POLITECNICO DI MILANO

School of Architecture, Urban Planning and
Construction Engineering

MSc Building Engineering

# BIM AND VIRTUALITY CONTINUUM: APPLICATIONS OF A VIRTUAL REALITY PROTOTYPE FOR THE SAFETY TRAINING ON CONSTRUCTION SITES

Supervisor: Prof. Vittorio Caffi

Author:

Enrico Salcuni

ID: 842538

Academic year 2016/2017

*"The future is already here,*
*it's just not evenly distributed yet"*

William Gibson
writer and essayist

# Premessa

Facciamo finta di catapultarci a esattamente 100 anni fa, nel 1917, e pensiamo ad una tecnologia che ormai consideriamo fin troppo banale e scontata: il telefono.

Il suo sviluppo, grazie ad Alexander Graham Bell, ormai risaliva a vari decenni prima, e all'epoca la sua diffusione aveva raggiunto, seppur lentamente, vari tipi di contesto, dal servizio pubblico all'uso commerciale e privato. C'era tuttavia ancora qualcosa che mancava, o meglio, che era "di troppo": la presenza del filo. Farne a meno a quei tempi poteva essere considerato impossibile, fin troppo futuristico, quasi fantascientifico. E chissà, magari pure superfluo, visto che il telefono funzionava già bene così. Ad un certo punto arriva un certo Eric Tigerstedt, e decide che sì il telefono per carità va benissimo e la sua utilità è indiscussa, ma quel filo proprio no, gli sta stretto e vuole liberarsene. E alla fine, quest'inventore finlandese ci riesce pure, sviluppando una tecnologia che consentirà, in un futuro non troppo lontano, la creazione dei primi telefoni cellulari e, più avanti ancora, dei nostri attuali insostituibili smartphone.

Ma cerchiamo ancora di immaginarci nel secolo scorso, e poniamoci una semplice domanda: che tipo di reazione avrà avuto il mondo (accademico e non) davanti alle proposte stravaganti del signor Tigerstedt? Probabilmente scetticismo, incredulità e magari denigrazione. Qualunque sia la nostra risposta, nel nostro subconscio comparirà un mezzo sorriso compiaciuto che sembra dire "alla fine ha vinto il finlandese".

Ora torniamo nel 2017. Sentite qualcuno che afferma la seguente frase: “nel giro di pochi decenni, la realtà virtuale diventerà una tecnologia diffusa e accessibile al pari di un frigorifero o un tostapane”. Nuova semplice domanda: qual è la vostra reazione?

Per quanto concerne il settore dell’ingegneria edile e della sicurezza di cantiere, la frase può essere riformulata nella domanda seguente: “e se, nel prossimo futuro, i lavoratori di un cantiere potessero ricevere una formazione dettagliata e completa sulle norme di sicurezza e sulle procedure di emergenza tramite sessioni di simulazione in realtà virtuale?”

Queste considerazioni sono state lo spunto per la stesura della seguente tesi di laurea magistrale.

Nel corso degli ultimi mesi, il professor Vittorio Caffi, relatore di questa tesi, mi ha gentilmente messo in contatto con un gruppo di professionisti che, evidentemente, si stavano ponendo la mia stessa domanda. Il gruppo costituisce una start-up con l’obiettivo di creare un prototipo di simulazione in realtà virtuale per l’apprendimento e la formazione sulle norme di sicurezza cantiere. Il coordinamento è guidato da Graziano Lento, esperto del mondo BIM e con un passato manageriale nel gruppo Autodesk, il quale con somma pazienza e passione mi ha accompagnato lungo il progetto di tesi. Lo sviluppo del software e di tutta la sua struttura informatica è compito di un altro professionista del settore programmazione, l’ing. Erik Ripamonti. Infine, l’integrazione della normativa vigente in merito alla dottrina sulla sicurezza cantieri è demandata all’ing. Vittorio Mottola. Il connubio tra queste 3 forze ha portato allo sviluppo di una nuova piattaforma di formazione che, seppur in versione beta e con livelli di dettaglio elementari, offre ottime potenzialità e stimoli di sviluppi futuri.

Nella concezione odierna, la realtà virtuale è ancora qualcosa di poco definito e limitato tipicamente al mondo videoludico e dell’intrattenimento. Le sue potenzialità nel mondo ingegneristico, e in particolare nel mondo della formazione sulla sicurezza di cantiere, risultano ancora oscure. Ciò è dovuto principalmente ad una lentezza di applicazione della metodologia BIM (Building Information Modeling), lentezza alquanto marcata in Italia, soprattutto in relazione ai paesi esteri.

Per una comprensione chiara e particolareggiata di questo tipo di simulazioni, occorre ampliare lo spettro di indagine oltre il mero contesto di realtà virtuale, analizzando il panorama del BIM mondiale, le applicazioni extra-ingegneristiche della Realtà Virtuale, arrivando inevitabilmente ad esaminare anche concetti come Realtà Aumentata e Realtà Mista. Per questo motivo, la seguente tesi è suddivisa in 3 macro-sezioni: la prima (Section A) offre un punto di partenza analizzando il contesto BIM da una prospettiva sia progettuale sia economica; la seconda (Section B) introduce i concetti relativi al Virtuality Continuum e le sue applicazioni ingegneristiche, fino all’analisi dettagliata dello sviluppo del prototipo vero e proprio; la terza e ultima (Section C) si propone di studiare ulteriormente le nuove tecnologie di appoggio al mondo delle costruzioni, ma con l'ausilio della Realtà Aumentata.

Obiettivo di questa tesi è offrire una visione più chiara e completa sia del mondo BIM che della realtà virtuale, entrambi spesso soggetti a molteplici e confusionarie interpretazioni, e dimostrare la loro possibile ed efficace integrazione. La metodologia di sviluppo è articolata attraverso numerose fonti bibliografiche, documentazioni, interviste, nonché test diretti sul software del prototipo.

E come ulteriore obiettivo, chissà, magari riuscire a contribuire alla consapevolezza di un utile strumento di formazione che pone come fine ultimo, per citare le parole di Graziano Lento durante i nostri incontri di revisione, quello di "portare ogni sera a casa la pelle".

# Sintesi


Con il presente documento si forniscono le basi per una conoscenza approfondita del Building Information Modeling (BIM) e delle sue applicazioni nel contesto del virtuality continuum. In particolare, si propone lo sviluppo di un innovativo prototipo di simulazione in realtà virtuale, creato per la formazione sulla sicurezza in cantieri edili.

La sua struttura si articola in tre sezioni. Nella prima si evidenziano le realtà in cui trova impiego il BIM, i suoi modelli applicativi in mobility e cloud, chiarendo quindi i concetti di Livelli di Maturità e Livelli di Sviluppo (LOD). Si prosegue analizzando le linee guida in materia di BIM e sicurezza, in ambito sia italiano che internazionale.

Nella seconda sezione viene introdotto il concetto di simulazione in realtà virtuale, focalizzando i principali benefici in ambito ingegneristico. Una volta descritti i concetti teorici e applicativi delle simulazioni in realtà virtuale, si prosegue quindi con l'analisi del prototipo preso in esame, descrivendone la struttura software e il funzionamento di esecuzione con esempi pratici. Si arriva pertanto a definire le tipologie di utenti e le possibili integrazioni hardware e software, nonché ad analizzare le potenzialità dell'Intelligenza Artificiale interna al sistema e le relative condizioni al contorno.

Dopo aver discusso della tecnologia di simulazione in realtà virtuale, la terza sezione offre un quadro completo del virtuality continuum analizzando i concetti di realtà aumentata e realtà mista, dalle origini fino ai modelli applicativi attuali. L'attenzione di questa ultima sezione è posta anche sull'influenza, consapevole o meno, del virtuality continuum a livello sociale, e dunque sulla sua concezione moderna sia in ambiti di intrattenimento (cinema, libri, videogames) sia nell'ambito delle costruzioni (architettura e ingegneria edile/civile).

Obiettivo di questa tesi è offrire una visione più chiara e completa sia del mondo BIM che della realtà virtuale, entrambi spesso soggetti a molteplici e confusionarie interpretazioni, e dimostrare la loro possibile ed efficace integrazione. La metodologia di sviluppo è articolata attraverso numerose fonti bibliografiche, documentazioni, interviste, nonché test diretti sul software del prototipo.

# Abstract

This thesis provides the foundation for a thorough knowledge of Building Information Modeling (BIM) and its applications on virtuality continuum. In particular, it is proposed the development of an innovative prototype for virtual reality simulation, created for the safety training on construction sites.

Its structure is organised in three sections. In the first section the attention is drawn to the nowadays reality where BIM is adopted, its applicative models in mobility and cloud systems, thus making clear the concepts of Maturity Levels and Levels of Development (LOD). Then the guidelines about BIM and safety will be analysed, regarding both the Italian context and the international one.

In the second section the concept of virtual reality simulation is introduced, by focusing on the principal benefits in the engineering field. Once the theoretical and practical notions of VR simulations are described, the document shall proceed with the analysis of the prototype examined, by describing its software structure and the execution functioning with practical examples. Then the user's typologies and possible integration will be defined, as well as the potentialities of the Artificial Intelligence within the system and the relating boundary conditions.

After having talked about VR simulation technology, the third section provides a full picture of the virtuality continuum, analysing the notions of augmented reality and mixed reality, from the beginning till nowadays applicative models. The attention of this last section is focused also on the social influence, conscious or not, of the virtuality continuum, and therefore on its modern idea both in entertainment sector (movies, books, videogames) and in the construction one (architecture and building/civil engineering).

The aim of this dissertation is to provide a clearer and more complete understanding of both BIM and virtual reality, often subjected to various and chaotic interpretations, and then to demonstrate their possible and effective mutual integration. The methodology adopted for the development of this thesis is structured throughout several bibliographic sources, documentation, interview, as well as direct testing on the prototype's software.

# Table of Contents

# Table of Figures

# SECTION A

## BIM

# 1. INTRODUCTION TO BIM

*"If only one book were to be written about BIM, it might have «DON'T PANIC» printed in large uppercase letters on the front cover"*

Pete Zyskowski

According to the surveys conducted by research organizations across the world, Building Information Modeling is rapidly adopted by Architecture, Engineering and Construction firms globally. BIM's leading users include United States of America, United Kingdom, Canada etc., and the studies demonstrate that always more countries are implementing BIM for the accomplishment of construction projects. The survey also suggests that, a large number of AEC *(Architectural, Engineering and Construction)* firms and AEC professionals are willing to implement it in their upcoming construction projects.

Before with the advent of BIM, highly complex issues related to the design, operations and actual construction of the building were used to be faced by architects, engineers, contractors and owners. But then, after the adoption of BIM, all this professional figures have been able to sort out complex problems associated to design, construction and scheduling of building projects.

Now the scenario is such that they effectively manage to refine the building design to such an extent that they don't have to face costly and time taking rework during actual construction. The Building Information Models which are extensively developed by the BIM technicians of engineering companies are totally trusted by AEC professionals for their precision. Indeed, with the support of correct information design and construction professionals, they can manage to carry out seamless constructions, and they quite often handover the completed building to owners and general contractors much ahead of the specified dates, that means before the deadline.

In the early stages of BIM's adoption by AEC industry, not more than 17% of the firms used to implement it for providing high end architectural and engineering solutions to construction companies. A survey suggests that 49% of architectural and engineering companies started to implement it by 2009. BIM's constant adoption by architects, engineers and contractors, drastically raised its awareness among building owners who can have enormous benefits from it. So, now building owners also want AEC professionals to implement BIM while developing their buildings. This further raised BIM's adoption rate, which is now being used by approximately 71% of architectural and engineering firms (CADServicesIndia, 2015).

A 2015 survey (BIM4M2, 2015) developed by BIM4M2, a working group concerned with BIM for manufacturers, analyses the latest BIM Adoption Survey for BIM usage and awareness (which results are shown in Figure 1.1) foreseeing that that BIM would soon have been the norm.


*Figure 1.1 - BIM adoption foreseeing, 2014*

As can be seen below, a higher interest on BIM-related software is demonstrated also by terms of internet search. Making a comparison between Revit, a well know BIM-related software, to a “less BIMable” ArchiCad, trends values (taken from 2014 to March 2017) suggest for the first one an increasing growth in the interest of investment (Google Trends Web Site, 2017).

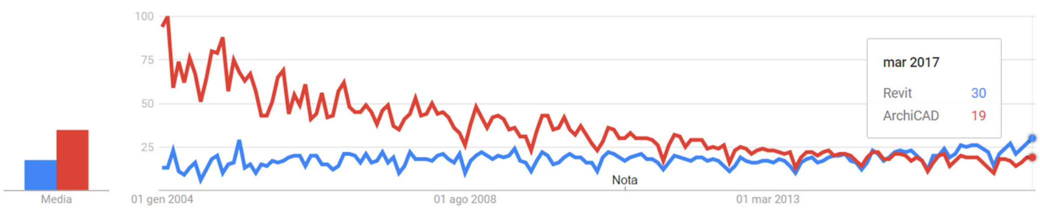



*Figure 1.2 – Italy trends*

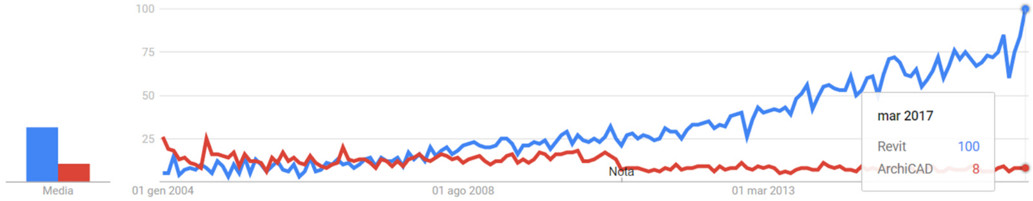



*Figure 1.3 – UK trends*

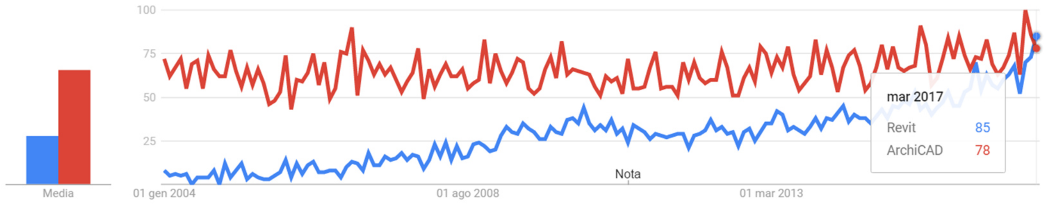



*Figure 1.4 – Germany trends*

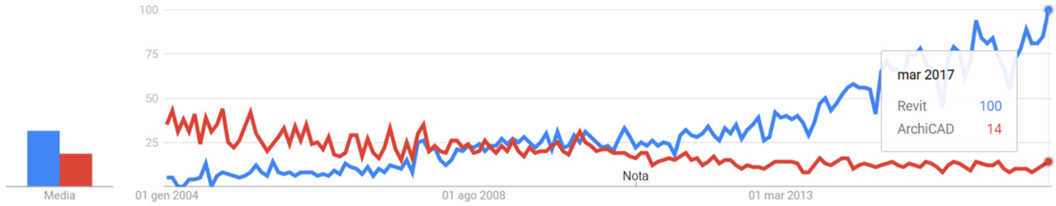



*Figure 1.5 – Spain trends*

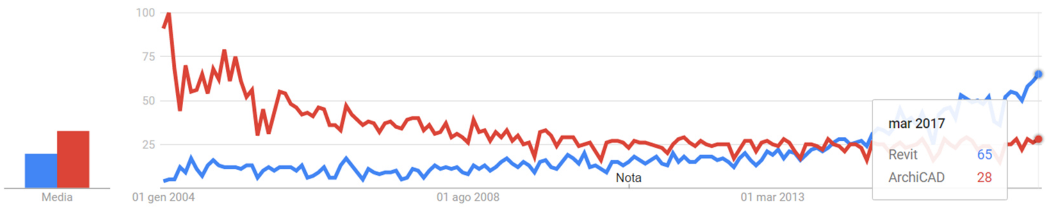



*Figure 1.6 – France trends*

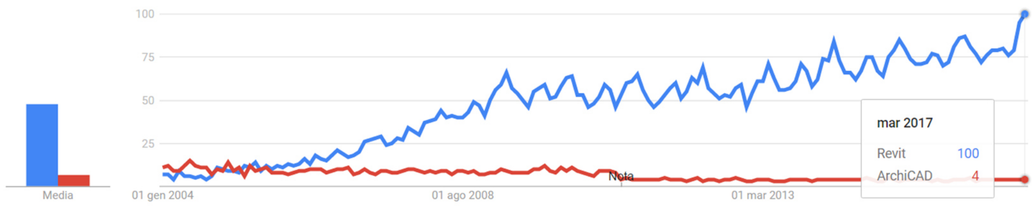



*Figure 1.7 – USA trends*

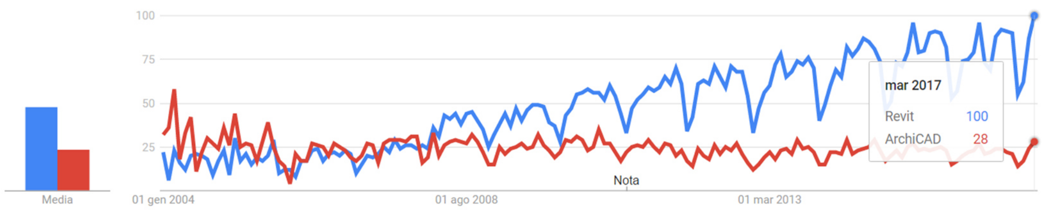



*Figure 1.8 – Australia trends*

# 1.1 Global State of BIM: Current Market Data

In 2014 McGraw Hill Construction published its first SmartMarket Report on the adoption and use of Building Information Modeling (BIM) for construction projects worldwide. The report reveals the value contractors find in their use of BIM in nine of the largest global construction markets: Australia/New Zealand, Brazil, Canada, France, Germany, Japan, South Korea, U.S. and U.K., and analyzes significant amounts of data on industry trends. Furthermore, the SmartMarket Report states that from 2007 to 2012, BIM adoption in North America jumped from 28% to 71% (McGrawHill, 2014). Taking a quick look to European countries, it is interesting to see how BIM has been implemented within construction firms between 2013 and 2015, giving thus a plausible forecast of its future growth.

