engaging in the activities that are the primary focus of the trainee's attention. An exciting opportunity lies in the possibility that events might be linked to the activities that are being systematised in the ergotechnical project. This 4D program, the GANNT schedule, can be developed with finer precision, therefore this possibility represents a win-win situation. The events have been described and developed based on years of professional skill due to the difficulties of basing this diagram on a real time-schedule.

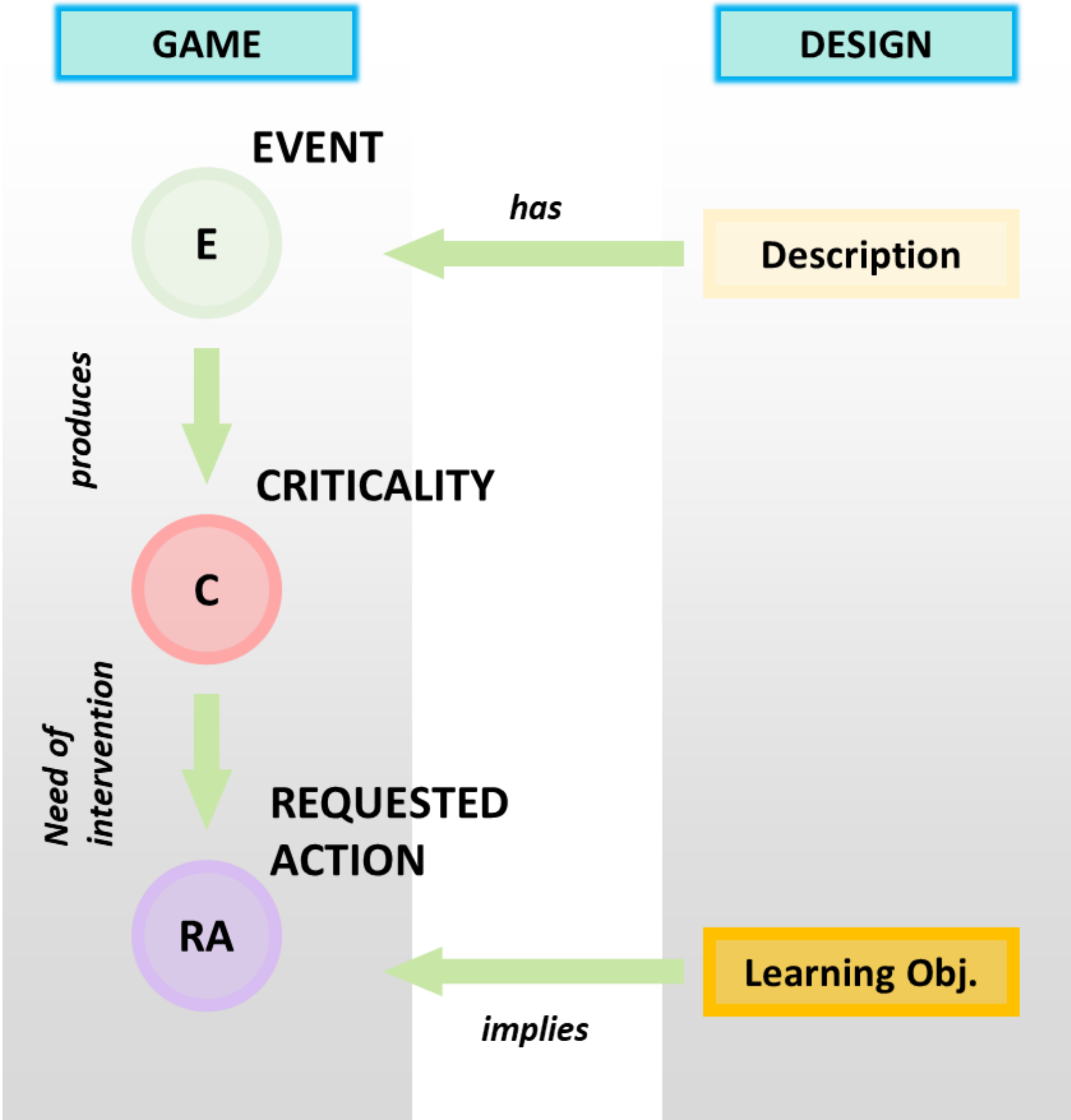



**Figure 20 – Game/Design swim lanes**

#### 4.1.3. Criticality

The most pertinent aspect of the procedure outlined here is the effective translation of the event's criticality. This section must be created with great care, as it is the linchpin of the success of the subsequent phase's response. The beginning event must be able to elicit the anticipated sensation of criticality so that it may be calibrated against the expected response in order to meet the learning aim. Criticality is developed with unfavourable on-site behaviours, such as the occupation of an excavator's buffer zone, rather than the execution of specific activities by non-expert worker or even (and probably more serious) the absence of control over personnel. These are only a few instances of the key challenges that the legislative order 81/2008 tries to disfavour.

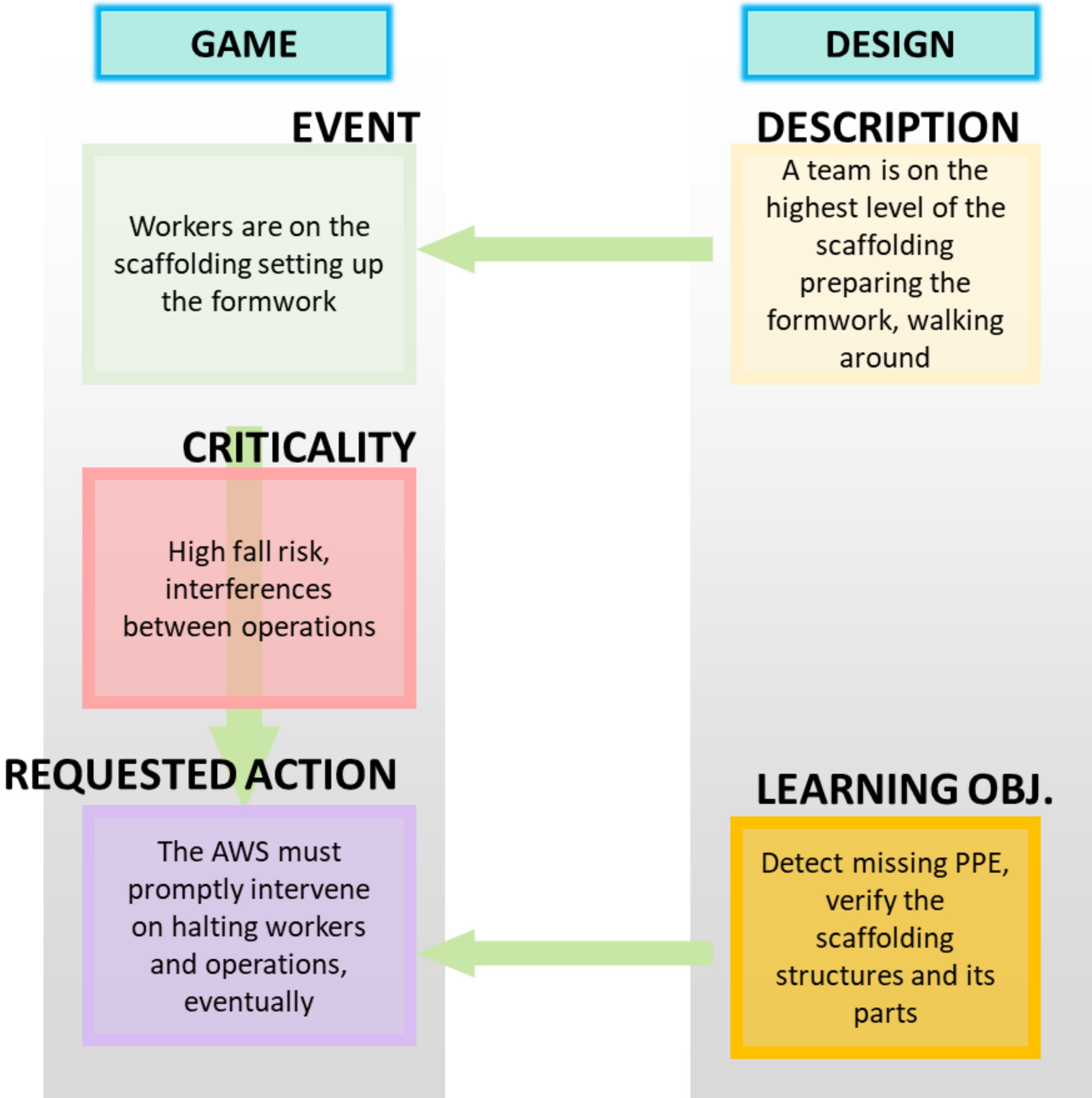



**Figure 21 – Game/Design Example**

#### 4.1.4. Requested action

The required action is the fourth phase of this scheme pertaining to the game production stack. This phase involves the randomness of the learner's response, so it is only possible to identify the most pertinent action. If successful, it is during this phase that the necessary procedures to be maintained on-site are learned. This phase is the design's synthesis, which is centred on the ability to make the response acceptable and consistent with the learning objective, as detailed below.

#### 4.1.5. Learning objective

The final phase, the fifth, consists of defining the learning objective, which is designed to highlight what you want the learner to demonstrate. This section again pertains to the design phase and not the construction of the application game, since it is derived from the comprehension and, consequently, synthesis of the regulations pertaining to worker health and safety. This phase works hand-in-hand with the required action phase, as it is based on what is described here that one must consider the learner's recognition and scoring for the activity accomplished. One could conceive of a scenario in which there is not just a net score but also an automatic and discrete evaluation that allows for nuanced scoring. Capable of recognising not only possible optimally coupled activities, but also acts that, while not exactly accurate, have a decent degree of success or at least don't completely fail.