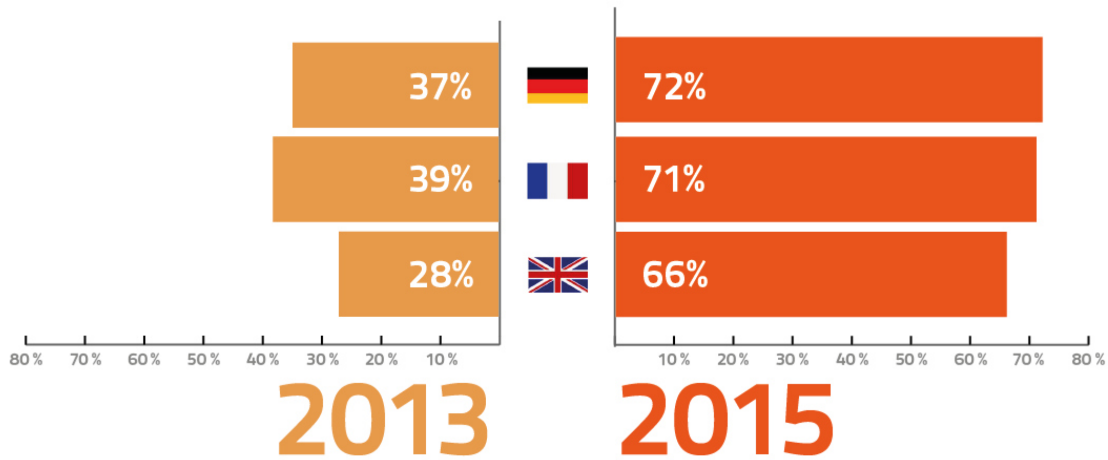



*Figure 1.9 – BIM growth in 2013-2015 (McGraw Hill Construction, 2013)*

Contractors in Japan, Germany and France report the highest Return on Investment (ROI) in BIM, while those in South Korea, the U.S. and the U.K. report the lowest. ROI metrics are mainly financial – reduced cost, higher profitability and higher productivity – and are supported by other metrics for project delivery – fewer Requests for Information (RFIs), fewer unplanned changes, higher customer satisfaction, and less process disruption. Across all regions, 60% of the contractors surveyed indicate that improved BIM collaboration as a result of visualization enhancements would positively impact their BIM ROI.

Findings show that contractors in nine of the world's top construction markets using BIM report that BIM helps them to improve productivity, efficiency, quality and safety on their projects, as well as their own competitiveness.

Based on its research, McGraw Hill poses several recommendations for the global future of BIM: Performance metrics can help both new and experienced BIM users continuously improve ROI for their BIM projects and make the case for new or increased investment.

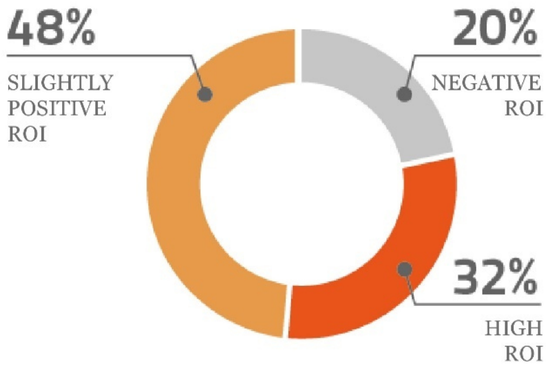



*Figure 1.10 – Estimation of Return on Investment from BIM (McGraw Hill Construction, 2013)*

Contractors should explore new technologies – such as laser scanning, augmented reality, simulation and analysis, and immersive visualization – to leverage the value of their BIM data and processes.

Construction is moving toward model-driven prefabrication and assembly of modular building elements on site, which will require contractors to adapt their BIM projects to a new paradigm.

- As their BIM engagement surpasses that of designers (the trend in North America), contractors have opportunities to redefine their long-term relationships with owners in project planning, standardization of custom-built modules, and model management.

Other critical findings from the report include:

- BIM ROI increases directly with a contractor's level of BIM engagement, represented by its BIM experience, skill level and commitment to doing a high percentage of its work in BIM.
- Over the next two years, contractors expect the percentage of their work that involves BIM to increase by 50% on average.
- Contractors in all markets are planning significant investments to expand their BIM programs over the next two years, including an increasing focus on internal and external collaborative procedures, as well as hardware and software upgrades.

## Benefits (and obstacles)

In order to better understand the potentialities of BIM, it's mandatory to understand some key points concerning the implications of its use.

**Realize the benefits:**

- Compared to traditional methodologies, BIM is immediate, clear and basically more user-friendly even to non-AEC figures. Thus, its adoption can be pretty helpful in presentations, for someone trying to sell the construction of a new project, as well as for commercial developer and building contractors.
- Using BIM is helpful for non-construction types: three-dimensional visualization helps them understand what they are seeing.
- BIM offers a substantial decrease of clashes and more clarity on the images of the products, with the consequent reduction of change orders.
- A correct adoption of BIM will eliminate collisions and overlap between trades, bringing so to saving time and money.
- Models will help us “own” the project or development, leading to better customer long term relationships
- Faster and more effective processes: information is more easily shared, can be value-added and reused.
- Better design: building proposals can be rigorously analysed, simulations can be performed quickly and performance benchmarked, enabling improved and innovative solutions.
- Controlled whole-life costs and environmental data: environmental performance is more predictable, lifecycle costs are better understood.
- Better production quality: documentation output is flexible and exploits automation.
- Automated assembly: digital product data can be exploited in downstream processes and be used for manufacturing/assembling of structural systems.
- Better customer service: proposals are better understood through accurate visualization.
- Lifecycle data: requirements, design, construction and operational information can be used in facilities management (Azhar, Hein, & Sketo, 2015).

**Realize the obstacles:**

- Ownership of the BIM data: how to protect it through copyright and other laws?
- Who will control the entry of data into the model and be responsible for any inaccuracies in it?

- The software is at times difficult to navigate, even after training. For the future, there is the expectation of more use-friendly programs that can be easily used in the field.
- There are folks in the field who have been reading 2D drawings their entire lives. Widespread acceptance of the technology will require it to be as easily accessed as a set of paper plans (Stewart, 2011).

## 1.2 BIM and Mobility

Mobile access to BIM models and processes from the field is another priority identified by contractors. Bringing the value of BIM from the office to the project site is an area of increasing interest for all contractors, and investing in the hardware and connectivity to enable that is a first important step. 61% of the contractors with very high BIM engagement say that new or upgraded tablets and other mobile devices for their teams represent a key investment for the next years. By comparison, 38% of all contractors have similar plans.

> *There are proven results in the value of information mobility investments, with contractors reporting* ***shorter schedules by 9%, project cost decreases of 10% and increases in project ROI of 2%.*** *We need to encourage the industry to track and report these benefits so they can justify investing in information mobility, thereby improving their profitability. Another challenge is determining access to data and information—ranked as one of the most important factors driving investments in information mobility. While the industry has made significant improvements in information flow within or outside an office, only 37% report that their workers onsite can access information outside the trailer. The two most important functions of information mobility reported by contractors are gathering real-time data from the jobsite and conducting analyses of those data* (McGrawHill, 2014).

Nowadays, the improvement and increasing of information mobility offer remarkable benefit to contractors and designers. One need only to think about the safety of using a tablet instead of conventional paper notebook: paper tends to lose all integrity in wet weather, and so an encased tablet would be a more than adequate replacement. It has been reported of companies that learned, from using an application called Formotus on iPads, to rapidly capture and centralise engineers' observation reports, recognizing so that viewing building information models in-situ often helped explain construction methodologies better than any paper drawings could (Wilkinson, 2013).

Currently, though, according to the SmartMarket report mobile devices still tend to be used predominantly to share PDFs and electronic versions of paper drawings and documents.

# 1.3 BIM and the Cloud

Cloud systems offers remarkable solutions for BIM management and model hosting. According to the McGraw Hill Construction' survey, 52% of the contractors with very high BIM engagement use cloud solutions to host models for team access, while 65% use it for access to project information and processes. These figures compare to 44% and 50%, respectively, for all contractors. Obviously, there are several could systems directly dedicated to a certain brand or design software, such as Bim360 for Autodesk, shown in the *Chapter 7.2*. In the following section, just the "neutral" clouds for general applications are presented in order to give an idea of all the related potentialities.

## BIC Cloud

BIC Cloud is a cloud service for process management. It is not just a tool for process modelling and analysis, but a simple process management software for beginners and experts.
BIC Cloud shows the users all necessary information in one location and stops local data hoarding and long search. Process management is accompanied by a variety of documents in the most organisations:

- written procedures
- process profiles
- checklists
- work instructions
- templates etc.

*Figure 1.11 – BIC Cloud's logo*

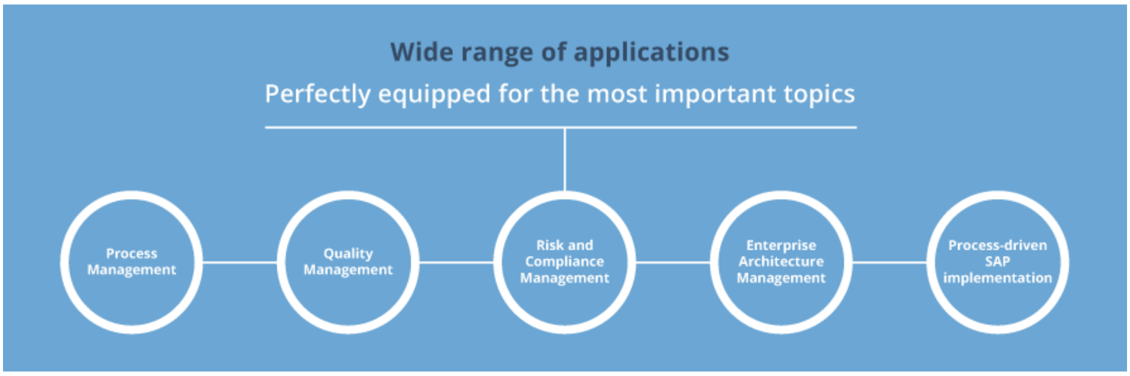



*Figure 1.12 - BIC Cloud's potentialities*

BIC Cloud optimally combines processes and documents. No long search efforts, no complicated system integrations. With BIC Cloud everyone finds his or her documents directly on the process in a few seconds (BIC Cloud Web site, 2017)

## BIM9

BIM9 is a solution that utilizes mainstream computer hardware technologies along with custom configurations, in order to allow design teams to work on large Building Information Models simultaneously from different physical locations. A BIM9 private BIM cloud provides secure access to all user's software applications and design data. Mobile users from around the world can access this data at any time from virtually any device. A BIM9 private BIM cloud gives all the benefits of cloud computing while keeping data fully under the user's control.

*Figure 1.13 - BIM9 logo*

With new CAD workstations typically costing upwards of $5,000 each, providing BIM capable hardware to each user at the desktop comes at significant expense. A BIM9 private BIM cloud allows multiple users, typically 3 to 5, to access virtualized desktops residing on a single workstation simultaneously with no degradation in performance. This has the potential to lower your hardware investment costs to as little as $1,000 per user. BIM applications are continually improving, adding new features and functionality. However, in order to fully take advantage of the new and enhanced tools, it often requires upgrading to the latest hardware and operating systems (BIM9, 2017). With a BIM9 private BIM cloud, the computing power comes from your cloud significantly reducing the system requirements for the hardware residing on each user's desk. This provides workstation longevity by extending the useful life of your existing desktop systems by several years.

# 1.4 BIM Maturity Levels

As will be described below, the United Kingdom has established a precise metric for the BIM process, in order to detect the ability of a construction supply chain to operate and exchange information (BimTalk.co.uk, Levels of BIM maturity). Here below a schematization of the maturity levels is presented (designingbuildings.co.uk, 2016). In *Chapter 2.2* it is possible to find further and more detailed discussion on the UK legislation.

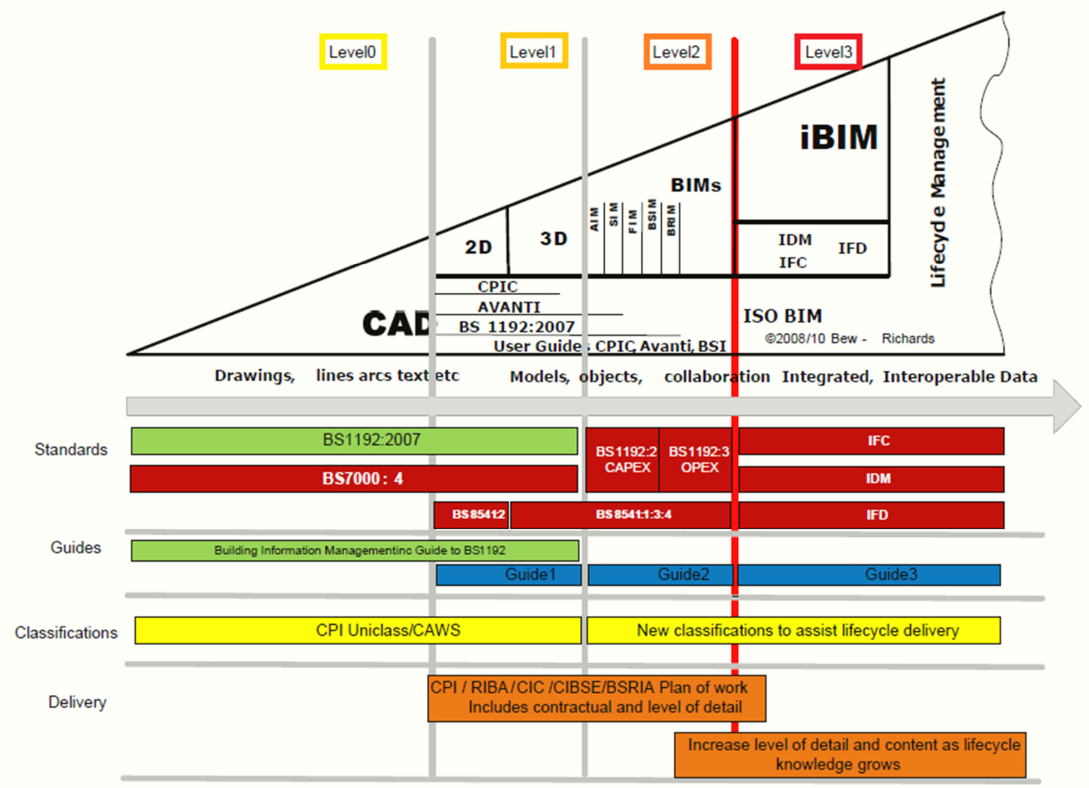



*Figure 1.14 – BIM maturity levels*

**Level 0 BIM**

It consists of unmanaged 2D CAD system including bi-dimensional drawings. The mechanism of data exchanging is basically as text paper-based or electronic exchange of information, but without common standards and processes.

**Level 1 BIM**

Managed 2D/3D CAD system provided with the introduction of spatial coordination, standardized structures and formats, basically consisting of models that are not shared between project team members.

**Level 2 BIM**

The 3D models are now managed according to separated disciplines, with data associated to the objects represented. Doing so, the models are assembled to form a federated model, without losing their identity or integrity. These data may include 4D models (3D + time-related information) and 5D models (4D + cost-related information), sometimes referred to as “pBIM” (Proprietary BIM). Here the collaborative working plays a central role. This is the level that industry has called to achieve by the UK government for all works on public sector.

**Level 3 BIM**

A completely open source process, it consists of a single collaborative and online project model with provided with 4D and 5D information, as well as project lifecycle information (6D). Generally, it is considered as iBIM (integrated BIM) and it offer great potentialities in simultaneous engineering processes

**Furthermore... Level 4 BIM?**

This level results in the creation of a model that incorporates such fine details as seismic and gravity hangers, metal framing systems, and detailed models of components like rebar. Doing so, it is possible to provide wide inputs and reviews, test the constructability, determine the best materials and methods for design and construction and so on. These models can be used to produce permit documents and shop drawings, pull material quantities, produce accurate model-based estimates, perform cross-trade prefabrication, and produce actual installation drawings (dpr-review.com).

The adoption of BIM levels in the previous years has surely brought to benefits. One only needs to think of the passage from Level 2 and 3: construction teams that decided to adopt the newest Level 3 processes found strategic and technic advantages in creating less waste, delivering in less time, as well as producing a better outcome while retaining a healthy profit margin (perspectives.3ds.com). It is remarkable to note that Level 2 has indeed brought significant benefits to architects, although its tools tend to focus on the mere design coordination problems, without analysing more deeply the construction process. The Level 3 finally offered a new approach able to connect the data chain from start to finishing, providing less ambiguity in the interoperability: indeed, BIM data is not converted into files and emailed to the other figures involved in the design process, but just a Single Source of Truth is established, stored in a database on the cloud and accessible by all project contributors via web. These potentialities bring to a clearer data comprehension concerning construction, fabrication and even facility management.

## 1.5 Levels of Development

In the design process, it is becoming quite necessary to clarify and define the detail level and features required for a project, relating to both graphic and geometric information. One of the main task of BIM is the achievement of a certain degree of data convergence, in order to better and easier detect all those useful to the commitment and adopted from the professional figures collaborating to the whole project.

This characteristic is named Level of Development (LOD), namely the reference that enables to specify and articulate with a high level of clarity the content and reliability of Building Information Models at various stages in the design and construction process.

The LOD increases as the project proceeds: at first stage, information is usually related to the existing model, then in the following phases there's an evolution that leads to an "as-built" virtual model (Bimforum.org). With this procedure then there's not only an improvement on the graphic point of view, but also a better providing of all the information that enable the client to manage and develop the project itself, as well as giving a level of reliability of the BIM information.

The concept of LOD has been defined since 2008 in the document *"AIA E202-2008: Building Information Modeling Protocol Exhibit"*, which describes and illustrates the characteristics of different building system elements at different Level of Development (AIA, June 2013).

As a matter of fact, building construction market is able to achieve great benefits from BIM, thanks to the potentiality to generate highly interoperable elaborates and projects, but only under the condition of a reliable control and validation system for every stage of the development, i.e. the correct interpretation of LOD regulation.

Indeed, digital modelling nowadays is generated through software more and more distant from the vector-based CAD of the previous decades, and has crossed the line from a mere geometrical representation towards a more intelligent system provided with extensive amount of information, able to create different degree of relationship between all the construction components.

Thanks to the LOD procedure, smart parts have been finally developed, i.e. the digital families of building components that gather the useful data that characterize not only the simple form, but also the cost, performances, installation procedures, and all other information that are will be implemented as the definition level of the projects goes on.

However, great attention must be paid talking about LOD as Level of Development. Indeed, this acronym may also (unfortunately) refer to Level of Detail, that are mainly related to the graphic detail of digital components, as seen in the different project elaborates, plans, elevations, sections, three-dimensional rendering and so on. Indeed, in UK, concerning the level of definition within a BIM project, the PAS 1192-2 defines two different components:

- Levels of Detail (LOD), which relates to the graphic content of models.
- Levels of Information (LOI), which relates to the non-graphical content of models.

Referring to Level of Development, the focus is put on the quantity of information provided. The 2013 revision of the *G202-2013 Building Information Modelling Protocol Form* clearly defines the different levels, as shown below (Harpaceas.it):

- **LOD100**: the elements are represented by a simple 2D symbol, giving a mere graphic approximation of position and shape in a bi-dimensional plane.
- **LOD200**: the elements are represented by a generic 3D solid, with approximate shape, dimension and localization, with the possibility to be provided with a link addressing to related attached documents.
- **LOD300**: the elements are represented by a structured 3D solid, including the architectonic characterizations as length, width, height, volume, material definition, main stratigraphy definition, with the possibility to be provided with a link addressing to related attached documents.
- **LOD350**: the elements are represented by a complex 3D solid with dimensions equal to the real ones. Differing from the previous LOD300, there is the possibility to integrate, within the project itself, the parameters that put in relation particular elements to each other: in this way, information such as reciprocal distances, boundaries and limitations can be quantified directly from the model, without referring to external documents.
- **LOD400**: differing from the previous LOD350, specific data of the furnisher, materials and finishings are provided. The complete stratigraphy is included, as well as certifications, structural capacity and acoustic properties.
- **LOD500**: the elements of the model have been verified in site, confirming all the data on shape, quantity, dimension and position.

T

herefore, LODs can be used at all levels of the projects in order to offer a high amount of detailed information adopted by the different project figures. Indeed, it is possible to define even intermediate levels of LOD according to the project need. For this reason, the implementation of a methodical data structure using LODs can certainly facilitate the project process, avoiding the issues and problematics coming from a lack of technic communication between the professional figures involved in it (BuildingSmartItalia.org).

With the aim to summarize and associate to every LOD its correlated project phase, here below is presented a table showing also an example of the graphic detail level related to a column (ibimi.it).

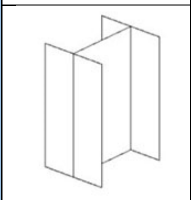
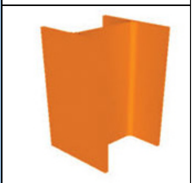
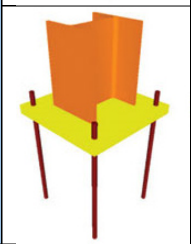
| LEVEL | GRAPHIC DETAIL | PROJECT PHASE | MADE BY | EXAMPLE |
|---|---|---|---|---|
| LOD 100 | CONCEPTUAL | PRELIMINARY | DESIGN ENGINEERS |  |
| LOD 200 | APPROXIMATED GEOMETRY | | |  |
| LOD 300 | PRECISE GEOMETRY | DEFINITIVE | |  |
| LOD 350 | PRECISE GEOMETRY | | |  |
| LOD 400 | CONSTRUCTION | EXECUTIVE | CONTRACTOR |  |
| LOD 500 | AS-BUILT | AS-BUILT EXECUTIVE | | |

*Figure 1.15 – Levels of Development*

# 2. BIM NORMATIVE AND DOCTRINES ON SAFETY

*"Evolution of BIM implementation came in parallel with willingness to collaborate and share project information, the move toward integrated practice that is much talked about in the industry"*

Phillip G. Bernstein

The adoption of BIM in safety processes is surely an innovative process, able to simplify the risk analysis in all the working procedures. This analytical approach during the design phase is more and more felt necessary from the engineering operators, in order to create an efficient and functional administration of the issues related to the safety in construction sites and the productive activities. One of the most remarkable benefits of BIM in this field is the immediate comprehension and detection of the construction areas and the whole logistic, through a user-friendly methodology and without language barriers, giving thus a better management of all the operating costs.

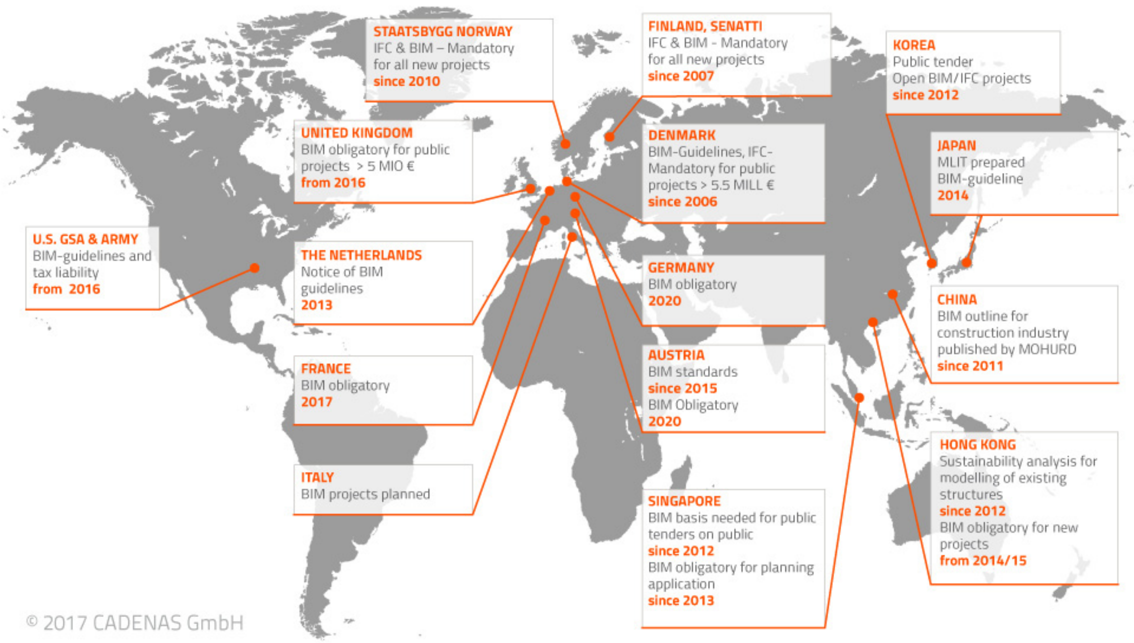



*Figure 2.1 – BIM normative in the world (www.cadenas.de)*

For this reason, a higher request of technology is spreading throughout the AEC field, with particular attention to the dynamic simulation of all the construction phases considering the time factor, i.e. the 4D modelling. Doing so, more detailed and evolved layouts can be defined, and consequently all the graphics and plans required by the safety designers: thanks to the BIM therefore, all the aspects related to the design, i.e. structure, architecture, plant system, energy, cost-control, scheduling and so on, can be included within a unique integrated environment.

Substantially, one important thing can be emphasized: the BIM method does not claim to be a substitute for already consolidated working approaches, but rather to renovate and develop them into a new digital perspective.

## 2.1 Italy

The BIM methodology was first introduced in 2009 throughout the **UNI 11337**, in which it was finally detected (part 1) the basic concept of BIM and interoperability and (part 3) suggestions about a digital sheet of the constructions products containing all the data such as LOI (Level of Information), LOG (Level of Geometry) and LOD (Level of Development). It is remarkable to note that this process started years before the renowned PAS 1992 part 2 of the English regulation; however, the Italian norm was still weak and merely introductive to the real problem, so that its development and application resulted in a little success.

After two years working by **UNI/CT 033/GL 05** "Codificazione dei prodotti e processi in edilizia" (Gruppo di Lavoro 05 della Commissione Tecnica UNI 033 "Prodotti, processi e sistemi per l'organismo edilizio), UNI 11337 has been revised in January 2017, under the following schedule:

- January 2017: part 1, 4, 5 (modelli, oggetti, LOD, clash e code, capitolato informativo –EIR - e piano di gestione informativa – BEP)
- Spring 2017: part 6 (esempio di capitolato informativo)
- Autumn 2017: part 2, 3 (classificazione, LOI e LOG)
- December 2017: part 7 (qualificazione figure professionali)
- Thereafter: part 8 (qualificazione organizazioni)

The aim of the revision is to finally introduce, albeit gradually, a defined set of modalities and applications within the digitalization of every day working activity, in order to achieve the most amount of benefits for each professional activity comparing to the traditional methodology . For Italy, this revision represents a substantial step in the European direction, followed also by the first introduction of the BIM concept in an Italian normative text: the **D.lgs. 50/2016** (*Codice Appalti*). Inside the document for the first time there is a clear reference to the "methods and specific electronic tools such as modellation for building and civil constructions".

Here it is reported part of "*Art. 31. Ruolo e funzioni del responsabile del procedimento negli appalti e nelle concessioni*":

*9. La stazione appaltante, allo scopo di migliorare la qualità della progettazione e della programmazione complessiva, può, nell'ambito della propria autonomia organizzativa e nel rispetto dei limiti previsti dalla vigente normativa, istituire una struttura stabile a supporto dei RUP, anche alle dirette dipendenze del vertice della pubblica amministrazione di riferimento. Con la medesima finalità, nell'ambito della* ***formazione obbligatoria****, organizza attività formativa specifica per tutti i dipendenti che hanno i requisiti di inquadramento idonei al conferimento dell'incarico di RUP, anche in materia di* ***metodi e strumenti elettronici specifici quali quelli di modellazione per l'edilizia e le infrastrutture***. (D.lgs. 50/2016 art. 31, 2016)

The urgent need of a better organic approach comes indeed from the Italian awareness of a weak productivity and technologic backwardness, in particular regarding the slow and cumbersome procedural aspects. Moreover, considering that the construction sector covers around 10% of gross domestic product, it's easy to foreseen an improvement of the productivity rate brought from the expansion of a better digitalization of the construction field (BibLus-net, 2016).

In conclusion, UNI 11337-2017 and the integration of BIM within the D.lgs. 50/2016 will set the basis for a complete digitalization in the construction's sector. However, it's significant to stress the importance of a true investment in human capital. Saving costs is going to be significant thanks to BIM, making it possible to create the conditions of lifting a sector in crisis, but this is not going to happen if BIM will be adopted merely for the 3D graphic: in order to achieve this technological leap forward a considerable investment in people and formation is required, as well implementing both hardware and software.

## INNOVance

The revision of the UNI 11337 has its roots from INNOVance, a research project financed by the Italian Ministry for Economic Development with the aim of creating the first national construction's database, containing information about products, works, spaces, etc., along the whole constructions service life (Pavan, et al., INNOVance: Italian BIM Database for Construction Process Management, 2014).

Indeed, the construction process involves several professional figures and stakeholder, such as purchasers, users, designers, components' manufacturers and builders. All their roles cover each different phase of the building life-cycle, from the design and construction to the use and management, until the facility management and the eventual disposal. Therefore, a great amount of data is gathered during the processes, with the result of a higher probability of making mistakes that can bring to schedule's delay and increase of budget, as well as affecting the performances of the final building developed (Pavan, et al., Gestione informativa delle costruzioni, INNOVance per il processo costruttivo, 2014). To avoid this issues, INNOVance created a well-structured database in order to describe all the objects and processes of the construction design by using BIM.

The main advantages achieved thanks to this project are the following:

- Giving an unambiguous name to everything in the construction process
- Obtaining a standardised technical sheet related to each professional figure involved in the respective process
- Offering a web portal that allows users to benefit from the developed information

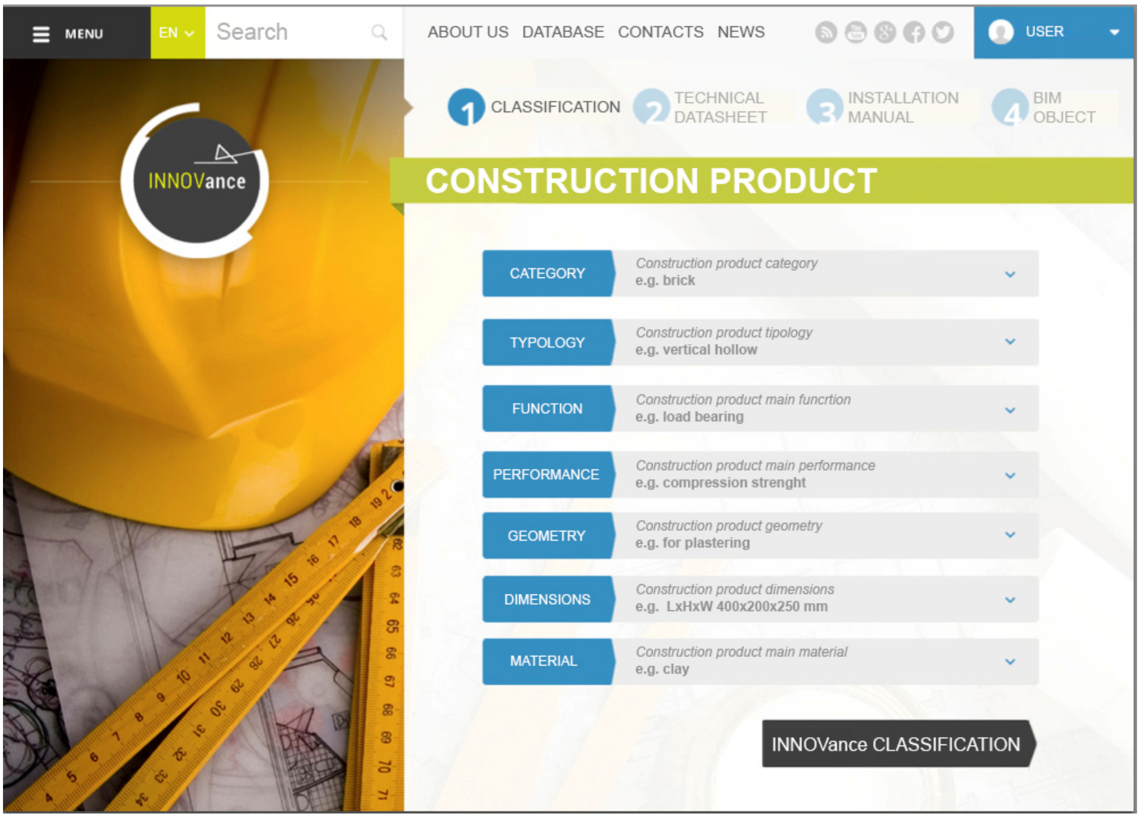



*Figure 2.2 – INNOVance's constructor product sample*

Obviously, there is the awareness that the road of INNOVance has been – and still is – pretty long, but high hopes are expected for a project that *"will finally bring to an efficient* *standardisation of materials and processes throughout the elimination of those interpretation difficulties that are very common in the public works sector"* (Lento, 2013).