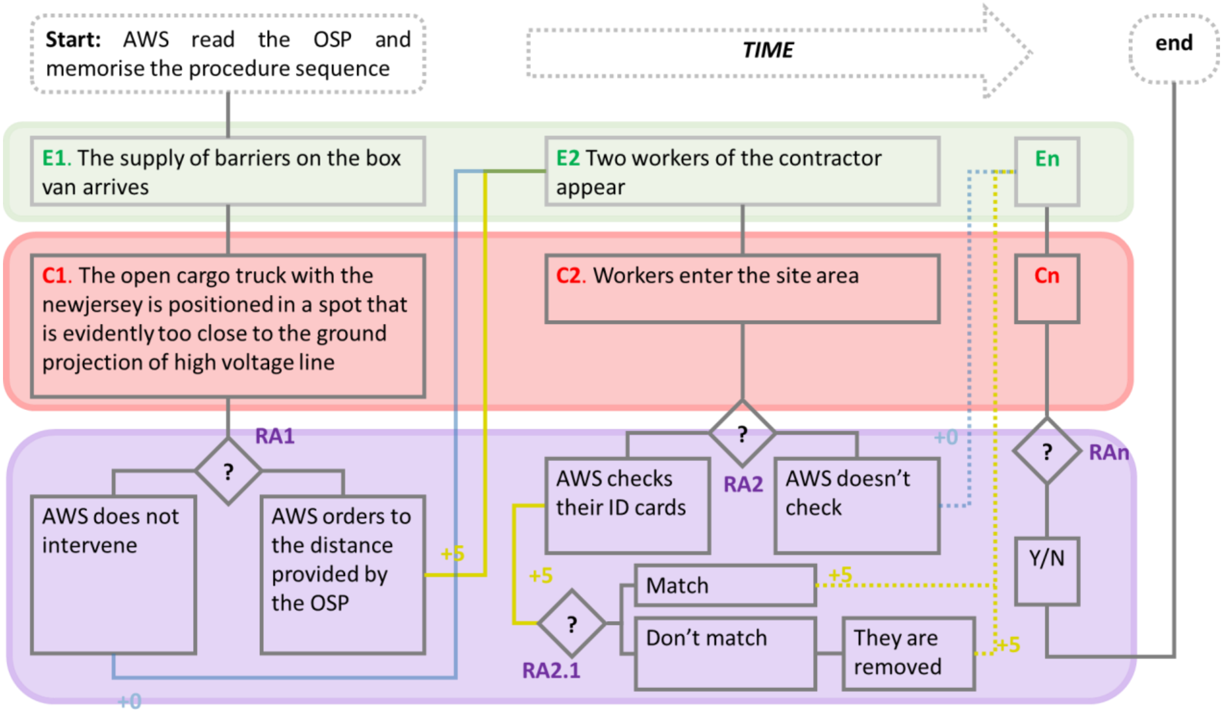



**Figure 22 – Game logic workflow**

## 4.2. Gamification process

To implement our methodology, it has been conducted a literature review about the existing gamifying processes, the author considers that the most accurate and applicable to our case is Morschheuser. According to (Morschheuser et al., 2017) there are 7 phases to be undertaken to develop a gamified application. Those phases are: (1) Project preparation, (2) Analysis, (3) Ideation, (4) Design, (5) Implementation, (6) Evaluation and lastly (7) Monitoring. The following paragraphs are meant to elaborate those and provide a reference with our case study. For the whole workflow it is possible to refer to Figure 23 taken from (Morschheuser et al., 2017). In this section describing the workflow, we wish to make clear to whom this thesis effort is directed.

The development of such an advanced training application is mostly applicable to general contractors and contractors, excluding subcontractors. The proposed training product has complete applicability in formations where the Appointed Work Supervisor must oversee many interfering jobs (both geographically and temporally), thereby rejecting the instance of a subcontractor assigned to conduct a single work as a specialist. Therefore, the application may be developed internally by the work group or by external experts, choosing for a custom solution rather than a platform-based one.

### 4.2.1. Project preparation

In the planning phase of a project, Morschheuser asserts that objectives should be used to guide and assist expectation management. The information gleaned from the literature research and the interviews performed for the scope of their work suggests that the primary objective of this phase is to define the gamification project's goals. Definition, prioritisation, and justification of project objects are therefore recommended. In our situation, it was determined that the training is intended to help AWS comply with the existing regulation. Regarding the building of a ranking that can be used to tally the scores earned throughout training, a reward-based strategy rather than a punitive one was selected; the concept is to assign a set score for each requested activity and add each positive result to the previous one. Thus, the learner will not be deterred from studying, even if he makes mistakes, and will be able to compete with himself and his peers in order to better his score.

### 4.2.2. Analysis

Proceeding to the analysis of the context and users, it is acceptable to assume that a thorough comprehension of the target audience and the characteristics of the system to be gamified are crucial to the design of effective gamified approaches. The majority of the reviewed literature on the design of gamification has placed great focus on understanding the users but has generally ignored the significance of the underlying system being gamified. In contrast to the papers examined by Morschheuser, this study focuses primarily on the research of the gamification system, presenting questions and providing answers regarding the most suitable systems for development. The context analysis involves identifying and comprehending the situation in which gamification should be implemented. In addition, they determined that the definition of success measures should occur during this phase. The user analysis focuses on the description and characterization of target groups, including the assessment of user needs, motivations, and current system behaviour. A designer must determine the granularity of the user analysis and segmentation based on the situation.

### 4.2.3. Ideation

During the third phase of the realisation of a playful educational application, consideration must be given to the conception and creative process in order to develop a thorough list of ideas. This is necessary in order to realise the full potential of the application. The author of this study agrees with the findings and conclusions reached by his fellow researchers regarding the informal and collaborative approach that is typical of brainstorming.

Repeated brainstorming sessions give the working group (which, in this case, is limited in terms of the number of participants) the opportunity to collect a large number of ideas that will subsequently be validated and aggregated in order to form the core that will satisfy the requirements of the users (AWS). As opposed to a dull review of the technology or gameful components, the purpose of this exercise is to place a larger emphasis on the learner's active engagement.

### 4.2.4. Building Information Modelling

The creation of prototypes constitutes the fourth phase of the development process. The need that surfaced from the interviews that were conducted by (Morschheuser et al., 2017) is widely shared in the sense that it is recommended that rapid production of prototypes in any format be carried out in order to iteratively test the ideas that were generated in paragraph 4.2.3 Ideation even if those prototypes take the form of sketches or wireframes. Moreover, this recommendation is widely shared in the sense that it is widely accepted. In order for the work to advance and for the product to be improved, it is necessary to provide ongoing feedback and to make adjustments, as shown in the Figure 8 – Training workflow. Because no resources other than direct experimentation were found for the validation of the playful training design idea, one must not lose sight of the fact that the primary objective is to develop an application that is not solely appropriate in terms of design but also in terms of social outcome. The prototype model is also tested from the point of view of information and the ability to communicate and perceive it.

### 4.2.5. Implementation of Building Information Model

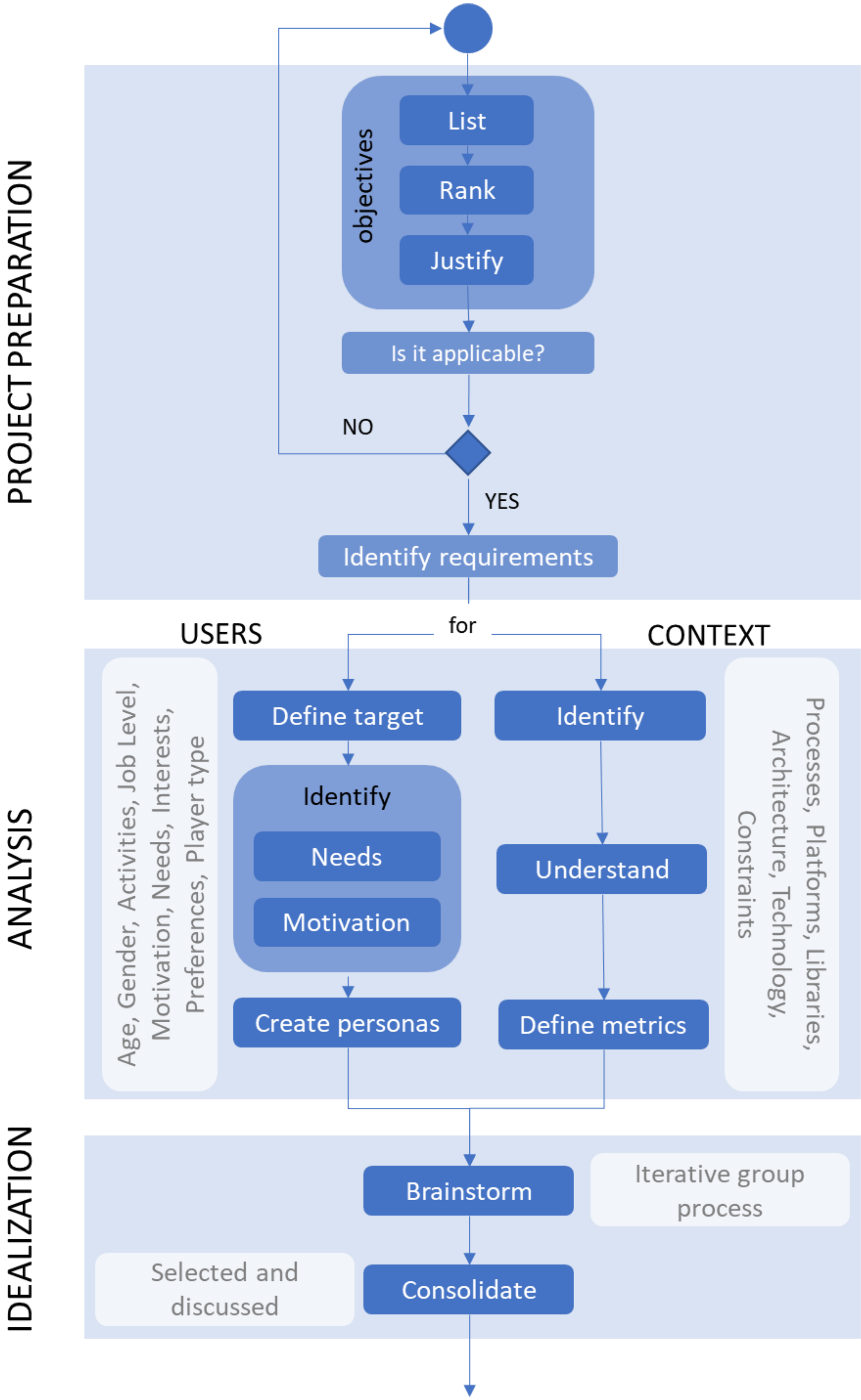
The fifth phase entails the realisation of the project's concept, as a result of the preceding phases. In reality, this phase shares many characteristics with the previous phase of prototype design, and one may thus wish to treat it as a single phase. The primary distinction is in the fact that a crucial decision regarding the future development of the application is taken during this phase. In practice, it is a matter of determining whether the gamified application will be built in-house (by a specific team) as opposed to relying on a team from outside the established working group and outsourcing the task. Adapting the project concept to current gamification platforms is a last option that may be selected at this point. In our case, we propose the development of the storyboard through the Certus HS-BIM application, which, despite not being designed for the specific development of this product, is in fact proposed as the only platform capable of implementing gameful features (such as animated characters) that, recalling the idea of fiction and the representation of virtual reality, could, with the necessary implementations, represent a first platform integrated with the BIM process, having the potential to revolutionise the way in which storyboards are developed.

### 4.2.6. Evaluation

The sixth phase, as implied by its name, involves product review. The objective is to determine whether or not the creation of the gamified solution meets the desired goals. However, the question arises as to how the anticipated goals might be deemed to have been achieved. Various approaches are given based on both qualitative and quantitative considerations; however, based on interviews performed by Morschheuser, direct observation of the participants may be the most effective method for collecting feedback. It has been discovered that participants in these activities sometimes have difficulties verbalising their experiences; therefore, it is possible to combine both data collection methods, i.e. monitoring participants and collecting feedback at the conclusion of the activity.

### 4.2.7. Monitoring

The final step in the creation of this gamified application is monitoring. Contrary to how one might conventionally interpret the creation of this product, it is not a straightforward piece of software with a distinct beginning and end. It is recommended to conclude this process with the monitoring phase, as it is an iterative and time-constrained procedure that allows the developers to continue to improve the product while also verifying the actual achievement of the desired outcomes.


PROJECT PREPARATION
objectives
List
Rank
Justify
Is it applicable?
NO
YES
Identify requirements
for
USERS
CONTEXT
ANALYSIS
Age, Gender, Activities, Job Level, Motivation, Needs, Interests, Preferences, Player type
Define target
Identify
Needs
Motivation
Create personas
Identify
Understand
Define metrics
Processes, Platforms, Libraries, Architecture, Technology, Constraints
IDEALIZATION
Brainstorm
Iterative group process
Selected and discussed
Consolidate

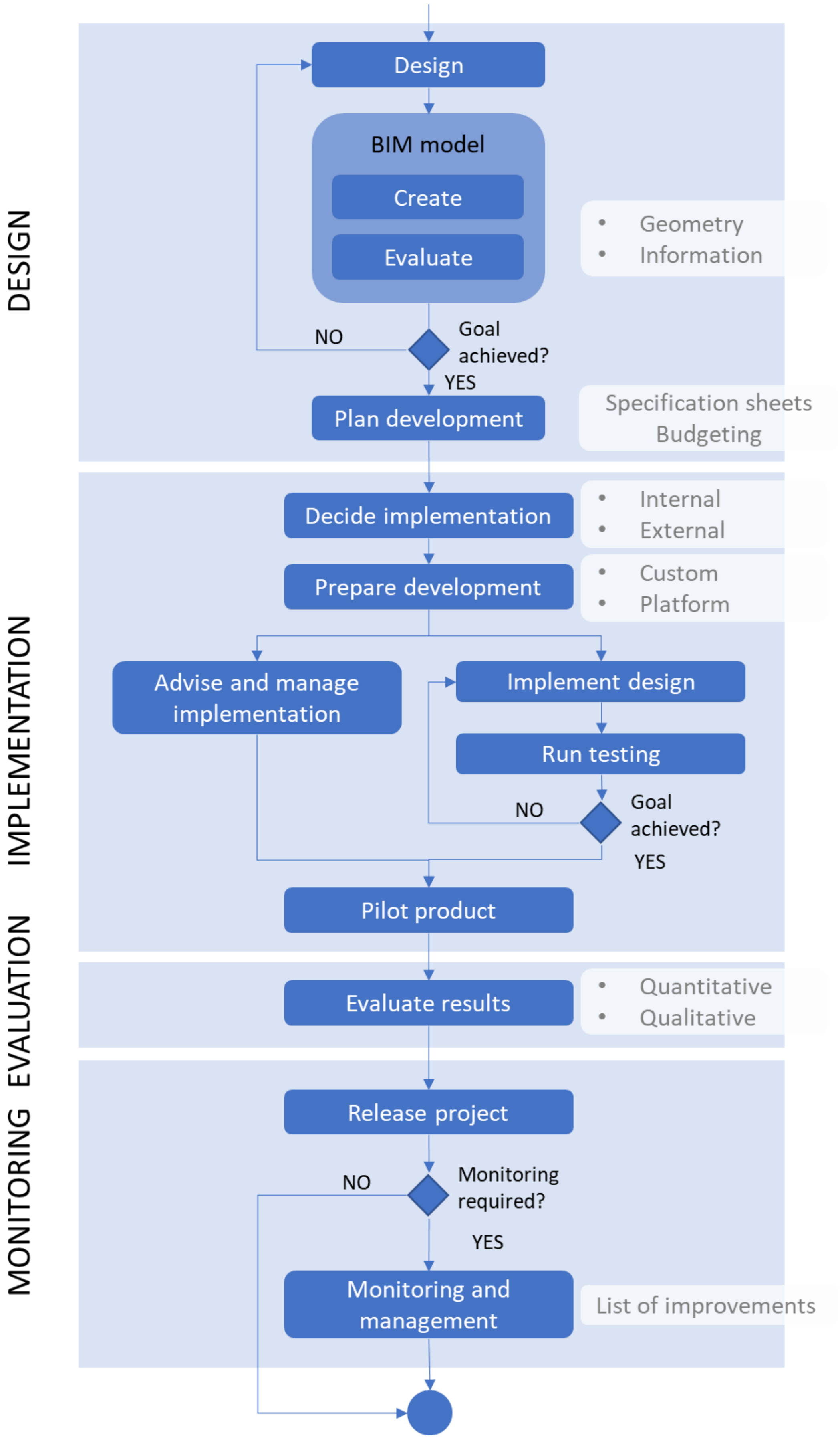



**Figure 23 –From design to deploy of gamified application**

### 4.3. Certus HS-BIM

In light of the strategy that was laid out in the paragraphs that came before this one, it was decided that it would be appropriate for the present work to concentrate on developing a commercial solution that could be seen as a natural extension of the BIM methodology. This decision came after considering whether or not it would be acceptable.

This case study is organised as an exercise for analysing the current limitations and defining possible future directions that take into account other market-based solutions; taking into account the fact that it is aware of the innovative nature that gamification brings to the AECOM industry and the consequent immaturity of the tools that are currently available. The author aims at incorporating ergotechnical design into the flow of information, he thinks that it is possible to arrive at an application that may also be used for educational and instructional purposes. This is the objective that it is intended to accomplish by gazing into the future, which, one can only hope, will not be too far away.

ACCA software is an Irpinian based company, a leader in Italy in the development and sale of software for construction professionals. ACCA holds 19 certificates that are connected to the ISO 16739 Industry Foundation Classes (IFC) standard for data sharing in the construction and facilities management industries as it can be seen in Figure 24 taken from (buildingSMART, 2022a). All certifications are associated with the 2x3 schema and cover the MVD Coordination View 2.0 for architecture, structures, and MEP; these certifications have been accessible for their products since 2015. This is a concrete example of how this softwarehouse complies with buildingSMART International's request that, in order for the market to derive the maximum benefit from IFC, there must be a robust implementation in the software that is available to users in the respective regions and markets. This is a requirement that has been met by this softwarehouse as buildingSMART International provides a platform for certification as well as a mechanism for continual certification for applications that use IFC2x3 Coordination View 2.0 and IFC4 Reference View 1.2.

| Vendor | Product | Schema | Exchange Requirement | Import / Export | Status | Started | Completed | Report (link) |
|---|---|---|---|---|---|---|---|---|
| ACCA Software S.p.A | Edificus MEP | IFC 2x3 | CV2.0-MEP | Export | Finished | 2019-04-12 | 2022-01-24 | https://ifc2x3.b-cert.org /ords/ifc/certification /getCertificationReport/923 |
| ACCA Software S.p.A | CerTus-HSBIM | IFC 2x3 | CV 2.0 | Import | Finished | 2018-04-10 | 2019-06-25 | https://ifc2x3.b-cert.org /ords/ifc/certification /getCertificationReport/865 |
| ACCA Software S.p.A | Edificus MEP | IFC 2x3 | CV 2.0 | Import | Finished | 2019-04-12 | 2019-06-25 | https://ifc2x3.b-cert.org /ords/ifc/certification /getCertificationReport/867 |
| ACCA Software S.p.A | Solarius-PV | IFC 2x3 | CV 2.0 | Import | Finished | 2018-04-10 | 2019-06-25 | https://ifc2x3.b-cert.org /ords/ifc/certification /getCertificationReport/866 |
| ACCA Software S.p.A | usBIM.code | IFC 2x3 | CV 2.0 | Import | Finished | 2017-09-29 | 2019-06-25 | https://ifc2x3.b-cert.org /ords/ifc/certification /getCertificationReport/863 |
| ACCA Software S.p.A | usBIM.editor | IFC 2x3 | CV 2.0 | Import | Finished | 2019-04-12 | 2019-06-25 | https://ifc2x3.b-cert.org /ords/ifc/certification /getCertificationReport/864 |

**Figure 24 – IFC Certified Software**

After performing a market analysis, it was determined that no other programme could develop the topic of site management in such a detailed and particular manner as this software. When using this product, a variety of objects and models relating to the construction site become apparent. These objects and models include a variety of construction site machinery, equipment, and construction site vehicles that can be easily transported within the working environment and help to improve both the virtual representation of the real environment and to bring more specific information relating to the distinct use that health and safety represents in terms of BIM.

Similar to other many authoring software, Certus-HSBIM is compatible with several additional file types. In this instance, it may import a large variety of file formats, allowing the ergotechnical designer to develop, parameterize, and model numerous families. The figure below depicts some of the families already existing in the software and accessible through their web repository. Figure 25 juxtaposes a few of the functioning machines with the interface that allows the designer to import data, so illustrating the path that may be taken to import model files processed on different tools.