## D.lgs. 50/2016 (*Codice Appalti*) & TU 81/2008 (*Testo Unico*)

On April 18th 2016 the new legislative decree about the public contracts has been approved. It includes also the contents of the **2014/24/UE** directive, and therefore the adoption of BIM becomes mandatory. This decree repeals all the contents of the Italian **D.lgs. 50/2016** (*Codice Appalti*) that were not matched by the European regulations, in order to let Italy catching up with the rest of countries.
The new code prescribes that:

- the electronic tools must be interoperable platforms
- it is mandatory to use open files

This is in order to not limiting the competitiveness between technology dealers.
Furthermore, the new Codice Appalti prescribes for the first time that **BIM will be mandatory, from 2019 onwards, but only for public works of more than 100 million €.** Then, after a series of "progressive deadlines" (D.lgs. 50/2016 art. 23 comma 13), the system should come into effect fully on 2022, when BIM will become compulsory (unless there are further modifications).

In order to get everybody prepare for the new prescriptions about BIM, a 3-steps calendar has been set:

**Step 1: 2019**

BIM will be mandatory for enormous works, i.e. over 100 million €. Not so many, considering that in 2016 only 26 works exceeded that threshold (CRESME data, 2016).

**Step 2: 2019 – 2021**

Obligations will expand to other profiles, following a criteria of complexity of the work (rather than cost): BIM will be mandatory only for strategic constructions, with particular safety standards.

**Step 3: 2022**

BIM will be mandatory for every work, except for those not requiring particular safety issues, such as small residential works.

The introduction of this calendar is necessary within the Italian sphere, being the formation level still low, and hence the immediate introduction of the mandatory BIM would be inconceivable (EdilTecnico.it, 2017).

In the Italian context, integrated building design has to pay attention to all the technical requests described in the “Testo Unico” **TU 81/2008**, that is considered as the forerunner regarding engineering design in general as well as the topic of safety.
Analyzing the TU, the “Section IV – Formation, Information and Training” gives an idea of the potentialities of VR simulation trainings. In detail, here is reported the first part of “Article 37 – Formation of the workers and their representatives”:

*1. Il datore di lavoro assicura che ciascun lavoratore riceva una **formazione sufficiente** ed adeguata in materia di salute e **sicurezza**, anche rispetto alle conoscenze linguistiche, con particolare riferimento a:*
*a) **concetti di rischio, danno, prevenzione, protezione**, organizzazione della prevenzione aziendale, diritti e doveri dei vari soggetti aziendali, organi di vigilanza, controllo, assistenza;*
*b) rischi riferiti alle mansioni e ai possibili danni e alle conseguenti misure e **procedure di prevenzione e protezione** caratteristici del settore o comparto di appartenenza dell’azienda.*

*2. La durata, i contenuti minimi e le modalità della formazione di cui al comma 1 sono definiti mediante Accordo in sede di Conferenza permanente per i rapporti tra lo Stato, le Regioni e le Province autonome di Trento e di Bolzano adottato, previa consultazione delle parti sociali, entro il termine di dodici mesi dalla data di entrata in vigore del presente decreto legislativo.*

*3. Il datore di lavoro assicura, altresì, che ciascun lavoratore riceva una formazione sufficiente ed adeguata in merito ai rischi specifici di cui ai titoli del presente decreto successivi al I. Ferme restando le disposizioni già in vigore in materia, la formazione di cui al periodo che precede è definita mediante l’Accordo di cui al comma2.*

*4. La formazione e, ove previsto, l’addestramento specifico devono avvenire in occasione:*
*a) della costituzione del rapporto di lavoro o dell’inizio dell’utilizzazione qualora si tratti di somministrazione di lavoro;*
*b) del trasferimento o cambiamento di mansioni;*
*c) della introduzione di nuove attrezzature di lavoro o di nuove tecnologie, di nuove sostanze e miscele pericolose54.*

*5. L’**addestramento** viene effettuato da **persona esperta** e sul luogo di lavoro.*

*6. La formazione dei lavoratori e dei loro rappresentanti deve essere **periodicamente ripetuta** in relazione all’evoluzione dei rischi o all’insorgenza di nuovi rischi.*

*7. I dirigenti e i preposti ricevono a cura del datore di lavoro, un’adeguata e specifica formazione e un aggiornamento periodico in relazione ai propri compiti in materia di salute e sicurezza del lavoro. I contenuti della formazione di cui al presente comma comprendono:*

*a) principali soggetti coinvolti e i relativi obblighi;*
*b) definizione e individuazione dei fattori di rischio;*
*c) valutazione dei rischi;*
*d) individuazione delle misure tecniche, organizzative e procedurali di prevenzione e protezione.*
*7-bis. La formazione di cui al comma 7 può essere effettuata anche presso gli organismi paritetici di cui all'articolo 51 o le scuole edili, ove esistenti, o presso le associazioni sindacali dei datori di lavoro o dei lavoratori.*

*8. I soggetti di cui all'articolo 21, comma 1, possono avvalersi dei percorsi formativi appositamente definiti, tramite l'Accordo di cui al comma 2, in sede di Conferenza permanente per i rapporti tra lo Stato, le Regioni e le Province autonome di Trento e di Bolzano.*

*9. I lavoratori incaricati dell'attività di* ***prevenzione incendi*** *e lotta antincendio, di* ***evacuazione*** *dei luoghi di lavoro in caso di pericolo grave ed immediato, di salvataggio, di primo soccorso e, comunque, di* ***gestione dell'emergenza*** *devono ricevere un'****adeguata e specifica formazione*** *e un* ***aggiornamento periodico****; in attesa dell'emanazione delle disposizioni di cui al comma 3 dell'articolo 46, continuano a trovare applicazione le disposizioni di cui al decreto del Ministro dell'interno in data 10 marzo 1998, pubblicato nel S.O. alla G.U. n. 81 del 7 aprile 1998, attuativo dell'articolo 13 del decreto legislativo 19 settembre 1994, n. 626(N).*

*10. Il rappresentante dei lavoratori per la sicurezza ha diritto ad una formazione particolare in materia di salute e sicurezza concernente i rischi specifici esistenti negli ambiti in cui esercita la propria rappresentanza, tale da assicurargli adeguate competenze sulle principali tecniche di controllo e prevenzione dei rischi stessi.*

## Certification

ICMQ is the certification authority responsible for issuing certificates concerning the BIM field. The Italian Codice Appalti, after the described integration of all the addictional informatization amendments BIM-related, doesn't impose yet the obligation for BIM, though defining it facultative from contracting entities for public works over 5.225.000 €. An interesting reflection can be provided by the words of Lorenzo Orsenigo, CEO of ICMQ:

> *"Keywords for the future of construction are few, but clear: sustainability and BIM are among these. And the two aspects are perfectly complementary".*

The professional profiles that can be certified are three:

**Bim Specialist**: responsible for the creation and development of the 3D modelling and the subsequent extraction of the 2D documentation and data information. This figure also perfomes the technical analysis (structure, plants and environmental sustainability)

**Bim Coordinator**: responsible for the coordination of the Bim Specialist involved in the project, in order to guarantee the application of standards and processes. Moreover, this figure develops and update all the BIM contents (libraries and standards)

**Bim Manager**: responsible for the management and updating of the BIM model for all its disciplines, by coordinating the activities of the previous two figures. Besides, this figure guarantee the coordination of the project, handling the roles and phases, and detects the interferences reallocating then the adjustments within the project team (ICMQ Web site, 2017)

## BIM and Safety perception: from regulation to contractors *(interviews to Fabio Del Carro, Angelo Deldossi and Antonio Crescini)*

In the Italian Region of Lombardy, the promoting and the strengthening of the health and safety protection of the workers in construction sites is the task of ASLE (L'Associazione per la Sicurezza dei Lavoratori dell'Edilizia). Its territorial jurisdiction cover 249 municipalities in the provinces of Milan, Lodi, Monza e Brianza. ASLE was established in 1998 and trough an agreement between the 3 main labour organisations of the building sector (Fillea-Cgil, Filca-Cisl, Feneal-Uil) and the associations representing construction companies of provinces of Milan and Lodi (Assimpredil Ance). This association is based on the Italian decree L. 626/94 at the time, now D.Lgs 81/08, that provides for the establishment of the Worker's Safety Representative, named "Rappresentante dei Lavoratori per la Sicurezza di ambito Territoriale" (RLST), who shall exercise the powers in matter of safety with regard to the territorial companies - or production units – in which the Worker's Safety Officer, named "Rappresentante dei Lavoratori per la Sicurezza" (RLS), has not been elected or appointed. It's pretty clear to note that the RLST is a figure of paramount importance, especially considering the size of the construction's enterprise (generally with an average of 5 employees) and it is for this reason that ASLE has the task of coordinating and supporting the activities of each RLST.

As Fabio Del Carro, General Secretary of Filca Cisl Milano, pointed out in an interview with the author, it's interesting to analyse the most frequent criticalities occurring in the construction sector. A lack of culture is the basis of everything: it's not so uncommon to find cases of evasion from the safety prescriptions, avoiding even the simplest key concept about protection of workers, above all the failure to use protection helmets. These phenomena generally occur in smaller construction sites, where safety procedures are barely followed. High-falls are included in the criticalities, especially during the first stages of working sites, with additional negative consequence in case of a lack of individual protections.

In 2015, according to report held by INAIL (Istituto Nazionale Assicurazione Infortuni Sul Lavoro), **341.120** injuries occured in Italy (not including the ones occurred "out of the company", such as during travels). Among these, **37.310** are concerning construction activities (Banca Dati Statistica, 2017) corresponding thus to more than **10%** of the total (Inail, 2016).

As well as Del Carro, same concerns about the interaction between State and contractors is felt by two renowned professional figures constituting ESEB (Ente Sistema Edilizia Brescia): the Chairman Angelo Deldossi and the CEO Antonio Crescini, both interviewed by the author. According to all them, he main problem about BIM regulations is that the contractors are moved to adopt it not so much for a genuine awareness of its potentialities and benefits, but rather for not incurring penalties applicable to infringements, creating then a sort of “policy of restrictions” fundamentally wrong for a correct application of BIM.

All the interviewed thoughts prove to be well-founded following a review held by Ance:

> *Frequently, outside interferences are not properly considered. A lot of criticalities are not taken into account, especially when it comes to suspended loads during the material handling with lifting appliances, communications and alerts for loading and unloading procedures during small-scale exceptional maintenance, lack of proper system of signage, issues related to the storage of hazardous materials and so on. Furthermore, hot water and heating systems are not provided, and agreements with public places for bathrooms and food courts are extremely rare. Concerning the execution phases, it seems that workers are not sufficiently trained in safety and risk of occupational disease. […] Work at height remains by far the most exposed to risk, generally by shortage of signage and protections systems.* (ANCE-RLST, 2013)

Moreover, it is common belief new technologies, including VR integrations, should be taken in consideration for the future of building engineering, particularly concerning construction sites. During his professional activity, Engineer Deldossi personally experienced improvements in the design process thanks to the BIM method: his company, despite the initial understandable hesitance of the employees, found a more efficient and powerful operability in the adoption of new digital instruments (such as Robot™ Structural Analysis by Autodesk) comparing to previous traditional techniques.

AS a conclusion, concerning the possibility to integrate new digital technologies in aid of building engineering processes, as well as the prospect of future collaborations between federations and start-ups VR-related, really noteworthy is Del Carro’s answer: “I certainly should hope that, otherwise I don't know what the world's coming to”.

## 2.2 EU legislation about BIM

Most of EU States have been revisiting their normative concerning BIM between 2012 and 2014, or they're still doing it at present time.

In general, only one thing can be said about BIM legislation: no legislation starts from the State. Generally, it is proposed by the state through Universities, it finds agreement and support from the purchasing sector gaining enough knowledge in order to come back to the State, and therefore the subsequent guidelines, best practices and standards can be emitted. Only four European countries have declared that BIM must be mandatory by national decree: Denmark, Finland, Norway and United Kingdom.

The tools adopted for introducing BIM are basically the followings:

- Creation of a digital platform (as happened in Germany)
- Creation of a task group based on the British BIM task group model
- Studies from foreign examples (Spain and Ireland)
- Throughout a pilot project (France)
- Creation of best practices, guidelines and national standards (northern Europe countries)

Concerning BIM, nowadays there is a wide range of ISO regulations, such as:

- ISO STEP 10303 "Standard for the Exchange of Product model data"
- ISO 12006 "Building construction - Organization of information about construction works"
- ISO 16354 "Guidelines for knowledge libraries and object libraries"
- ISO 16739 "Industry Foundation Classes (IFC)"
- ISO 16757 "Data structures for electronic product catalogues for building services"
- ISO 29481 "Building information modelling. Information delivery manual (IDM)"
- ISO/TS 12911 "Framework for building information modelling (BIM) guidance"

During the last years, BIM has been introduced within the international normative thanks to the cooperation of the group ISO/TC 59/SC 13/WG 13 "Information Management", promoted and coordinated by the United Kingdom. The new ISO, named **ISO 19650-1** ("Information Management Using Building Information Modelling"), stems from the English PAS 1192 (part 2 and 3) concerning BIM managing in the project and executive phases, as well as management and maintenance. The Italian representatives are composed of Alberto Pavan (UNI – Politecnico di Milano) and Angelo Ciribini (Università di Brescia)

Since February 17$^{th}$ 2017 these regulations are freely available for public revision until April 11$^{th}$ 2017. They consist of two parts:

- BS ENISO 19650-1 Organization of information about construction works – Information management using building information modelling. Part 1: Concepts and principles
- BS ENISO 19650-2 Organization of information about construction works – Information management using building information modelling. Part 2: Delivery phase of assets

As explained in the introduction of the relative draft, the first part sets out the concept and principles for successful information management at a stage of maturity described as "BIM according to ISO 19650". This International Standard provides recommendations for a framework to manage information including exchanging, recording, versioning and organizing for all actors addressing every working environment. This standard applies to the whole life cycle of a built asset, including strategic planning, initial design and construction, day-to-day operation, maintenance, refurbishment, repair and end-of-life. The concepts and principles contained in this part of the standard are aimed at all those involved in the asset life cycle. This includes, but is not limited to, the asset owner/operator, the project client, the asset manager, the design team, the construction supply chain, an equipment manufacturer, a system specialist, a regulator and an end-user. There are many different procurement routes and appointment arrangements for asset owners/operators or project clients to choose from to best meet their specific requirements. Although the roles, procedures, processes, activities or tasks described in all other parts of this standard might vary, the concepts and principles described in this document should be adopted and applied in accordance with the specific circumstances and requirements of the asset management or project delivery activities (ISO 19650-1, 2017).

On the other hand, the second part specifies requirements for information management, in the form of a management process, within the context of the delivery phase of assets and the key exchanges of information within it, when using building information modelling. This International Standard is primarily intended for use by:—those involved in the management or production of information during the delivery phase of assets;—those involved in the definition and procurement of construction projects;—those involved in the specification of appointments and facilitation of collaborative working;—those involved in the design, construction, operation and maintenance of assets; and—those responsible for the realization of value for their organization from their asset base (ISO 19650-2, 2017).

Here below in detail, the individual situation for the most influencing countries concerning the construction sector, analyzing the annual remarkable step-by-step processes.

## United Kingdom

In 2011 UK disclosed the document "Government Construction Strategy", updated the following year with the "Government Construction Strategy: one year on and action plan update", in which several financial objectives for the 2016 have been set down as well as the relative tools for pursuing them, including among them also the BIM technology. After that, a European consultative group named "EU BIM Task Group" has been created with the aim of coordinating and gathering all the arrangements and rules necessary to the introduction of BIM into the public works of the European Union.

Beside all the official documents aimed at specifying policies and targets, the British Standard Institution developed a range of remarkable standards, such as the BS 1192 – Pas 1192-2 // 3 // 4 // 5 and others related to them. The acronym PAS stands for *Publicly Available Specification*. Just recently, on Christmas 2016, the British guidelines **PAS 1192-2** relating BIM went under public revision. They are Specifications, meaning they resemble a Norm in the way they are written but they are drafted on a speed track, often responding to an urgent market need and equally often in areas of rapidly evolving technology. The official standard they refer to is the British Standard carrying the same number, **BS 1192** (Rizzarda, Pas 1192-2 is under revision, 2017). After this revision, the Employer Information Requirements are getting more structure than before, with the identification of the most important professional figures within the BIM process:

- the **Digital Plan of Work**
- the **BIM Execution Plan** (pre contract)
- the **Master Information Delivery Plan** that states who is going to deliver what and in which stages. It is in close contact with the Responsibility Matrix, the Model Production and Delivery Plan and, consequently, the Model Production and Delivery Table
- the matrix for **Project Roles and Responsibilities**
- the **Contractors Proposal**

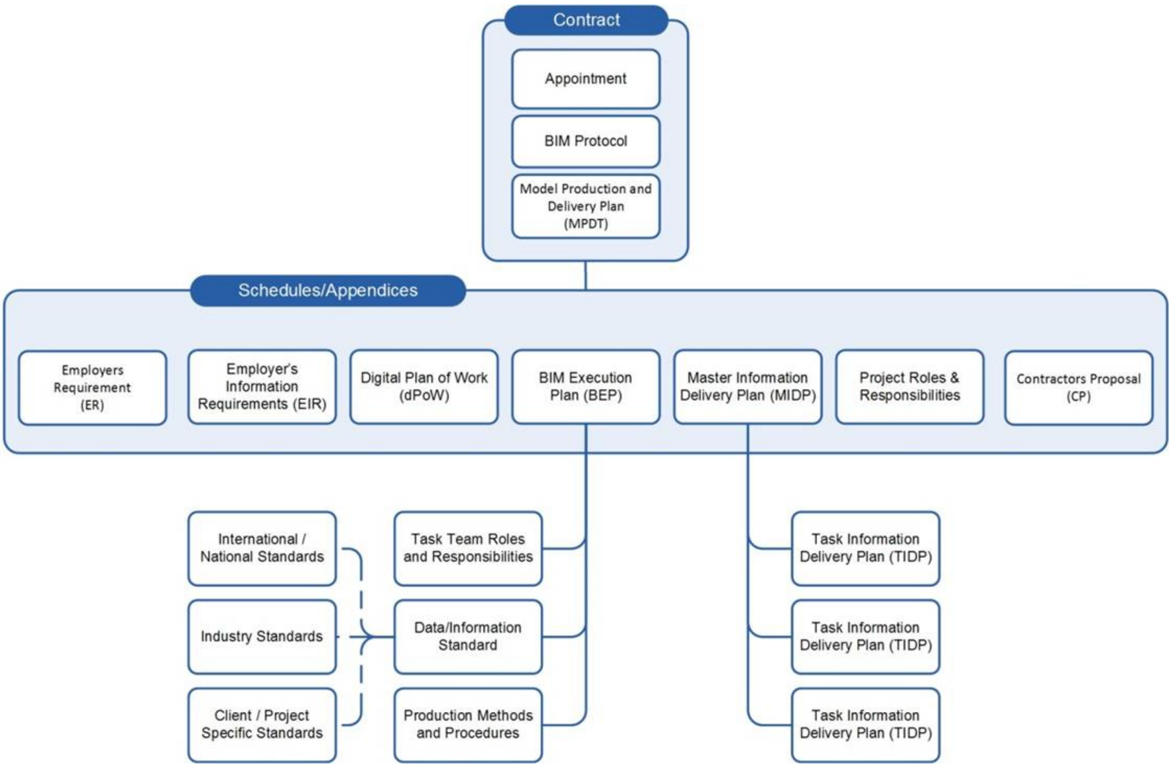



*Figure 2.3 – Structure of the contract phase*

These standards represent an important reference to the application of BIM, analyzing all the building life cycle, from the design to the construction and management.

In particular, the British Standards embraces all the known BIM maturity levels, from level 0 (CAD) to level 2. It is basically a Code of Practice that regulates the collaborative production of information related to the AEC field. It's interesting to note that the acronym "BIM" never occurs in this document. On the other hand, the relative PAS 1192-2, accorded to the British Standard, is the document published by the British Standard Industry but sponsored by the Construction Industry Council, whose goal is the specification of the requirements necessary to the achievement of the level 2 BIM (Shelidon, 2015). Here, the acronym "BIM" occurs around a hundred times. In a nutshell, the BS 1192 is the regulatory reference under which all the different PAS 1192 show how to achieve the BIM objectives following the guidelines expressed by the standards.

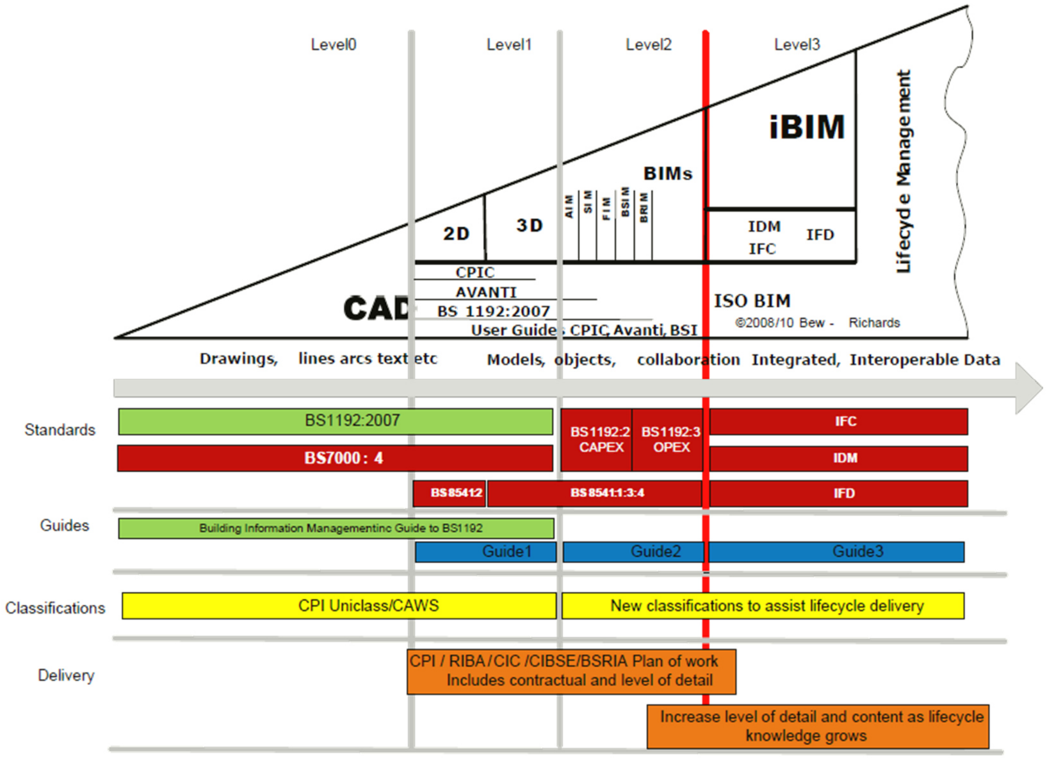



*Figure 2.4 – UK standards and guidelines*

As a conclusion, the Pas 1192-2:2013 offers the identification of two distinct areas, related one to BIM (named "Common Data Environment – CDE") and the other (the cycle around) to the management of the whole design process:

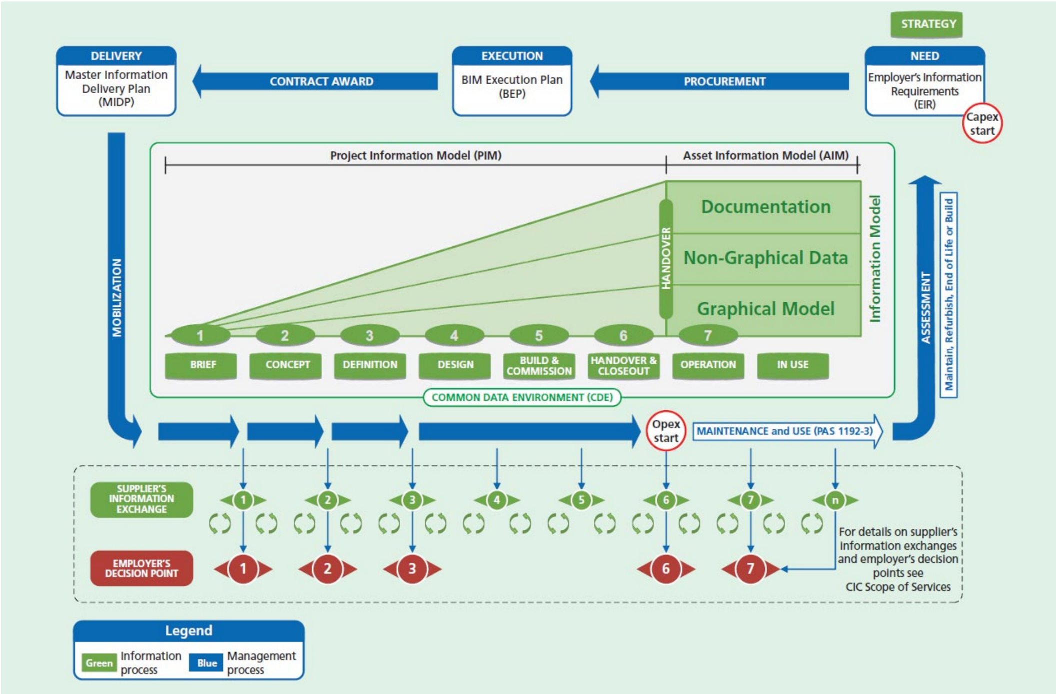



*Figure 2.5 – Information delivery cycle*

Referred to the PAS 1192, in 2015 the BIM Technology Protocol v2.1 (constantly updated) has been released with the following scopes:

1. To maximise production efficiency through adopting a coordinated and consistent approach to working towards the UK Government levels of BIM maturity.
2. To define best practices that ensure delivery of high quality information and uniform information exchange across an entire project.
3. To ensure that digital BIM files are structured correctly to enable efficient working in a collaborative environment across all project participants (AEC (UK) BIM Technology Protocol v2.1.1, June 2015).

Specific BIM Protocols exist for different software products, such as Autodesk Revit, Archicad, Vectorworks, Bentley AECOsim Building Designer and so on, including even a BIM Execution Plan template and a Model Matrix.

## Germany

2012: The Federal Ministry for Trasports, Construction and Urbanism (*Bundesministerium für Verkehr, Bau und Stadtentwicklung – BMVBS*) commissioned a year-long research project named ZukunftBAU, i.e. *"Future Building"*. It represented actually the BIM-Guide for Germany, a six-pages document that analyzed the existing situation with respect to the other countries' one, giving input and suggestions on future studies and objectives (ZukunftBAU, 2013).

2015: During the Munich's BAU Fair in January, it has been announced the launch of a digital platform for constructions (Plattform Digitales Bauen) with the aim to gather all the experiences and contributes in order to study a future national strategy for the adoption of BIM. At the actual time, no federal legislation about the public contracts in BIM has been adopted, although there is talk of a warrant concerning infrastructure by the end of 2020 (Rizzarda, 2016).

## France

In January 2015 France approved a 20 billion € fund for a transition to a digital environment. This plan, guided by Jerome Mast after a six-months research moved forward by Bertrand Delcambre since 2014, has the aim of developing around 500,000 housing projects with BIM technology by the end of 2017[1]. After that, the final goal is meant to be the adoption of BIM for every public works in the country, both for construction and management (Boughriet, 2016).

## Greece

Despite the progressive development of BIM throughout Europe, not all the countries are willing to adopt it. A remarkable example is the one of Greece, convinced of how would be wrong to teach BIM during the architects' formation, as expressed by Matthaios Papavasiliou (architect and educator at the Civil Engineering Department of the Metsovio University of Athens) during an interview in 2011:

*"In general, my opinion is that BIM should not be introduced in architectural training. I believe that because it has integrated designing tools, most of which have certain libraries that offer certain architectural aspects such as openings and a general design pattern. In my view this could be an inhibitory factor in architectural composition"*

And again:

*"BIM can help work upon the lighting, the environmental information and various other data related to the design. But its use, of course, does not ensure the creation or the completion of a better architecture"* (Chatziandreu & Kostopoulou, October 2012).

[1] (Knutt, 2015)

# SECTION B

## VR SIMULATIONS & THE PROTOTYPE

# 3. VIRTUAL REALITY SIMULATIONS

*"I hear and I forget. I see and I remember.*
*I do and I understand"*

Confucius

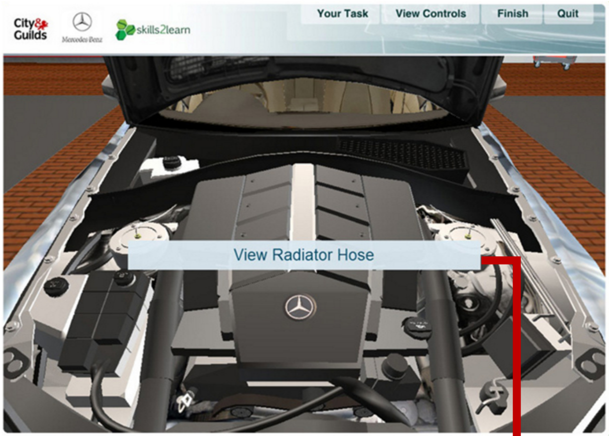
## 3.1 What is a Virtual reality simulation?

Virtual reality simulation consists of the adoption of 3D objects and environments to create immersive and engaging learning experiences. Teach, practice and check a user's knowledge is the principle of virtual reality e-learning, and all this is achieved with the implementation of interactive scenarios and environments in order to reflect real-life situations.

The environment or situation can be created using the 3D technology, that is referred to as Real World Environment. Through this immersive technology, virtual reality simulation provides a truly interactive experience. Users can move freely around the environment, interact with objects, carry out tests, make decisions and mistakes until they have mastered the subject.

By letting learners practice in a virtual environment, it is possible not only to be able to see what they've learnt but also they're approach and thought process to a problem.

Immersive simulation can be done with or without headset.




In example, Skills2Learn's virtual reality simulation is carried out on a computer screen using mouse and keyboard, so the user doesn't have to worry about wearing or investing in a headset or any other expensive equipment. The uses of this virtual reality simulation can range from replicating the way machinery operates to soft skills, such as human actions and behaviour.

Using 3D and virtual reality environments as part of training methodology allows students or workforce to experience an entirely new side of training. This type of technology breathes life back into traditional computer based learning and re-awakens the enthusiasm in users who are used to this technology in other circles outside of training (Skills2Learn Web site, 2016).

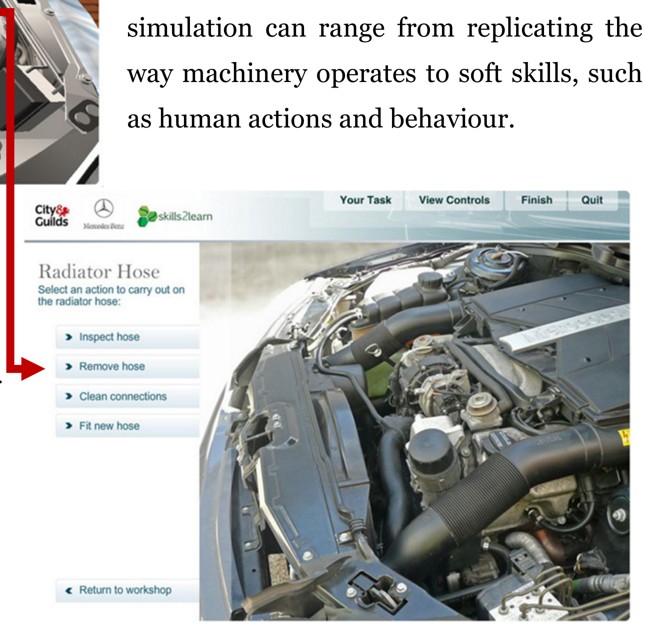



*Figure 3.1 – Skills2Learn*

# 3.2 Immersive VR simulation

Skills2Learn is probably one of the most basic example of VR simulations, but of course it's possible to find nowadays more advanced applications enabling the user to better experience potentialities and benefits of such technology.

## VirtuSphere

One among all is VirtuSphere, brainchild of brothers Ray and Nurulla Latypov, inventors who are famous for their numerous discoveries and developments in the field of computers user interfaces and games. It is created by Virtusphere Incorporation, a developer of high-end simulation systems and solutions that deliver the most-advanced setting for fully immersive simulated training, gaming and virtual walk throughs.

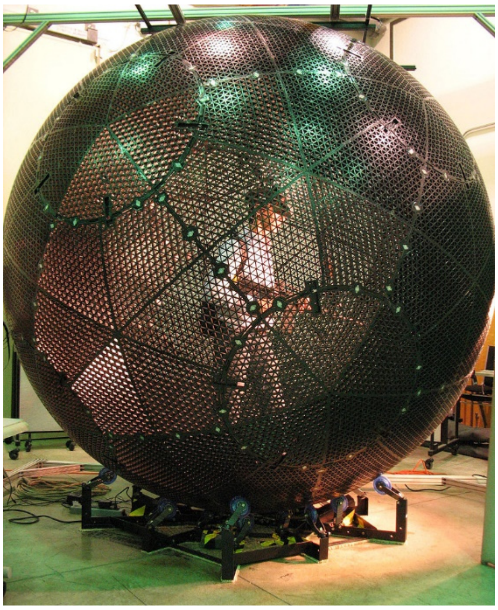


*Figure 3.2 - VirtuSphere*

The system is a spherical VR device consisting of a 3-meters diameter hollow sphere, placed on a special platform that allows the sphere to rotate freely in any direction according to the user's steps (VirtuSphere Product Description, 2016). Consequently, the system is able to rotate according to the walking movements, potentially granting an unlimited plane upon which the user can operate. A head-mounted display is provided with the system, in which gyroscopes allow both the tracking of the user's head movement and the accurate displaying of the virtual environment. By now, VirtuSphere has been adopted mainly for military-training purposes (e.g. examining future weapon systems, training of tactics, evaluating soldiers), but its market and applications may also include obviously the video gaming industry, events and shows, fitness clubs and medical centers, museums, as well as architects and real estate professionals.

As conclusion, VirtuSphere can be considered as the ultimate immersive VR simulation, being it able to allow a "full body motion": the Virtusphere was initially designed to allow people to walk in cyberspace. In addition, a user can run in the sphere (even at a very fast pace), crabwise, jump and roll. There is quite a lot of space inside the sphere, so users can punch, kick and do all kinds of moves with their whole body without encountering a physical obstacle (VirtuSphere FAQ, 2016).