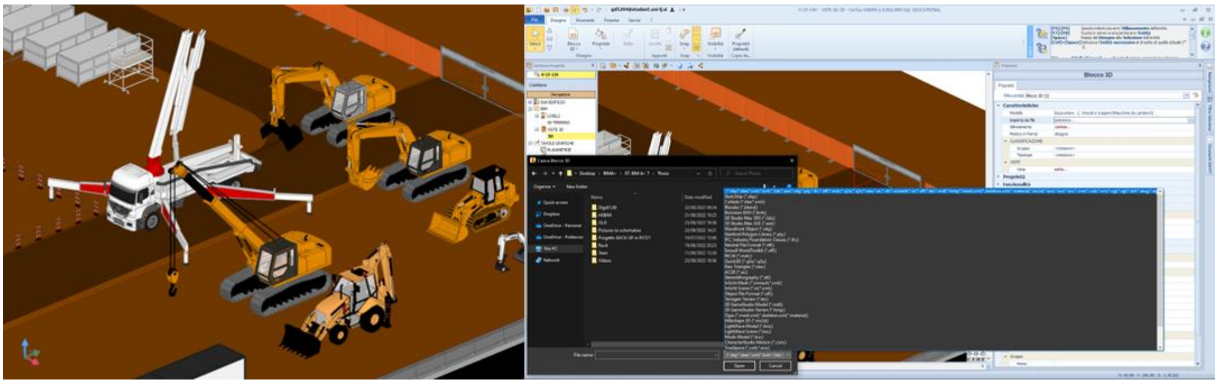


**Figure 25 – Examples of default ACCA's families**

Following in Figure 26 is a list of the most intriguing, imported file formats that are distinct from those used by more mainstream authoring software. It is uncommon for an application of this type to support so many different file types.

In this instance, we would like to highlight some of the more specific ones, such as the Neutral File Format (.nff), which is a minimal description language established for 3D scenes. Textual data identifying lighting points of view, colours, shading parameters, geometric shapes of a scene, and comments may be contained within an NFF file. In this regard, it is ideally suited for importing more realistic and complicated scenes to depict and render a dynamic world.

Biovision (.bvh) is a file format designed to provide motion capture data as well as skeleton hierarchy information in addition to motion data. This file format is also ideal for describing movement within this software related for example to work machines.

Wavefront Object (.obj) is a geometry specification file format initially developed by Wavefront Technologies for its Advanced Visualizer animation software. The file format is accessible and has been adopted by various developers of 3D graphics software.

The Collada file format (.dae), which stands for COLLaborative Design Activity is a file format enabling interoperability between 3D applications and whose source code is released for free, is also quite essential to the interoperability activities.

This brief list of examples of the specificity and diversity of imported formats makes it possible to integrate a multiplicity of resources via 3D Studio Max and to incorporate them in a process that can generate new content and assets for the Unity game engine.

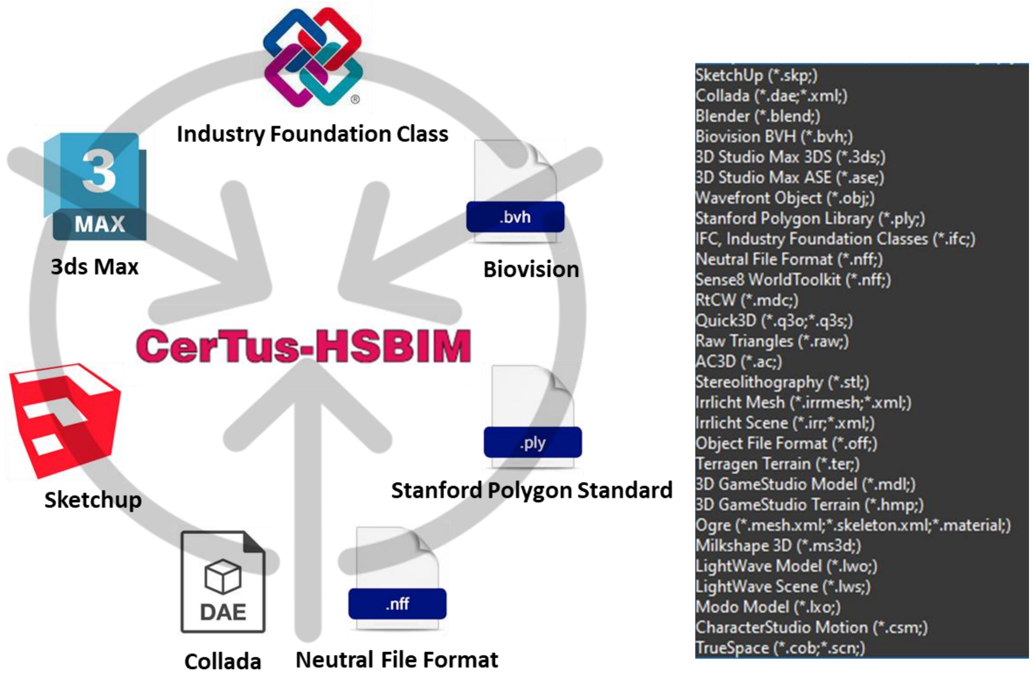



**Figure 26 – Imported file formats in Certus-HSBIM**

The previous roundup of file is meant to demonstrate that this programme is more prepared than its market competitors to incorporate several sources for animations.

It should also be noted that the exported file formats can be classified into two categories. The first category relates to the transfer of files with only geometric content; the data it sends has nothing to do with object attributes, but rather with their definition in the 3D environment. The other grouping consists of a single element that can export both geometric and alphanumeric data.

On the first grouping, the .OBJ format (intended as a geometry definition file format), the .SKP format (intended to contain 3D models), the .DAE format (intended to allow users to share digital images), the .STL format (intended to describe raw unstructured triangulated surfaces), and the .PLY format (intended to define 3D objects) are together. On the other hand, we find another format that is distinct from the others, namely IFC.

It should be emphasised that the virtual reality implemented by this application is primarily meant for visualisation and only to a limited extent for interacting with the content model. It would be desired if the already available options could be expanded so that not only are the actions programmed by animations of imported families observable, but that information can also be searched. Currently, the programme enables the content to be queried by returning textual information on any attachments (e.g., data sheets, maintenance sheets, identification tags, etc.), but it does not support so-called "dynamic navigation."

This sort of dynamic navigation would differ from the others in that the user would be able to interact more with the context and both the geometric and textual information provided, with the goal of generating actions to which NPCs could respond. This extra function's objective would be to facilitate the integration of the educational function to correct conduct throughout job phases.

### 4.3.1. Integration attempt

With the aim of experimenting with the use of the Certus HS-BIM software and its capabilities in consideration of the use of this thesis and a possible real-world workflow, the work file was exported from the modelling authoring software into IFC.

#### 4.3.1.1. Interoperability

To accurately simulate the development of a training application using the authoring software available on the market and deemed most suitable for this purpose, the case study files were analysed to determine the feasibility of matching the phase definition as a possible tool for separating the levels.

IFC is familiar with the concept of phase, but not in the sense to which we speak, or at least not in a format suitable for the intended use. In actuality, Certus-HSBIM will never be able to read the phases as they are described in Revit. This is not due to any flaws in the programme, but rather because IFC represents a snapshot in time and can be configured to export specific sets of information relating to the use stated in the MVD. As shown in Figure 27, it is required to pick which phase to refer to when exporting so that just that phase is taken from the model.

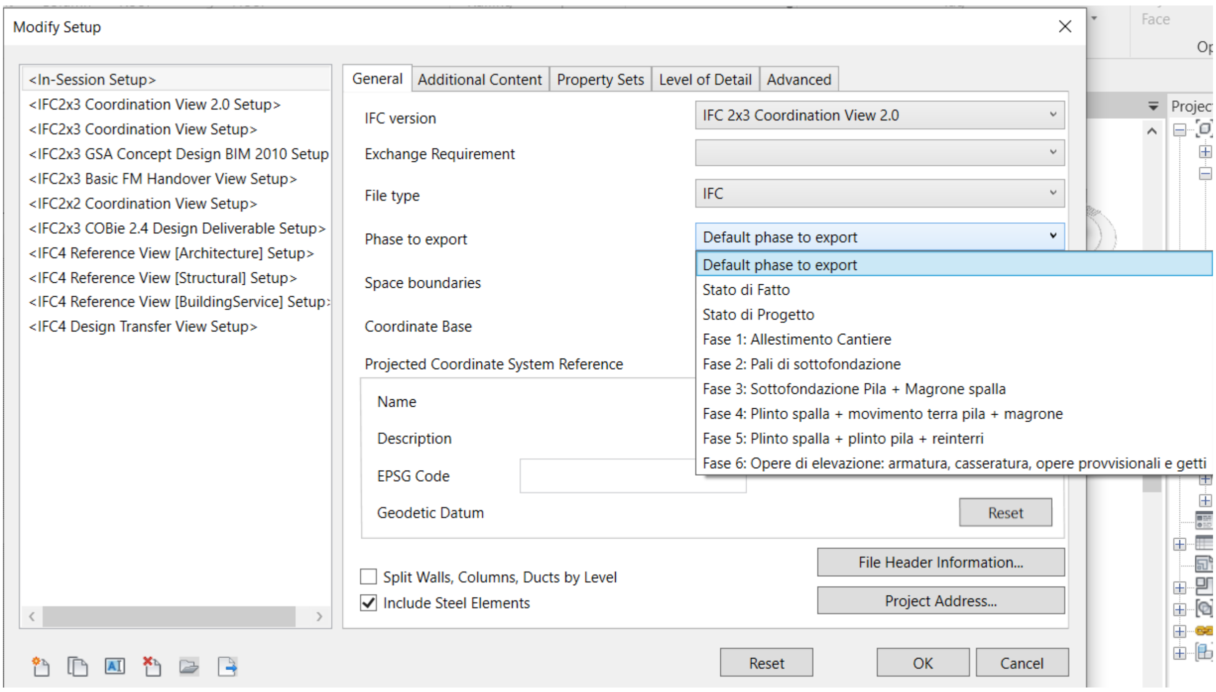



**Figure 27 – IFC phase export settings**

However, ideas pertaining to phases are contained in both the IFC 2x3 TC1 schema, version 2.3.0.1 (referencing the document ISO/PAS 16739:2005) and the 4.3 schema, version 4.3.0.0 (released and available online as of March 7, 2022 and now being voted on by ISO) (buildingSMART, 2022b). If we examine the IFC 2x3 schema in detail, we can see that the entity IfcPerformanceHistory contains an attribute called LifeCyclePhase that describes the applicable building life-cycle phases. Typical values for this attribute are DESIGNDEVELOPMENT, SCHEMATICDEVELOPMENT, CONSTRUCTIONDOCUMENT, CONSTRUCTION, ASBUILT, COMMISSIONING, and OPERATION. This attribute is used to document the actual performance of an occurrence instance.

The IfcContext object also contains the idea of phase. IfcContext is the generalisation of a project context, which defines objects, type objects, property sets, and properties. ObjectType, LongName, Phase, RepresentationContexts, UnitsInContext, IsDefinedBy, and Declares are be attribute of this entity. The Phase property is described as the current project phase or the life-cycle phase of the current project. This attribute does not hold the demolition phase, but rather depicts the construction only. In this regard, it is obvious that although IFC provides properties for phases ranging from the 2x3 TC1 schema to the 4.3 schema, they are not suited for our intended use.