It's not so difficult to understand why this technology has been viewed with great interests from the military sector, as can be deduced by the words of Jim Dimascio (Chief Operating Officer of VirtuSphere Inc.) during a 2009 appearance on the TV show "Shark Tank":

- *"Jim Dimascio is asked why somebody would need to get into the VirtuSphere, just to experience a virtual reality environment"*

- *Jim Dimascio answers the question by saying that for combat training, they can put a soldier in the middle of Baghdad and go through simulation training, both as a single and as a mission rehearsal as a team. This allows the soldiers to experience what it is like to be in Baghdad, without risking their lives* (ABC shows, SharkTank Season 1 Episode 9, 2009).

In the TV show, Jim Dimascio and the co-founder Latypov were seeking an investment of $1.5 million in exchange for 10% of their company. Unfortunately, it was not seen exactly a consumer product made for mass merchandising, being sold at about $50,000. Along with a hefty price tag, its size also made it a hard sell. Moreover, it's important to remember that it was 2009, where VR simulations were considered as still obscure matter. For these reason the investment was rejected. Maybe it was just the wrong season to appear on the show (SharkTankBlog, 2017).

*Figure 3.3 - VirtuSphere*

VirtuSphere Inc. is still active, with a dozen customers that have purchased the virtual reality simulator coming from the USA, Germany, Russia, Switzerland, and the UK.

## Cyberith Visualizer

A brighter and more fortunate destiny has marked the development of Cyberith Visualizer, original idea of Tuncay Cakmak and Holger Hager, physicist and researchers from the University of Vienna. The Austrian duo created a new hardware that aims to revolutionize the concept of immersivity.


*Figure 3.4 - Cyberith Visualizer*

The main difference easily noticeable from the predecessor VirtuSphere is obviously its reduced size (taking just 2 $m^2$ of a room), allowing the system to be mounted pretty much anywhere (VR Gamer, 2014). This new technology grants the achievement of a total immersive experience, thanks to the integration of complex sensors that allow to detect even the exact body position when crouching, as well as the height reached when jumping (Cyberith Web site, 2017).

Its potentialities are virtually infinite, and the first application include the field of fitness, gaming and architecture, with the final goal to eventually adopt devices (such as suites) able to perfectly trace the movements of all the limbs and the rest of the body. As a strength, it is also possible to find the price factor, of around 600 $ (VR Focus, 2014).

## CAVE2

It is possible to benefit not only from the potentialities of Virtual Reality, but also, at the same time, from experiencing Augmented Reality features. This can be granted by CAVE2, a hybrid (Mixed) reality environment developed in 2012 and successor of the original CAVE. The system is composed by 72 “near-seamless, off-axis-optimized passive stereo LCD panels” an approximately 2,4 m tall cylindrical shape, with a 7,3 m diameter.


*Figure 3.5 – CAVE2, structure*

This assemblage offers then 320-degree panoramic environment for displaying information at high definition, both 2D and 3D. An optical tracking system composed of 10 IR cameras allows to track different types of user-defined markers inside all the circular inner area, providing their position and orientation in space (Alessandro Febretti, 2013). The most important potentiality of CAVE2 is related to its dimensions: the space inside is large enough for having the possibility to move or sit on table collaborating with other users. Furthermore, headset devices are not required, bringing then the user to feel less stress during the session, permitting even longer session compared to the other technologies.

*Figure 3.6 – CAVE”, internal perspective*

## 3.3 Benefits of virtual reality simulations

From both a trainer and trainee point of view, VR technologies can bring the following benefits:

- ✓ **Theory and Practice**

One of the main benefits is to use e-learning to impart the theoretical understanding and knowledge, and then virtual reality scenarios to test the information learned in a life-like situation to give users the complete package. The virtual reality enables to view the competency of learners, see the decisions they make and how they then react to the consequences.

- ✓ **Real-Life Situations**

Virtual reality is used to create interactive scenarios which reflect real-life situations. Virtual reality e-learning can be used to simulate the way equipment responds; emulate the way machinery works or to replicate soft skills such as human actions and behaviour.

- ✓ **Making Learning Fun and Interesting**

As a child, anyone watched, listened and played. Everybody was intrigued by colours, shapes and sounds and the only way to found out how something worked was by playing and using it. Virtual reality simulations use these basic principles of learning to produce fun, compelling and memorable end results. Moreover, an intriguing consequence of virtual reality is to engage the user with breath-taking graphics, informative audio and interactive scenarios using 3D virtual environments to give a sense of really being there.

- ✓ **Save on Cost**

Most of times it is common to have limited training resources, equipment that is scarce or expensive, or too many people to train at one time. Then using virtual reality could be a perfect solution. By modelling the equipment, possibly down to the last detail, it is possible to distribute a training programme to all employees or learners that will allow them to interact with it, follow best practice procedures or carry out fault finding scenarios, all without having to access (and possibly damage) the real item. The adoption of virtual reality helped many clients save money and materials such as copper piping and solder flux. Of course there's no substitute for the real hands-on training but this solution goes a long way towards giving learners the knowledge and preparing them for a real life situation.

- ✓ **Complex Situations Made Easy**

Complicated pieces of equipment, processes or systems can be recreated using a number of techniques. This form of e-learning allows users to learn about mechanisms and processes that would be physically or logistically difficult to do so in other conditions.

- ✓ **A Safe Environment**

There are some occasions when training the staff is expensive and it can sometimes be hazardous, with real risk of personal injury or damage to expensive equipment. With virtual simulation it is possible to develop highly interactive, virtual reality environments to help with these issues. By creating an environment which simulates a potentially harmful real-life situation or replicating a piece of dangerous equipment, the interactive scenarios remove these concerns and help the user gain a knowledge and understanding of the subject matter without being put into a costly or harmful environment ("The Benefits of Virtual Reality and 3D Simulation", Skills2Learn Web site, 2016).

## Dale's Cone of Experience

It's easy to note that this kind of learning and training offer an immediate feedback in terms of memorization of the information, much more than the usual techniques generally offered to future employers. Indeed, it happens that notes, books, static visual information generally do not permit a sufficient achievement of the targets concerning easy learning and fast memorization: especially in the field of construction engineering and safety in sites, everything comes to be quite technically complicated and, in absence of a real interface with the physical environment, books and static visuals are pretty insufficient. For this reason, it is useful to go back to the last century and analyse a deep and wide study held by Edgar Dale, an American educator who developed the so-called *Cone of Experience*. Even though this study has no base on scientific research, and Dale himself warned not to take the cone too seriously (Lawrence, 2015 ), it offers a clear example of the VR potentialities.

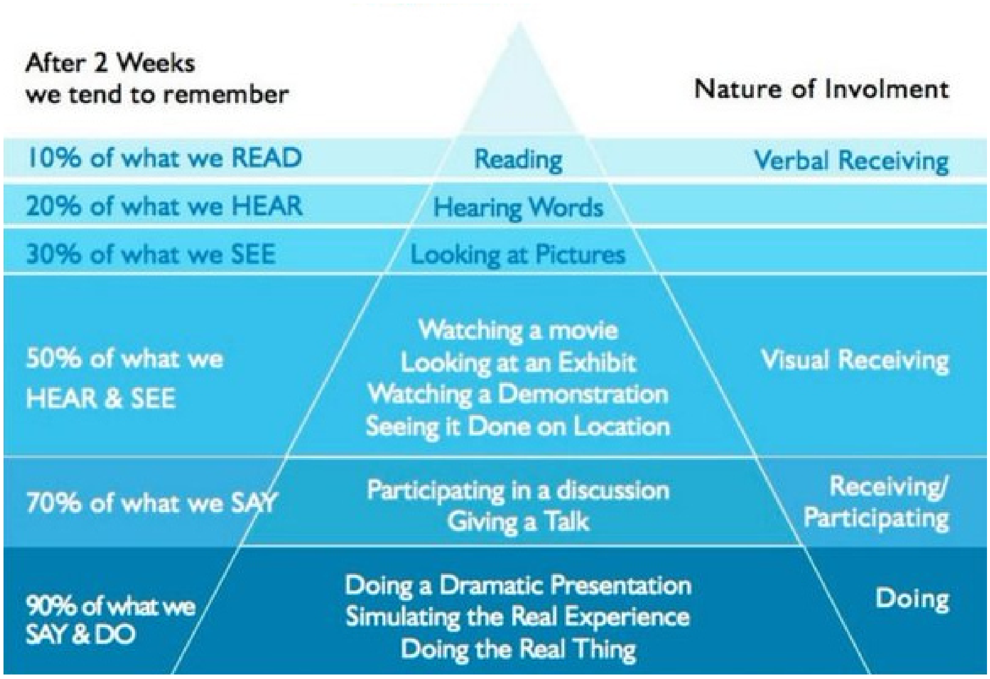



Figure 3.7 – Dale's Cone of Experience

According to his studies, Edgar set out the existence of two kind of learning:

- **Passive** learning: read, listen, look at pictures or watch movies
- **Active** learning: take part in a conversation, held a speech, give a presentation, simulate the real experience (intended as, for example, repeating a speech in front of a mirror) and do the real experience

This is the basis of the scholar or academic study method. A fast example could be made with the differences between reading a book and follow a frontal lecture: generally, after two weeks, one is able to remember only the 10% of the information read; on the other hand, it is possible to store up around 20% of what is heard. Then associating these two action it would be possible to achieve the result of 50% of stored data. As a consequence, simulations within a VR environment are able to offer a high degree of memorization thanks to the combo effect of all the sensorial inputs during the experience.
For this reason, an increasing number of VR platform for the education system are wide spreading in the last years. Indeed, according to a recent report (MarketsandMarkets, May 2016), the VR market is expected to grow more than $407 million and reach more than 25 million users by 2018. To give an example among all, **Unimersiv** developed VR educational experiences (available on *Samsung Gear VR* and *Oculus Rift*) about history, space exploration, anatomy, simulation of the original Acropolis of Athens and even an immersive exploration of the Titanic (unimersiv.com).

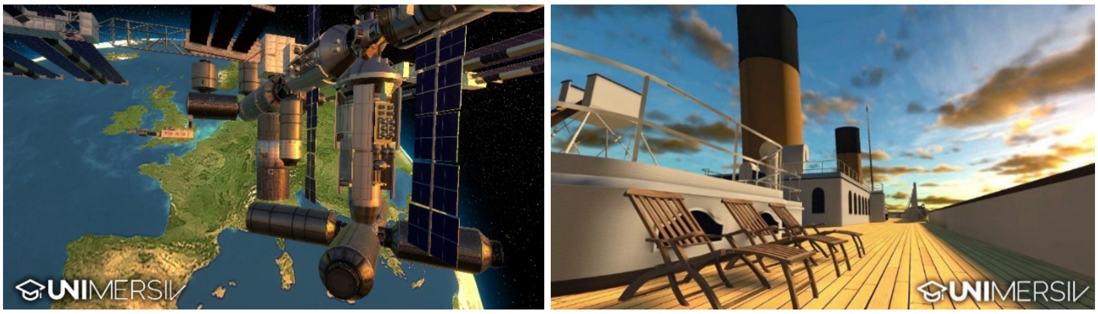



*Figure 3.8 – Unimersiv applications*

## 3.4 Applications of Virtual Reality

Nowadays most of people are familiar with the term 'virtual reality' but the uses of this technology remains still unsure for them. Gaming is an obvious virtual reality application as are virtual worlds but there are a whole host of uses for virtual reality – some of which are more challenging or unusual than others.

Here is a list of the many applications of virtual reality:

- Business
- Construction
- Education
- Engineering
- Entertainment
- Fashion
- Film
- Healthcare
- Heritage
- Media
- Military
- Programming Languages
- Scientific Visualisation
- Sport
- Telecommunications

There are many more uses of VR than first realised which range from academic research through to engineering, design, business, the arts and entertainment. But irrespective of the use, virtual reality produces a set of data which is then used to develop new models, training methods, communication and interaction. In many ways the possibilities are endless.

The only stumbling blocks are time, costs and technological limitations. Virtual reality systems such as a CAVE system are expensive and time consuming to develop. Plus, there are issues of ergonomics, specifically the need to design systems which are 'user friendly' and not likely to cause problems such as motion sickness.
But if these problems are solved then there is an exciting future for virtual reality ("Applications Of Virtual Reality", Virtual Reality Society Web page).

## Virtual Reality in Construction

The field of construction industry can achieve considerable usefulness in the adoption of virtual reality, being it known as having a very high amount of inefficiency and low profit margins. Using a virtual environment, an organisation can not only render the resulting structure in 3D but also experience them as they would in the real world.

Building a construction project in a virtual environment offers many key benefits. One of the most obvious of these is having the ability to test a number of factors without the time and cost of building the structure, reducing the number of errors present in the completed building.

## Benefits of VR in the construction design

- ✓ **Feasibility**

One important factor that needs to be thoroughly tested is the feasibility of an architectural design. For many years, human judgement and scale models were the only methods to determine whether a structure was viable or not. As we know, human judgement can be highly, and sometimes intentionally, erroneous and scale models cannot fully simulate the environment the structure must withstand.

- ✓ **Virtually Exploring the Design**

Not only can the feasibility of a building be tested before it's built, construction workers and employees can actually explore it. Feedback about a design from this is remarkable, being able to pick up even small details such as whether a worker can fit in within a space.

In designing, for example, an airport passenger terminal, one needs only to think of the application of CAD and 3D design to produce renderings and animations. With today's VR technology, it would be possible to experience the visitor journey: arriving at the terminal by taxi or car, finding the entrance, going through security to the airside, to the gate, and so on. This is just an applicative example in which it's easy to note that VR has a great impact of increasing the value of the design itself.

VR-enhanced experience design could be used in any type of project: residential, retail, hospitality, healthcare, and offices, to name a few.

- ✓ **Simulated Construction**

Furthermore, the construction of a building can be simulated in virtual reality as it would in its normal environment. This allows an organisation to fine-tune construction processes for maximum efficiency and a minimum amount of change.

- ✓ **Virtual Reality for project collaboration**

Design is, to an ever-increasing extent, collaborative. Instead of having physical or video meetings, those involved in a project could meet in a virtual environment. In fact, they could meet in the building or environment that is being designed.

Many problems and errors in construction projects stem from poor communication. When collaborating, partners are able to present, explain, and alter the design in a shared space, misunderstandings and errors are less likely to occur.

- ✓ **Virtual Reality for decision-making**

Construction projects are a constant source of dispute, even before they are built, and many projects are extremely delayed because of citizen complaints. Delays can cost a lot of money, directly and indirectly. Eventual speeding up of the planning and building permit process has a high ROI.

Why are complaints so common? People are worried about how the proposed project would affect their environment: its property prices, scenery, safety, traffic, or health. Letting people see for themselves what the changes will look like from an individual's perspective can alleviate some of these fears and worries. It can also provide valuable feedback for property developers and designers in the early stages of planning.

- ✓ **Safety**

A significant benefit on using virtual reality simulations is the achievement of a high e-learning of all the on-site construction processes, giving so a forecast of all the critic events and design issues, minimizing consequently the occurrence of eventual accidents and injuries among the workers during the future real execution. Obviously, Simulators are costly, but cheap compared to training with real equipment. Modern VR gear can provide the same quality of training support for a

*Figure 3.9 - Tower Crane VR*

fraction of the cost: for example, in the training of tower crane operators with Tower Crane VR (Campfire Union Web site, 2016).

Safety is an age-old problem in construction. Safety training using VR could possibly prevent many human tragedies. A simulated construction site could show how and where to use safety precautions. A simulation could also show the site's progress at any given date.

There are many applications for the use of VR in educating architects and engineers. Surprisingly, most designers have never worked at or even properly visited a construction site before they graduate. A virtual construction site would be a safe way to understand what happens on site.

## 3.5 The future of VR

Although it's impossible to tell when exactly virtual reality in construction will become the norm, it's only a matter of time before it does. Virtual reality will allow us to make grander and more robust buildings in a shorter space of time – a very desirable property indeed ("Virtual Reality in Construction", Virtual Reality Society Web site, 2016).

Paradoxically, VR technologies are still lagging behind the visions that people have for their use. However, VR has already demonstrated its capacity to change the ways we design, make decisions about, and produce built environments.

According to the beliefs of Aarni Heiskanen, author and host of AEC Business Newsletter, there are basically two reasons why VR might finally break through in construction:

- Firstly, **3D** and **BIM** are widely adopted in the industry. The idea of virtual buildings and environments is nothing new and has become very natural.

- Secondly, there's a growing interest in **Gaming and Entertainment VR investments**. This will push the technology forward and make it affordable to consumers.

However, the mass diffusion of VR is still at its infancy, mainly bounded by the cost factor. One only has to think that in Berlin, one of the most technologically advanced city in Europe, only two museums offer a direct test on VR applications nowadays:

- the **Computerspielemuseum**, a museum showing the complete history of videogaming, where it is possible to actively experience gaming simulations with Samsung GearVR and Oculus Rift

- the **Game Science Center (GSC)**, where two workstations equipped with Oculus Rift devices are available for a passive virtual demonstration (pictures below)

*Figure 3.10 – VR demonstrations in CGS, Berlin*

According to Peeter Nieler's 7-page report "Investing Into Virtual Reality: Making Sense Of It All" (Nieler, 2016) there are **419 Virtual Reality startups**, 149 of which are within the European Union. Nieler points out that the official number is heavily underestimated. In Spring 2016, 118,000 Oculus developer kits (second version) had already been shipped.

Drawings or renderings can never quite capture the three dimensional, spatial nature of buildings. Designers and builders have always created physical models to help simulate the feeling or physical aspects of an actual environment or building. Physical models are quite time-consuming and often costly to build. They are mostly scale models and their materials or colors don't match the real ones. 3D printing can make model building faster and cheaper, but life-sized models are still exceptions.

Virtual Reality is what we experience while playing advanced computer games. It replaces the real world with a computer-generated environment. At best, it is immersive, but that requires high-quality visors, e.g. Oculus Rift and HTC Vive, and equipment like Virtuix Omni.

Moving to VR is easy in theory, since architects and engineers already create digital models of their designs. Practice has shown, however, that existing models need to be augmented or even rebuilt to be used for VR. Software developers and designers should take this into consideration.

Virtual reality is gradually developing into a useful tool. Unlike iPhones, VR will be adapted in phases, gradually. According to Nieler, VR is a platform business. The four leading platforms are Oculus, Valve & HTC Vive, Sony PlayStation, and OSVR. The number of competing platforms is a challenge for software and service developers, but also an opportunity, since rivalry speeds up development (Heiskanen, 2016).

# 4. REFERENCES OF SIMULATED SYSTEMS IN DIFFERENT MARKETS

*"We are yet to see a person who has experienced virtual reality and emerged unconvinced"*

Ekke Piirisild

In the last decades, the term "virtual reality" is widely spread through the mass, mainly for gaming applications and entertainment purposes. However, despite many people are familiar with this term, large part of it is still unsure about the use of this technology. In the following chapter it is summarized the first attempts of introducing virtual reality for non-gaming purposes.

## 4.1 Serious Games

A serious game consists in a technology adopted for education, training, strategic messaging, mission planning & rehearsal and scientific visualization. Its main goal is to create realistic, detailed training and educational solutions to improve safety, security and way of life. The great advantage of its adoption is the achievement of real and effective professional abilities in a safe, protected and relative non-expensive environment. In 2015 it has been foretold that the VR/AR market will grow to 150 billion dollars by 2020 (Merel, 2015).

The adoption of SG has the ability to motivate users with a challenging and even playful approach, and permits the use of artificial intelligence to detect users' knowledge in the specific content, granting consequently the advancement in the game only after the achievement of the required professional acquaintance.

The VR technique is used in this game in order to offer interactive and immersive environments, thus embracing the user in a real-time computational simulation. This association to a VR context was obviously not possible in the first phases of gaming history, principally due to hardware limitations and consequent expensive platforms and advanced processing capability. Then, with the development of efficient computing - including 3D environments, high rendering quality, non-conventional-interaction and real-time feedbacks - the line between VR and training simulations became finer and less costly.

In the global scenario of VR societies, VirtualHeroes gives a clear example of how SG is capable of providing helpful experiences for different kinds of professional field (Virtual Heroes' Portfolio, 2016). A few examples:

**Combat Medic** (2014) is a single/multi-player PC game that incorporates advanced virtual patient technologies into military medical training scenarios focusing on the top three preventable deaths on the battlefield
**Mission Critical Operator** (2016) is a single-player PC game that provides training in facilities that require stable power and temperature 24/7, 364 days a year. Learn to drill down on equipment failure to keep your facility online
**Moonbase Alpha** (2010) is a NASA-funded multiplayer game scenario with 20 minutes of play set on a hypothetical lunar outpost in 3-D immersive setting.
**Pressurized Heavy Water Reactor Trainer** (2014) simulates a nuclear reactor environment and fuel pathway.
**Zero Hour** (2008) trains first responders on mass-casualty incidents such as biologic, earthquake, chemical, and explosive attacks.
**Dr. Hero - A Game of Obstetrical Emergencies** (2010) is a single player virtual trainer on the California protocols for maternal hemorrhage.
**3DiTeams** (2007) is an immersive 3D medical education and team training environment created in partnership with Duke University Medical Center
**PwC Immersive Onboarding Training Environment** (2008) provides new hires controlled interactive business training scenarios.
And further more…

Talking about immersive SG, a remarkable example is offered by **Oil Rig Operator Training Simulator**.

Offshore oil rig is renowned of being one of the most complicated and expensive equipment that a worker can deal with. For this reason, it is mandatory to adopt efficient and safe operations during all the working movements, in order to safeguard the user’s life as well as avoiding subsequent catastrophes (such as the one occurred in the Gul of Mexico in 2010). It was indeed after the numerous historical blowouts all around the world that a real awareness of the training problem started to spread among the states and environmental offices, so that employers have been started to be asked to provide more safety and operational training to their employees, giving then the VR simulation a chance to be introduced in the training system.

Similar SG can be counted among the field of oil rig simulators, such as:

**Transocean Drilling Simulator**. Developed by *Transocean*, the world's largest offshore drilling contractor, the program includes 2 world-class training centres in Brazil and it offers the opportunity to simulate complex training for drilling, crane operators and well control (DrillingContractor.org, Transocean's new Kuala Lumpur facility to train more than 1,200 a year, 2011).

**Well Intervention Simulator**. Developed by *Shell Exploration & Production International Centre* in Rijswijk, in the Netherlands. This simulator deals with command-and-control types of scenarios and specific equipment operations, and according to Shell's belief it gives the opportunity to increase the technical level of students and their learning experience, granting a higher chance of engagement in their future career (DrillingContractor.org, Well intervention simulator tops off Shell's new advanced well control course, 2011).

## 4.2 Military

VR simulations find a remarkable application in the military field, especially in the USA armed forces, i.e. Army, Navy and Air Force. For a military point of view, obviously the classic real training arsenal is quite mandatory in order to achieve all the required knowledge about the battlefield action; however, in addition to this, providing the soldier (but also technicians, engineering officers, combat medics) with a VR combat simulation could surely be a way to improve their skills and techniques in a fast and secure approach.

In a VR combat simulation, the 3dimensional environment is obtained from a head mounted display and treadmill system o even with a CAVE fully immersive VR set up. In the first case, the virtual environment embraces the operator, moving around the user and engaging with him. The sense of realism is achieved with the adoption of head mounted displays that show the scene all around, that reports all the visual contents of the simulated mission. These contents are generated by the Computer Generated Force system, that creates the battle events and keep traces of the user's movements thank to a tracking system inserted on the body armor. Doing so, the CGF is able to calibrate both the position and the visualization of the soldier, elaborating then a series of scenarios controlled by an external supervisor or even by the software's internal control itself.

One of the potentialities of this technique is the achievement of better co-working skills, being the system able to teach a group of recruits at the same time, as a real combat unit. Provided with mock weapons (or VR guns) having the same weight and look of real ones, soldiers are given the opportunity to test the battlefield as effective member of a platoon, also with the advantage to rapidly learn during the simulation from more experienced team members, as well as from themselves but without fatal consequences.

Considering the prohibitively expensive military training, VR simulations offer great benefits to military, also concerning the time factor. Indeed, the hours spent in a VR simulation are exactly compared to the ones in the real environment. This is particularly useful for all those training that concern air combat, such as helicopters and fighter jets, being the most expensive and dangerous types of trainings. Concerning flight simulators, indeed, they consist of an enclosed unit which is provided with a hydraulic lift (or an electronic system) able to tilt, move or twist in order to simulate the possible flight movements. In addition to it, a force feedback system is included in the simulation, so that the trainee is able to feel the behavior of a real aircraft after all his/her decisions about movements, and regulate the actions according to the particular force feedback given by the machine. Not only the physics aspect are simulated, but also the external environment: a virtual landscape is represented through a series of monitor which display the outer scenarios, just like as the pilot would see them through the windows of a real aircraft.

An historical demonstration of VR applied on military training has been made at the Annual Interservice/Industry Training, Simulation and Education Conference 2011 (I/ITSEC) from November 28 to December 1 in Orlando, Florida. Here, Intelligent Decisions Inc. (ID), a leading global IT systems integrator, presented the Dismounted Soldier Training System (DSTS), the first-ever fully immersive virtual simulation training system. During the conference, ID demonstrated how this simulator was able to fully provide an immersive environment with hi-fi graphics and real-time interactions with combat equipment. In the simulation the users were able to communicate with the other members of their squad connected to the system. From the words of Gino Antonelli, Intelligent Decisions executive vice president at ID, the I/ITSEC offered “a rare opportunity for us to demonstrate the cutting-edge capabilities of this training solution to experts, exhibitors and attendees from across the globe” (IntelligentDecision, 2011). Indeed, a further historical presentation has been performed in 2013 by the 4th Joint Communication Support Element at the Air Force Base, Fort Stewart, Georgia. The simulator was the same DSTS, but obviously with improved graphic quality and better performing technology. The system was again described as an “innovative, out-of-the-box training system designed to be flexible, easily portable and transportable, and ready to be used in under 4 hours”, proving the applicative feasibility and usefulness of the VR technology (James, 2015).

Furthermore, not directly connected to the military sector but equally pertinent to it, there is also another use of VR that regards the cure of soldiers affected by Post Traumatic Stress Disorder. This kind of disease is very common among the war survivor and veteran, and VR is helpful in order to adjust the sufferer to their symptoms and developing coping strategies whenever they are placed in new situation.

## 4.3 Civil Engineering

Three-dimensional modelling is nowadays wide-spread throughout many engineering applications, granting a better comprehension and analysis of all the technologic aspects during the project phase. However, in addition to it, VR technology can be applied as a complement in order to achieve higher operative benefits both for education and professional practice, especially for the purpose of managing the transmission of information (both visual and interactive) related to the physical behaviour of the construction elements. Furthermore, concerning universities' education, this innovative kind of interaction could bring as a consequence to the end of passive learner attitudes that often can be found in traditional academic teaching contexts (Sampaio, Cruz, & Martins, 2011).

One of the most remarkable example in this field is the Virtual Construction Simulator (VCS), an educational simulation game developed by the Computer Integrated Construction research group, part of the Architectural Engineering Department at the Pennsylvania State university (Nikolic, Jaruhar, & Messner, Educational Simulation in Construction: Virtual Construction Simulator, 2011). The first version of the software was dated 2006, and subsequently other three updates have been performed until 2013. Compared to conventional methods for teaching construction sequencing, VCS offers the students the possibility to be immersed inside a construction context and make important decision about all the critical project issues, with the aim to let them freely plan and dynamically manage all the engineering process of a facility. The user is expected to pay attention to all the project constraints, variability, and performance feedback to actively make decisions regarding construction methods, daily resource needs, and construction sequences, obviously not forgetting to control the project duration and cost.

# 5. DEVELOPMENT OF THE PROTOTYPE

*“Vision without execution is a hallucination”*

Thomas Edison

Once explained in the previous chapter all the theoretical and technical notions concerning virtual reality simulations, it is possible now to go into the detail of the training prototype.

## 5.1 VR Structure

From the previous chapters, it is easy to note that VR training simulation require a non-trivial ensemble of technologic components, not only regarding the tools adopted by the users during the training but also the technology required to programming of the system itself. The main parts that constitute every VR training simulation can be summarized in components: Modelling, CGF and Visualization, as described in the following paragraphs.

### Modelling

Talking about 3D virtual environments, obviously the modelling of the simulated context has a leading role in the whole process. It incorporates all the preliminary gathering of the spatial and visual components, such as topographic surveys, satellite footages, pictures and photos of the elements and so on. Within the whole process, modelling constitutes the most expensive feature: the increasingly demand of various and numerous VR environment - with even more high-fidelity representation - is forcing the contractors to invest in modelling experts capable of dealing with several hours of processing and development. Indeed, examining a pie-chart with all the three pillars of VR structure, the modelling nowadays covers half of it concerning time and cost. However, in the near future a large number of already developed models is foreseen: as the years go passing by, an ever increasing amount of models will be available within the digital libraries, granting an easy and immediate adaption of them to the requested type of simulation (e.g. a certain bridge can be used for a track simulator as well as for the external environmental context of a flight simulator). This will bring to a cheaper modelling cost, cut by one-third or even half price.

Therefore, it would be an understatement to say that the modelling system concerns only the geometrical aspect of the simulated environment. Indeed, it gives a remarkable contribution do the definition of all the materials and provisional works concerning covered within the construction project, as well as cadastral category and access/exit routes, information data generally demanded to other external documents and, as a consequence, often with a lack of coherence or accuracy to the executive design.

## Computer Generated Forces (CGF)

CGF, also sometimes referred to as Semi Automated Forces (SAF), is a generic term used to refer to computer representations of forces in simulations that attempts to model human behaviour (Wikipedia). Being in development since the late 1980s, it provides an intuitive Graphic User Interface (GUI) that allows to build scenarios by positioning forces, creating routes and waypoints, and assigning tasks or plans with a simple point and click (MÄK, 2016). It actually consists of a mathematical model that collect a series of interaction-state algorithm, giving a logic structure able to offer an abstract representation of all the possible scenarios within the virtual simulation. As well as the visualisation component, CGF is developed within a computer graphic engine, generally Unity3D, responsible also for the dynamicity of the model.

Despite of the potentialities that the CGF has the power to offer, its nature presents a remarkable problem: it remains a predictable system. Actually, after experienced a couple times the virtual simulations, the trainee could able to distinguish between human-controlled and computer-controlled entities (Abdellaoui, Taylor, & Parkinson, 2009). Doing so, the trainee quickly learns to predict the behaviour of the CGF entity and easily defeats it in a way that would not happen with a human opponent, resulting in a negative or ineffective training experience; therefore, the main consequence is the need for humans to control synthetic entities and so increase the number of operators involved in the supervision of the simulation. However, if instead the Artificial Intelligence of these entities could be improved, the number of operators required will automatically be reduced. From this it is easy to understand the importance of further studies and research in the implementation of AI within CGF, able to grant a better training experience providing at the same time a smaller amount of supervising human control. Nonetheless, a great importance is assumed by the recording activity: following in a second time all the steps and procedure taken within the simulation has the potentiality to offer, to both the supervisor and the user, a higher degree of acknowledge about functional and technical issues occurred within the simulation, bringing to 2 main results:

If the simulation is related to a construction site **not build yet**, then there would be the time to modify and potentiate the site components (strengthen the scaffoldings, adjust the number of workers required for a critical task, etc.) *and maybe, if the building project is still in draft form, even adjust the project itself (improve the exit routes)*
If the simulation is related to a construction site **already built** or under construction, then the user will get more understanding and confidence with it, avoiding (hopefully) to repeat in the real environment those mistakes already made in the virtual one.

### Visualization

The visualization system has the aim to provide high-performance visuals for out-the-window visuals, offering video feedback of the virtual simulation. It reports the dynamics and physics provided by the CGF system, giving a visual reflection of the computed entity. Compared to the CGF, that can be considered as the "input", the visualization system is assumed to be the "output" of what the mathematical model coming from the CGF. Generally, it is written in C++ and accessed d via the Java Native Interface (JNI).

Visualization system is the main responsible for the "immersiveness", an aspect that shouldn't be underestimated, since not only it generates the sense of clearness of information from a visual point of view, but also it has the role of giving the right impression of a real-like environment, and so making everything more interactive and involving to the user compared to a book or an in-class study.

Between the 3 pillars, Visualization is the more subjected one to the existing technology, being it basically a powerful graphic card, and so with a very high update frequency. It takes all the intangible information from the Simulation system (who in turn takes the abstract models from the Modelling system) and convert them into visual outputs. The outputs consist not only of site and building structure, but also of eventual characters within simulation, as well as special visual effects resulting from reflection, glare, blurring, sparkling of electric lines, fire and water physic effects and so on. Moreover, for the same reasons, the weather effects are equally included in the simulation.

## 5.2 Inside the prototype

Now in the following paragraph a detailed analysis of the prototype is depicted throughout all its features and potentialities. This project has been developed in several months by a team composed by three professional figures: Graziano Lento, BIM expert and with a background as major account sales executive in Autodesk, is the chief coordinator; Erik Ripamonti, responsible for programming the software and all its IT structure; Vittorio Mottola, authority figure on normative, in charge of integrating the software with the mail safety procedures in construction sites.

However, it is important to point out that the prototype "has just been born", and its development was focused mainly on the basic three-dimensional visualization and few schematic samples on safety emergency procedures.

It's been estimated that around 100.000 € would be necessary in order to achieve an adequate software level, plus a 3-months additional development, while for the complete market distribution a 1.000.000 € should be invested.

Moreover, although the final aim the creation of a VR simulation, for programming and presentation reasons the software is provided with a third-person visualization. As it is possible to see in the following pictures, this character has the appearance of a sci-fi cosmonaut, taken just as a qualitative representation in order to give the user a special reference. At any moment, however, a quick switch between first and third person can be performed. Hence, the prototype is proposed as a quick user-friendly sample, very schematic and generalized, and obviously further improvements in its structure are desirable for the future.

## Launching

For the initialization of the simulation two programs must be started: first, for the visualization, the graphic software is opened (Unity 3D). Then the controlling program shall be executed, allowing so the supervisor to monitor and set the full simulation.