This means that, in order to implement the training application settings, it is not viable to export all phases in a single file, but rather, it is necessary to export them individually in as many files as there are phases.

#### 4.3.1.2. Information Delivery Specification

It is possible to say a few words about the specifications that Construction Site Information Management objects should have, notwithstanding what has been stated previously regarding the possibility of exporting and identifying a workflow that could be useful for ensuring the model's interoperability, as well as the corresponding limitations stated in section4.3.1.1

Information Delivery Specification (IDS) has reached 0.9 and is starting the process to reach Candidate Standard status from buildingSMART (buildingSMART, 2022c). It is a machine-readable document that specifies the Exchange Requirements for model-based exchange. It specifies the delivery and interchange of objects, categories, attributes, and even values and units. This may include Industry Foundation Classes (IFC), Domain Extensions, and other classifications and attributes (national agreements or company specific ones; either stored in bSDD or somewhere else). This is the standard by which the Level of Information Needs should be defined. It provides IFC validation to the client, modeller, and software tools that do (automatic) analyses. It is a fundamental element that can be utilised as an agreement to supply accurate information. It has the capacity to generate local- and use-case-specific project and asset portfolio requirements.

The literature refers to IDS as a tool which shall be embeded with certain features enabling to express requirements for properties, materials, and classes; furthermore it should be able to link to URIs containing further information. Such as bSDD content or PDTs. IDS will be capable of loading into authoring tools to enable users and software tools to develop, validate, and correct mapping of internal data to the required output; be machine-readable to provide automatic validation of IFC against the standards.

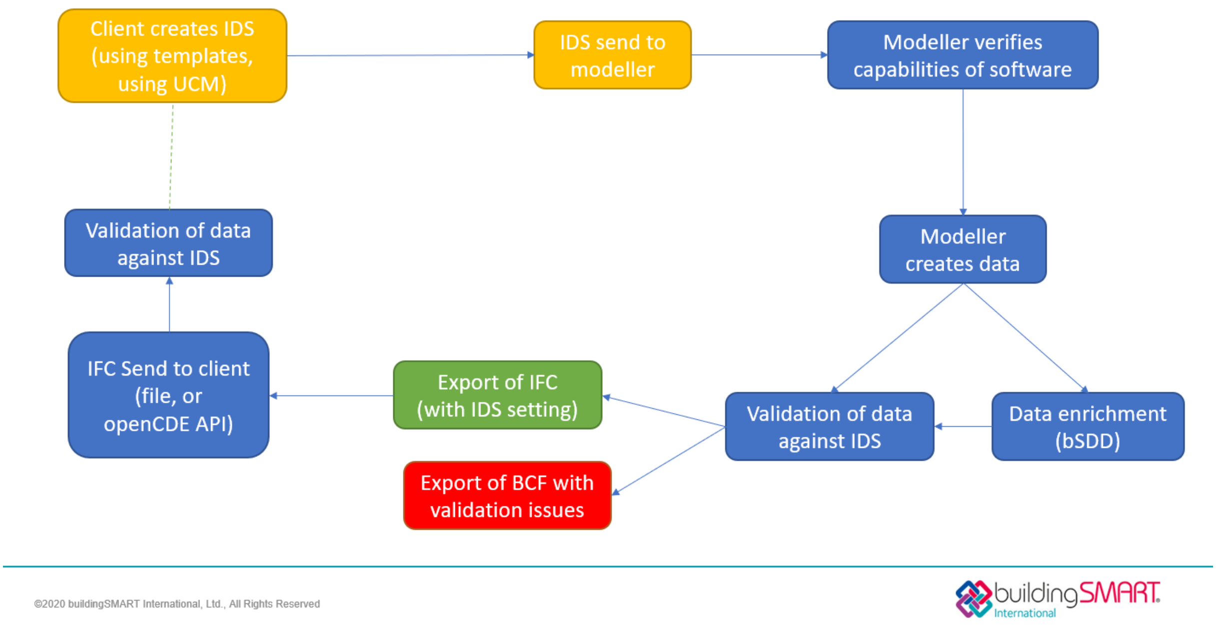



**Figure 28 – IDS Project Scope (buildingSMART, 2022)**

#### 4.3.1.3. Gamification as a new BIM use

Gamification is conspicuously absent from the available authoring software and the prevalent uses categorised in many ways, such as Penn State's Model Uses (Penn State, n.d.), Application Areas (Eastman et al., 2018), and others that may be found at (Succar, n.d.). Probably as a result of this circumstance, the passage through IFC is impracticable for modelling in these software resources that, for graphical and realism reasons, must be extremely precise. The goal of BIM is to promote a methodology that increases the capacity for information transfer throughout the construction process, therefore it seems more logical to represent assets e.g. trucks, excavators, and employees on software developed for this specific purpose. In this regard, the assets given by Unity (selected based on what is discussed in section 2.2.4 Examples of game engines in regards to other game engines), whether paid or unpaid, are significantly more appropriate and engaging for the training to be presented in this work. Integration with the BIM approach is conceivable, but not imminent. With sufficient investment and resources, it is anticipated that a commercially viable product might be developed in the medium term. Even if the import of geometries is feasible and well-documented in the scientific literature, the management of information associated with it still needs to be explained and enhanced.

Given the possibility of software evolution, the proposal of this work is to incorporate gamification and in this case training-related serious games as a potential BIM application.

# 5. OPEN QUESTIONS

In this final section, there are several questions with open-ended responses that can be discussed and debated.

As a request to anybody who will read this book in the future, I strongly encourage you to discuss your concerns and points of view in relation to the topics that are listed here, as well as any additional that may come to mind.

It has been explained that, in light of the criteria of openBIM, it is not possible to carry out a development of levels through phases at the present time, and that the concept of doing so does not match to the meaning that was intended.

If this is the case, would it be better to build phases in the platform or the game engines?

Due to the fact that the game application could be used for two different purposes—namely, the educational CoSIM and the mockup CoSIM; it is necessary to investigate the viability of the CoSIM mockup as well as the different ways in which the current process of the educational version could be re-engineered.

Is it possible to incorporate the CoSIM mockup with the digital twin in a practical manner?

If this training platform were implemented on a large scale, what kind of financial benefits may it bring about?

In what additional aspects of Certus-HSBIM should further improvements be made?

Furthermore, how many hours of utilising the digital application are required to adequately replace the hours of traditional, formal training that are now being used? This question is related to the defining of levels and stages that are required to have for a proper training application. In what particular order should they be placed? Should they be distinct from one another in order to depict and correlate to reality in a manner that is more accurate, or should they be structured as groupings of learning objectives that are comparable to one another?

# 6. CONCLUSIONS

The purpose of this thesis is to make an attempt to conceive of and sketch out a potential training programme that would be designed for the education of the Appointed Work Supervisor (AWS). The significant regulatory update that took place in April of this year in the so-called single safety text, Legislative Decree no. 81/2008, is the event that prompted the author to devote himself to this particular professional figure. It is vital to note out that because of the nature of the regulatory text, changes do not hesitate to follow one another so quickly that a further update was released in August of 2022. This is something that should be pointed out since it is essential.

The individuals who are the subject of this work, AWS, will not be affected by the modifications made with this most recent edition. As a result, this work will continue to be accurate at the time of its delivery and defence. The utilisation of learning strategies that are not of a formal nature forms the foundation of the operational framework that this work seeks to define. The first few chapters are structured to provide the reader with an understanding of the broad topic of gamification by providing a comparison between fairly frequent Lego® bricks and the tools that this approach makes available by defining a logic of use. This comparison will be carried out in a way that is both practical and intuitive for the reader.

This is then followed by a presentation of those tools that are necessary for the development of a gamified product such as game engines, their characteristics, their peculiarities, and the possible fields of application that these software allow the AECOM technician to approach for the development of bespoke solutions. The game engines are listed, presented, and compared so that the reader can have objective references for the development of his own critical choice of the resources that are currently available on the market. A significant amount of emphasis is placed on an open and free approach, both in terms of the use of the product and the resources that are currently accessible online.

In conclusion, a recommendation is made for a product that, in the author's opinion, constitutes an appropriate instrument to meet the needs of the software developer who, in the future, will be able to finalise the storyline and working framework that this thesis work outlines.

The logically applicable reference to the development of this work is presented in the 4.1 Methodology section, which outlines the terms and conditions under which this work was conceived. The comprehensive overview of the workflow is summarised in Figure 23. Compiling in the essential fields for the identification of the key phases in the definition of gamified training is accomplished by using the workflow proposed by (Morschheuser et al., 2017) that was found to be the most suited after an extensive-conducted search of the relevant literature.

The practical application of this work can be seen in the fundamental definition of the learning objectives that, in relation to the case study, are crucial for the successful training of the AWS. The development of the training site is modelled in BIM showing and foreseeing an application to mock-up CoSIM as integration of design and information modelling at the ergo-technic design. The development process may be broken down into five primary components, each of which is organised according to the domain in which it operates. This is the logic that drives the process. The actual gameplay and the overall layout of the game, the design, are the two aspects that are being analysed here. The conceptual roadmap is shown in Figure 20, and it begins with the description at the design level of an event that is digitally substantiated in the educational game reality. The progression of the dynamics of the game are conceived in such a way that the situation produced is deemed intentionally critical, and as a result, it requires a specific action for its resolution. The required action is therefore the result of a complex architecture based so that the AWS learner has the opportunity to achieve through training, specifically designed so that it can be iterative and rewarding, the learning objectives identified on the basis of regulatory prescriptions.

What emerges at the conclusion of this work is a wide-ranging examination of the state of the art and the currently available resources of software and APIs that would lend themselves well in terms of both capacity and flexibility to the development of the gameful application; furthermore, a detailed schedule of the steps necessary for the development of the product has been outlined that could be a synthesis of shared efforts and skills; The beneficial effects of this approach have yet to be tested as, at the time of writing this work, further resources are required for the code development, verification and product testing stages and, finally, for the collection of data useful for validating the work.

It is possible that stakeholders such as ACCA software will be involved in the process of developing the application. Stakeholders such as ACCA software, well known for their effort in openBIM approach, have the skills and capabilities that will allow them to implement the resources that are already available and put them to use in the service of another emerging market segment. This could be accomplished through the development of APIs that could act as a bridge between their products and other specific applications and other BIM uses. This would allow a solid interoperability between the training scenario and the BIM model developed for the use of construction site management.

A data gathering campaign might be carried out by collecting feedback and experiences from users of the programme. This would be useful to corroborate the process of collecting and validating results. The same, if made available to construction training schools, enterprises, employers, and managers in charge of required education and training, might be widely tested and verified in order to provide appropriate feedback for the full and complete growth of the project.

There are still unanswered questions about the game levels that will be suggested, such as which ones and how many of them are required for the application to be successful.

How exactly should they be arranged? Should they be different from one another to more accurately depict and correspond to reality, or are they to be constituted as groupings of learning objectives that are comparable to one another?

How many hours of using the digital application are necessary to adequately replace the hours of traditional, formal training that are currently being used?

The synchronisation and integrated management of training could be an opportunity presented by the digital application. This opportunity pertains to the establishment, management, and archiving of the training register that is mandated by the legislation.

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# ANNEX I

This appendix summarises an example of structuring levels and employing the methods given in Methodology, 4.1.

We determine the 1) Event, 2) Description, 3) Criticality, 4) Learning Objective, and 5) Required Action for each Situation.

| Event | Description | Criticality | Learning Objective | Requested Action |
|---|---|---|---|---|
| | | Start Level 1 | | |
| The dump truck for supplying the barriers appears | The box truck positions itself in the shadow of the ground projection of the power line | When handling a telescopic boom, there is a risk of contact with the high-voltage line | Checking the correct positioning of the box van in relation to the projection of the power line | The SS places the box van at a safe distance |
| Two workers from the contractor appear, one of whom is ATL1 | the two workers are supporting the activities to be carried out | Unidentifiable workers may not be regularly employed | Verification of workers' identity | |
| | workers must be identifiable and identified | Unidentifiable workers may not be duly employed | Verification that the names of the workers correspond to those indicated in the SMP | The CSS verifies that the names match the contents of the SMP |
| A worker starts climbing onto the body of a dump truck | one of the workers starts a potentially dangerous activity | In case of slipping, the worker risks falling and injuring himself | Check that no dangerous situations are created in relation to the activity | The CSS must provide a ladder to access the skip |
| | | End Level 1 | | |
| | | Start Level 2 | | |
| EWP and mini-excavator appear; mini-excavator is on a high-bed truck | EWP and mini-excavator arrive with two different transporters that must not clash | Improper handling of the mini-excavator carries the risk of overturning and possible personal injury and property damage | Identify and plan the correct operations to be undertaken to carry out the work safely | The CSS unloads the mini-excavator unsuitable truck |
| The low-bed truck appears with the mini-excavator | A worker starts tipping the ramps | The use of personnel not trained to carry out a specific task entails the risk of an accident due to ignorance of the safety measures to be taken | Check that the operations are carried out by the appropriate personnel, in this case the truck drive | The CSS replaces the workman with the lorry driver, calling him |
| | | End Level 2 | | |
| | | Start Level 3 | | |
| A worker gets on the mini-excavator and prepares to start work | The worker getting on the mini-excavator is interrupted and identified by the ASS | Driving vehicles by unqualified personnel poses a serious accident risk | Check the operator's qualification to drive the vehicle | The CSS interrupts the activity to replace the driver with a qualified one |
| The mini-excavator begins excavation and digging activities | excavation activities are for the removal of the first few metres of soil until hard rock is reached | Obstruction of excavation activities is a source of risk to operators | Check that the area is clear of obstructions and that the vehicle buffer zone is observed | The CSS keeps workers away from the area where the vehicle is operating. |
| The hydraulic truck-mounted crane with container arrives, at the same time a worker from another company appears | The vehicle is in charge of moving and placing the precast plinths and gantry posts, the worker on the ground directing and steering the plinth to the exact position | The use of personnel from different companies entails potential risks due to poor coordination | Check for interfering activities between companies | CSS' coordinate to carry out the activity |
| | | End Level 3 | | |

**Figure 29 – Methodology by examples, pt.1**

## Fencing supply and installation

1. Provision of temporary transit prohibition barriers at overhead power lines using a box truck, unloading of the carrier in accordance with the procedure, and installation by an operating

team comprised of a team leader (PSQ) and an attendant, at the distance from the ground projection of the overhead power line specified by the applicable SMP. Elimination of the supply vehicle.

2. The delivery of a tracked elevating work platform (EWP) and a tracked mini-excavator on a low-bed truck, with ramps built up by the driver of the vehicle and machinery lowered to the ground by a qualified operator.
3. Using a mini-excavator, prepare the space for the placement of aerial work platforms and the installation of prefabricated plinths for the building of overhead power line signal gateways. Planting topsoil in the region of the site. Installation of operationally configured EWPs at the northern gateway.
4. The delivery of prefabricated piles and plinths for the construction of portals using a hydraulic truck-mounted crane with caisson. Placing of plinths, raising of piles, and installation of signposts utilising synchronised actions of a truck-mounted hydraulic crane and EWP driver, after stabilisation of the vehicle by the driver, by an operating team comprised of a team leader (PSQ2) and a competent worker.
5. Repetition of operations 3-5 by reversing the direction of the truck crane's arrival (to ensure the safety distances of the crane from the power line).

| | | | | |
|---|---|---|---|---|
| | | Start Level 4 | | |
| It appears an excavator with bucket for soil removal | the excavator for soil removal is also functional for levelling | Obstruction of excavation activities is a source of risk for operators | Ensure that the area is clear of obstructions and that the vehicle buffer zone is observed | The CSS drives away workers intent on working in the vicinity of the vehicle's area of operation. |
| It appears a concrete mixer for unloading lean concrete as a foundation for the barracks | the concrete mixer starts unloading by means of a chute moved by a worker | the distraction of one of the workers can cause damage by pouring concrete, impact with the chute | coordinating activities between the driver of the concrete mixer and the casting worker | the CSS ensures that the casting is carried out safely by supervising the workers involved |
| It appears workman with bare copper cable for the earthing installation | the worker with the copper rope works in the vicinity of the concrete mixer truck and the other workers | Mutual interference between casting and copper rope-laying activities | Ensure that operations are carried out with mutual attention | The CSS coordinates the workers ensuring adequate distance for health and safety of workers |
| | | End Level 4 | | |
| | | Start Level 5 | | |
| It appears a tractor with a trailer transporting prefabricated modules | The trailer transports the prefabricated modules that will serve as offices | safety for the entry and circulation of heavy goods vehicles must be guaranteed | Verify compliance with the construction site road network, imposed speeds | the PCC monitors and verifies that the construction site viability is respected |
| It appears to be a telescopic lift with an adjustable four-point sling bar | the telescopic lift with the sling bar is used to hook and hold the load in a horizontal position | the sling bar must be type-approved, in good condition, have no defects and be properly attached | Check the state of preservation of the sling bar, closure of the hooks, presence of the approval label | The CSS must check that all criticalities have been analysed before pulling the load |
| The prefab is hooked to the hoist | the prefabricated building is attached by means of chains and hooks | tensioning the sling bar in a semi-static manner | check that the lifting methods comply with the provisions of the SMP | The CSS supervises the operations of securing the precast to the vehicle, verifies the handling procedures |
| The prefabricate is in place on the concrete screed | the prefabricate is placed on the concrete screed with a crane | spatial interference with the hoist, the lifted load and workers | ensure that the handling area is free of obstacles | The CSS draws attention to any workers in the vicinity of the firing line |
| | | End Level 5 | | |

**Figure 30 – Methodology by examples, pt.2**

### Sculpting and/or disrobing-related actions

1. Supply of pickets on a box truck; materialisation on the ground of the buffer strip of the overhead power line in the workplace area; and identification of the perimeter of the excavation anticipated in the project by a team leader and a worker.

2. The crawler excavator and wheel loader will be delivered via low-bed trucks from the farm road. Installation of ramps by the driver of the vehicle and lowering of vehicles to field level by qualified employees.
3. Progressive stripping with storing of topsoil in an SMP-designated storage area.
4. Loading the topsoil onto dump trucks positioned parallel to the farm road in the cleared area using a loader.

| | | | | |
|---|---|---|---|---|
| Start Level 6 | | | | |
| It appears excavator with overturning bucket for soil removal | the excavator for soil removal is also functional for levelling | Obstruction of excavation activities is a source of risk for operators | Ensure that the area is clear of obstructions and that the vehicle buffer zone is observed | The CSS drives away workers intent on working in the vicinity of the vehicle's area of operation. |
| It appears a 3-axle dump truck for transporting the removed soil | the truck positions itself adjacent to the excavation area | identification of personnel for carrying out the work and for driving the means of work. | Verify excavation operations and the absence of interfering personnel in the area. Ensure that the caissons are closed to prevent debris from being thrown onto the road. | The CSS ensures that the soil transport caissons are closed before leaving the excavation site |
| End Level 6 | | | | |
| Start Level 7 | | | | |
| It appears the concrete pump with folding arm | the concrete pump is positioned in the correct direction adjacent to the excavation by opening the outriggers | Excessive proximity to the excavation area could jeopardise the stability of slopes and cause a landslide | Check that the position of the vehicle complies with the SMP and that it is operated by suitable personnel | The CSS verifies the positioning of the vehicle according to the POS<br>ensures that the outriggers are correctly opened<br>ensures that ground sheets are in place against concrete spills. |
| It appears the concrete mixer for the supply of fresh concrete | the concrete mixer truck positions itself in reverse near the pump<br>a worker helps manoeuvre the truck. | risk of investment or collision between construction vehicles | verify that no accidents occur by monitoring ongoing operations | The CSS verifies that unloading and pumping operations are carried out by qualified personnel and not by ordinary workers |
| It appears the site inspector for quality control | other technical personnel may intervene during the processing phases to carry out parallel activities | possible interference between the various activities carried out in the performance of their tasks | supervise the activities and people around | The CSS must promptly report any hazardous situations to all workers involved |
| End Level 7 | | | | |

**Figure 31 – Methodology by examples, pt.3**

### Construction of a base camp

1. Excavation and placement of a concrete layer for levelling the prefabs' support layer.
   a. It looks that an excavator with a bucket is used to remove the top layer of dirt, followed by the same method for levelling and compaction.
   b. Supply of lean concrete for the building of a sufficient foundation to ensure a homogeneous surface for the support of prefabricated structures.
   c. Installation of an earthing system using earth rods or bare copper rope

2. Delivery of prefabricated modules on a trailer, including unloading and placement
   a. It appears a tractor and trailer conveying the prefabricated modules;
   b. A telescoping lift with an adjustable four-point sling bar is visible.
   c. The prefabricated object is secured to the hoist with chains and hooks.

d. The precast is hoisted and positioned on the concrete platform's flat surface.

**Activities involving excavation for the creation of foundations**

1. Marking the excavation site
   a. The surveyor marks the area with the excavation depth using flags.
2. On-site entry of an excavator with a reverse bucket.
   a. Excavator is positioned in accordance with SMP
3. Extraction and removal of soil, followed by loading onto a three-axle dump truck for transfer to the quarry for storage and lending.
   a. The excavator begins removing earth and puts it onto a three-axle dump truck;
   b. In the absence of the dump truck, work ceases and no soil accumulation is anticipated.

**Foundation casting activities**

**1.** Concrete will be supplied by pump and truck mixer;
**2.** Pump positioning prior to the machine; a. A pump appears for the cls, b. The pump is positioned according to the POS by opening the boom, and c. Sheets are placed on the ground to prevent spillage.
**3.** Concrete delivery with spillage into the pump hopper
   **a.** The concrete mixer looks to be in reverse gear near the pump. b. A worker assists with the concrete mixer truck's approach. c. The driver of the concrete mixer truck prepares the chute for discharging the concrete into the hopper.
**4.** Monitoring the pouring stage (concrete quality and execution)
   **a.** Quality checks are performed on the mixture.

# ANNEX II

This appendix provides an example of a storyboard created to comprehend the game's dynamics and the expected development for the building of an application suitable for AWS training.

The following graphics are designed to highlight the application's functions, which begin with those currently implemented and existing Figure 32, but enhance and detail them based on their intended purpose. Using the simple translations within the application as a starting point, a panel has been developed to identify the actions AWS can perform to fulfil its job. In addition to 1) Speak, 2) Call, 3) Measure, and 4) Modify, there are also functions for 5) Warn and 6) Provide Information Figure 33.

The four actions outline what the AWS can and must do in the event of an imminent and grave threat. It must communicate with the employees to instruct them on what to do in the event of danger, call the base camp if assistance is required, or alert the hierarchy of the situation. Must be able to measure to ensure that safety distances, as opposed to clearances, are in compliance with plans and cannot lead to hazardous circumstances. In addition, the opportunity to directly amend the risky condition is also supplied.

The two additional buttons serve primarily to formalise the play experience; with Warn, it is necessary to indicate what concerns the situation poses, while Info provides access to the loaded health and safety documents that are part of the ergotechnical design (e.g., SMP, SCP-e, etc.).

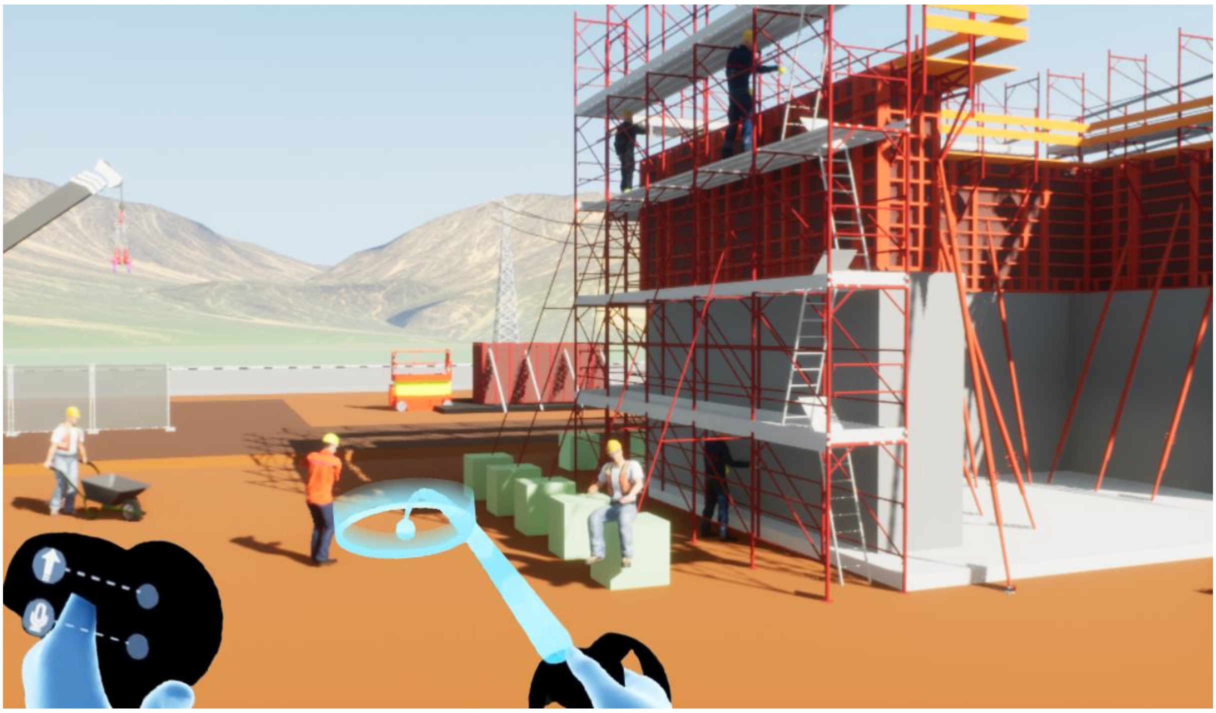

**Figure 32 – Storyboard shoot 1**

Temporal stimuli in the identification of the hazards are also included in order to comprehend, evaluate, and provide feedback for enhanced performance in harmful scenarios.Figure 34

The objective is to encourage the learner to make critical decisions in a short amount of time and to compare his current performance to his past performance in order to identify areas for growth.

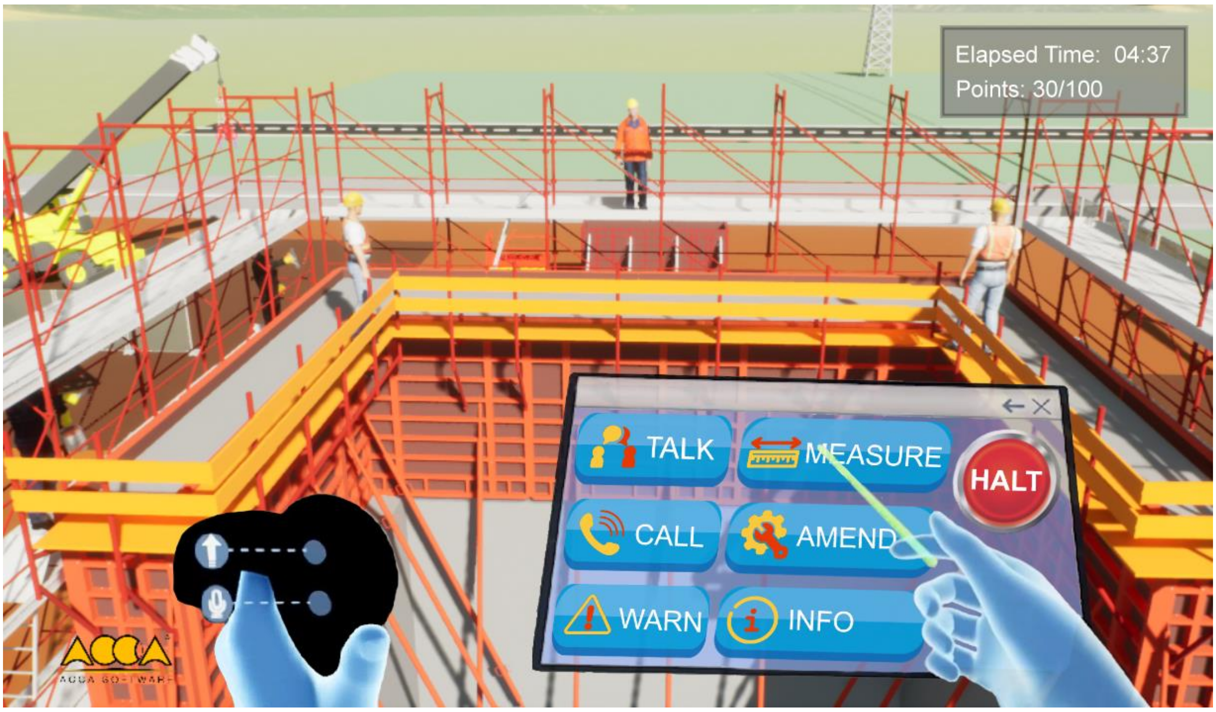


**Figure 33 – Storyboard shoot 2**

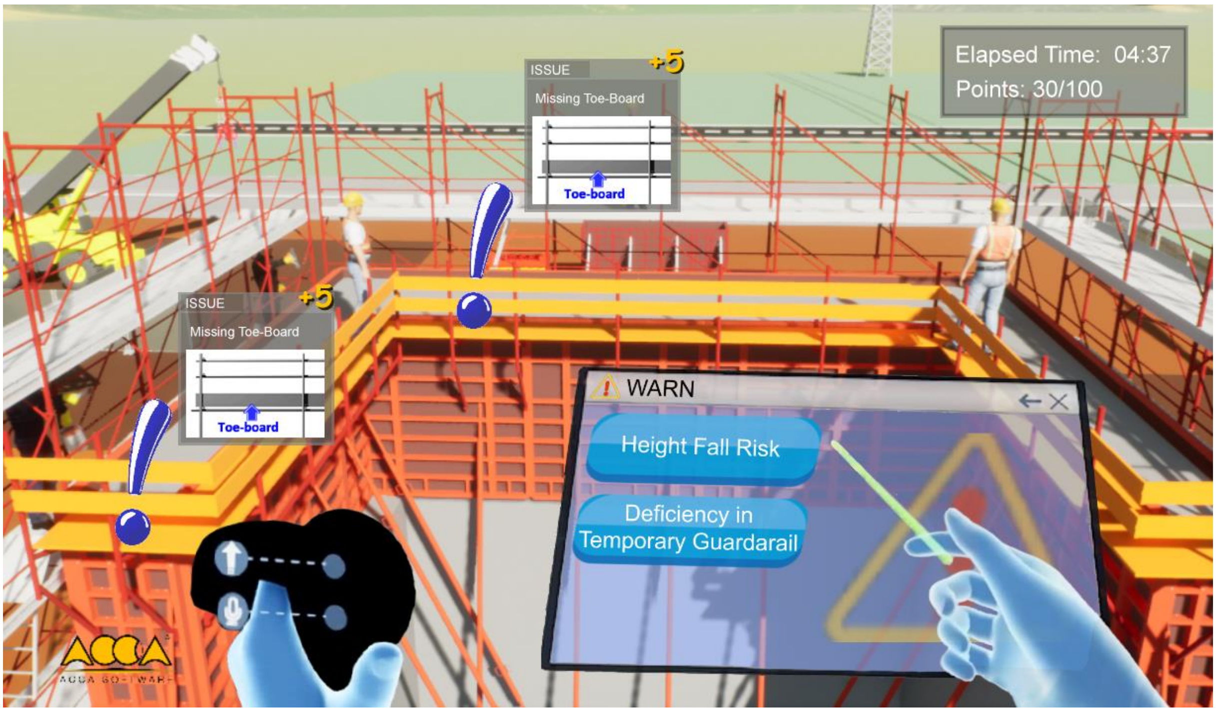


**Figure 34 – Storyboard shoot 3**

The identification of the risks then leads to the notification of the risks and the decision (Required Action) to be communicated to the workers involved, making them safe and in fact achieving the learning objective.

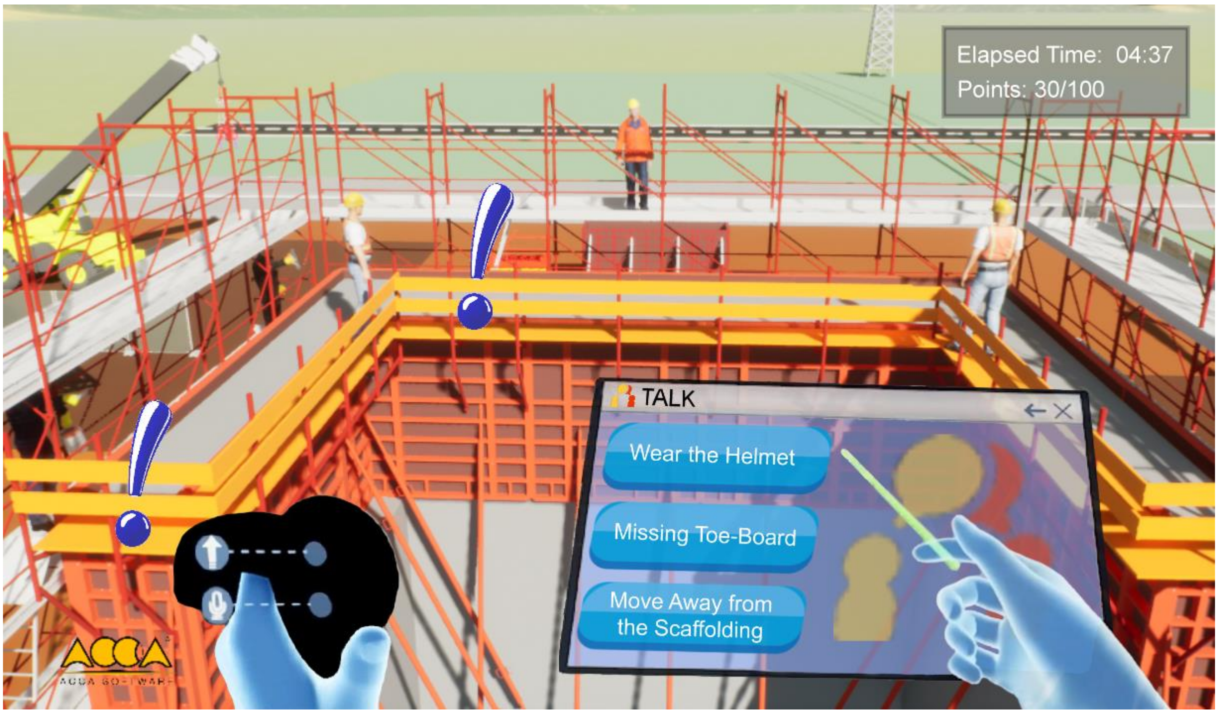


**Figure 35 – Storyboard shoot 4**

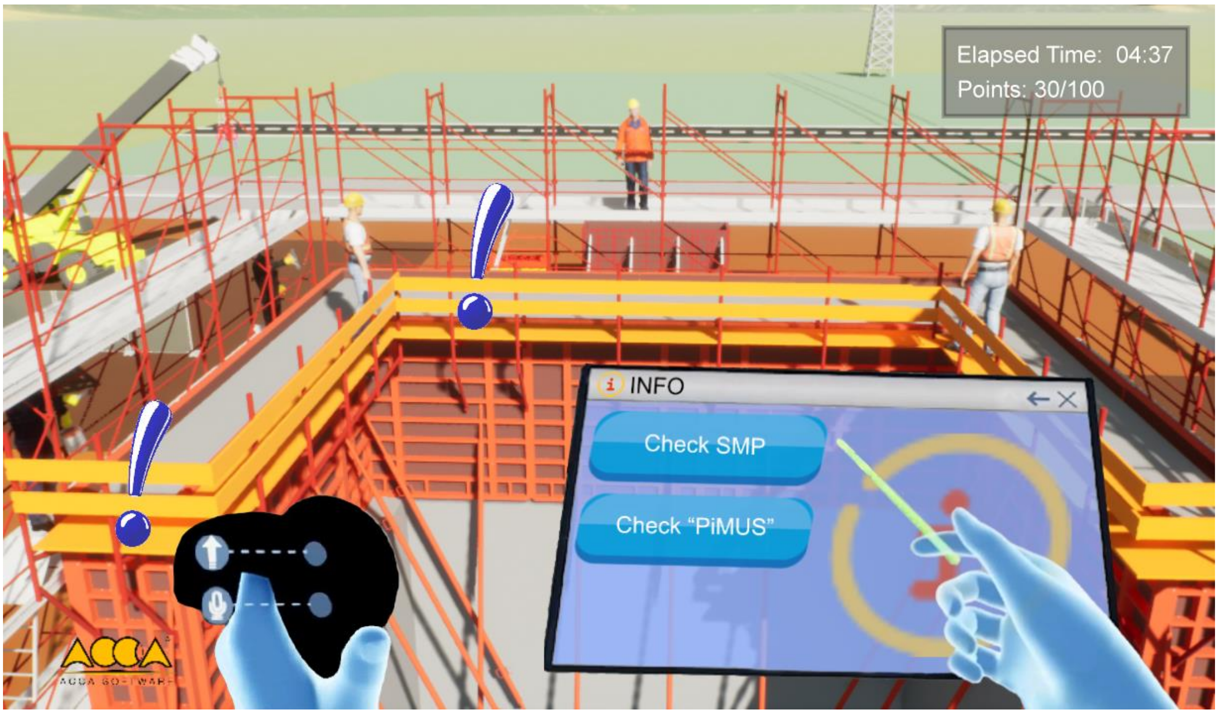


**Figure 36 – Storyboard shoot 5**

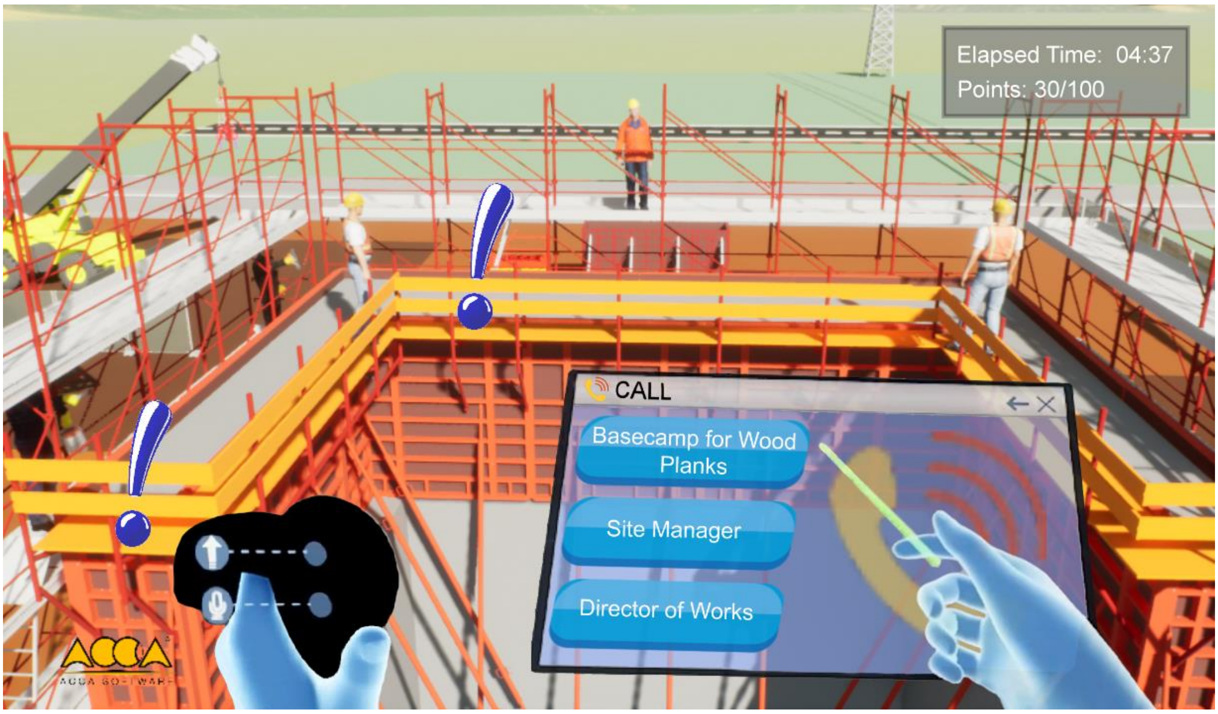


**Figure 37 – Storyboard shoot 6**

# LIST OF ACRONYMS AND ABBREVIATIONS

| In alphabetical order | |
|---|---|
| AECOM | Architecture Engineering Construction Operation Management |
| AI | Artificial Intelligence |
| AR | Augmented Reality |
| BIM | Building Information Modelling |
| CoSIM | Construction Site Information Management |
| AWS | Appointed Work Supervisor |
| CTL | Chosen Team Leader |
| EWP | Elevating Work Platform |
| MOOC | Massive Online Open Course |
| PPE | Personal Protective Elements |
| SCP-d | Safety and Coordination Plan – design phase |
| SCP-e | Safety and Coordination Plan – execution phase |
| SG | Serious Game |
| SMP | Safety Management Plan |
| VR | Virtual Reality |
| VRi | Virtual Reality Immersive |
| XR | Mixed Reality |
| | |