*Figure 5.1 – Unity 3D splash screen*

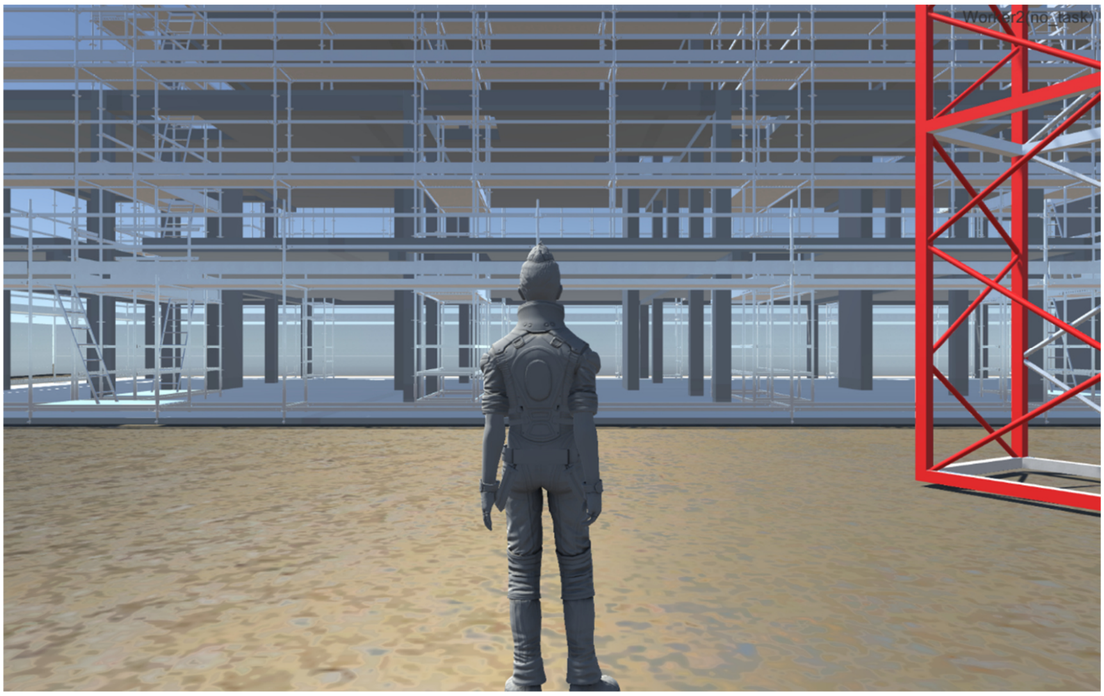


*Figure 5.2 – User's visualisation*

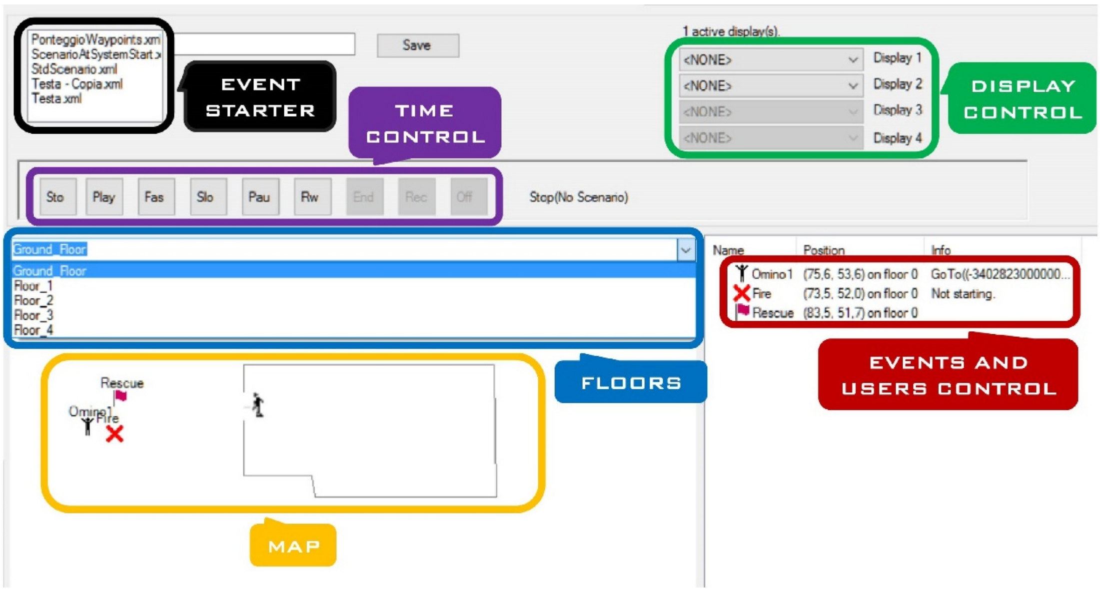



*Figure 5.3 – Supervisor's screen*

As previously explained, in the absence of an immersive VR device, the user is allowed to change the perspective of the view.

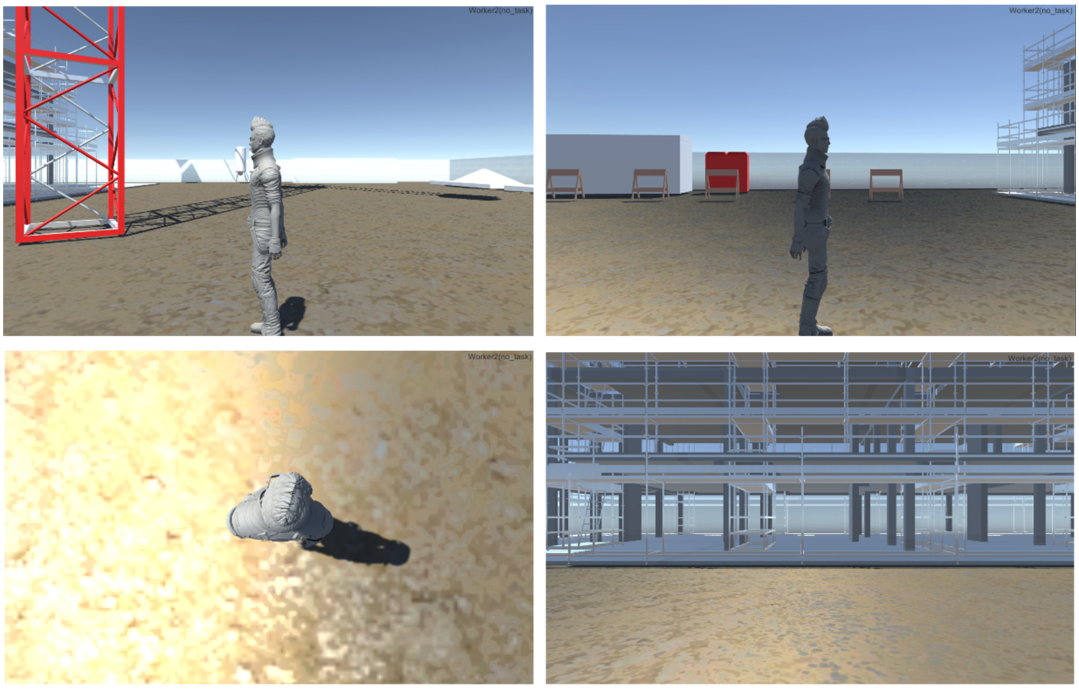


*Figure 5.4 – User's different views*

## Single user simulation

This simulation is specifically related to a simple fire drill. At any moment, the supervisor I allowed to simulate the outbreak of a fire (in this simulation, the fire is set at the ground floor), in a zone displayed both on the control panel and the user's simulation.

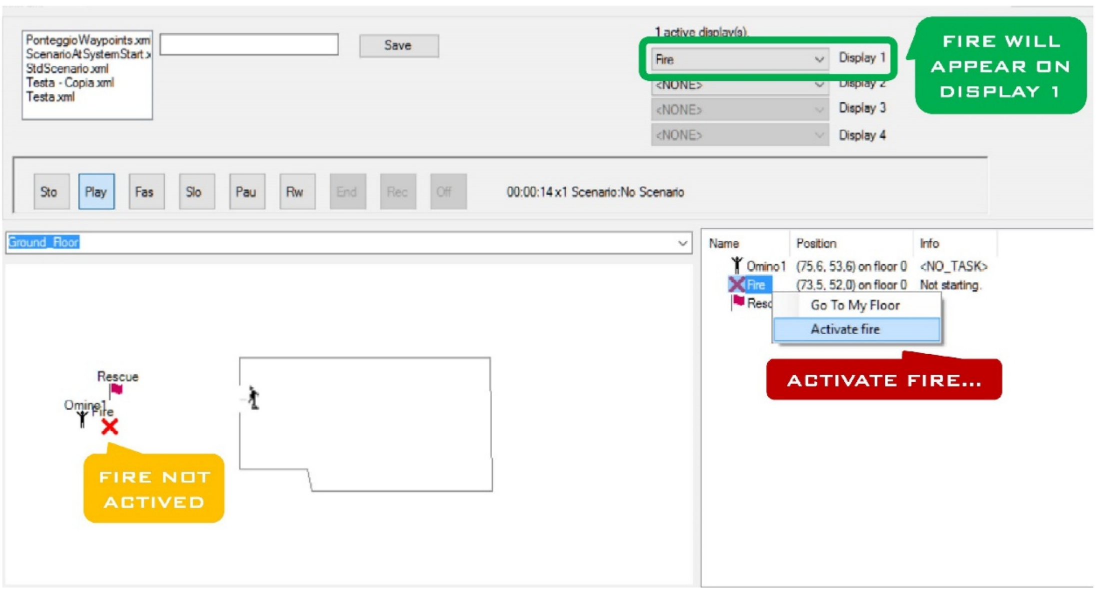



*Figure 5.5 – Fire activation (supervisor)*

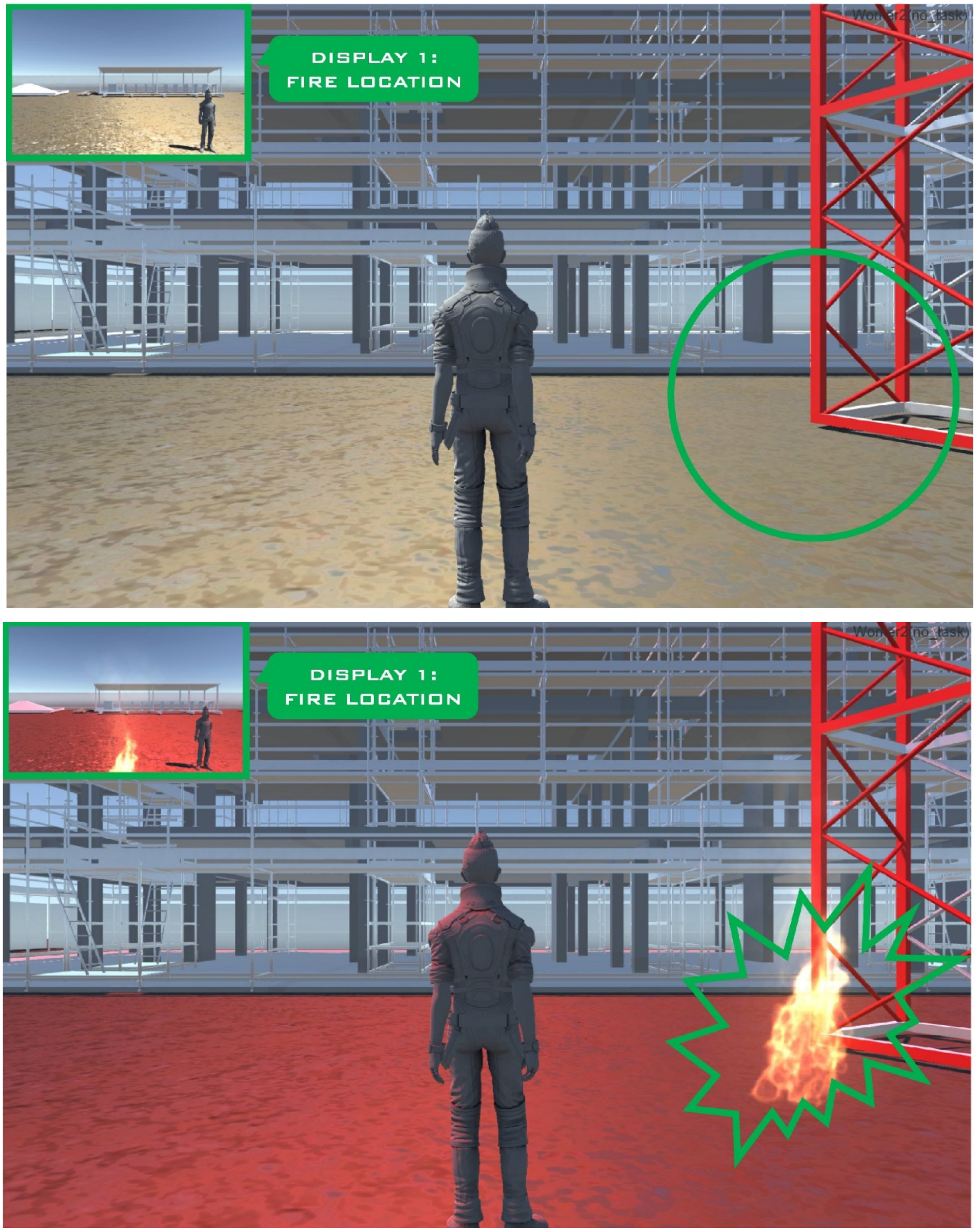



*Figure 5.6 – Fire activation (user)*

## Multi-user AI simulation

Now a different scenario will be presented, involving 4 extra users AI-controlled automatically moving around the working site. After a pre-established time (or whenever the supervisor will deem appropriate), the fire outbreak will occur and every user would gather in the rescue point.

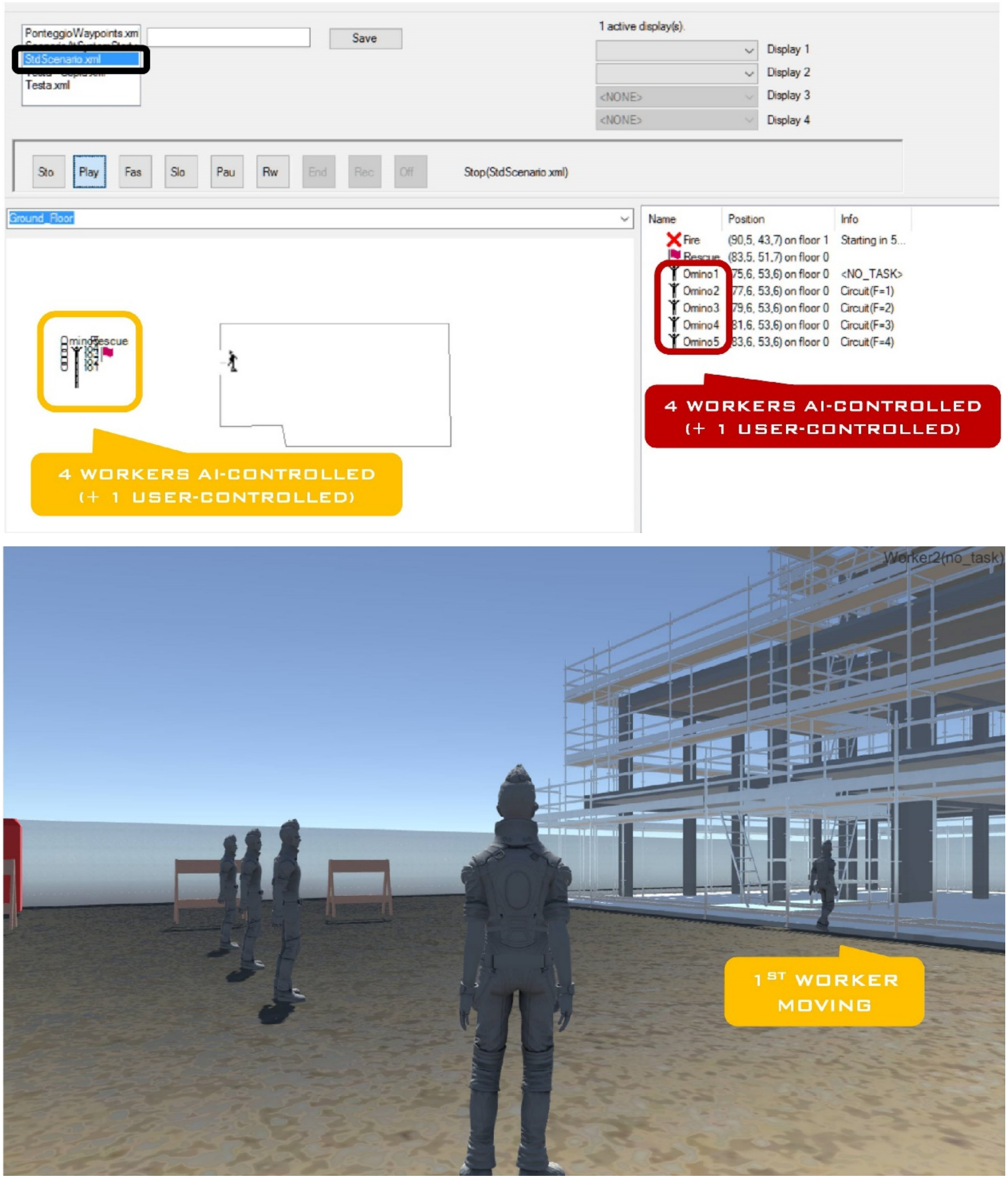



*Figure 5.7 - Multi-user simulation (a)*

It is useful to notice again that the supervisor has the full control of the user's movements (both AI and human controlled).

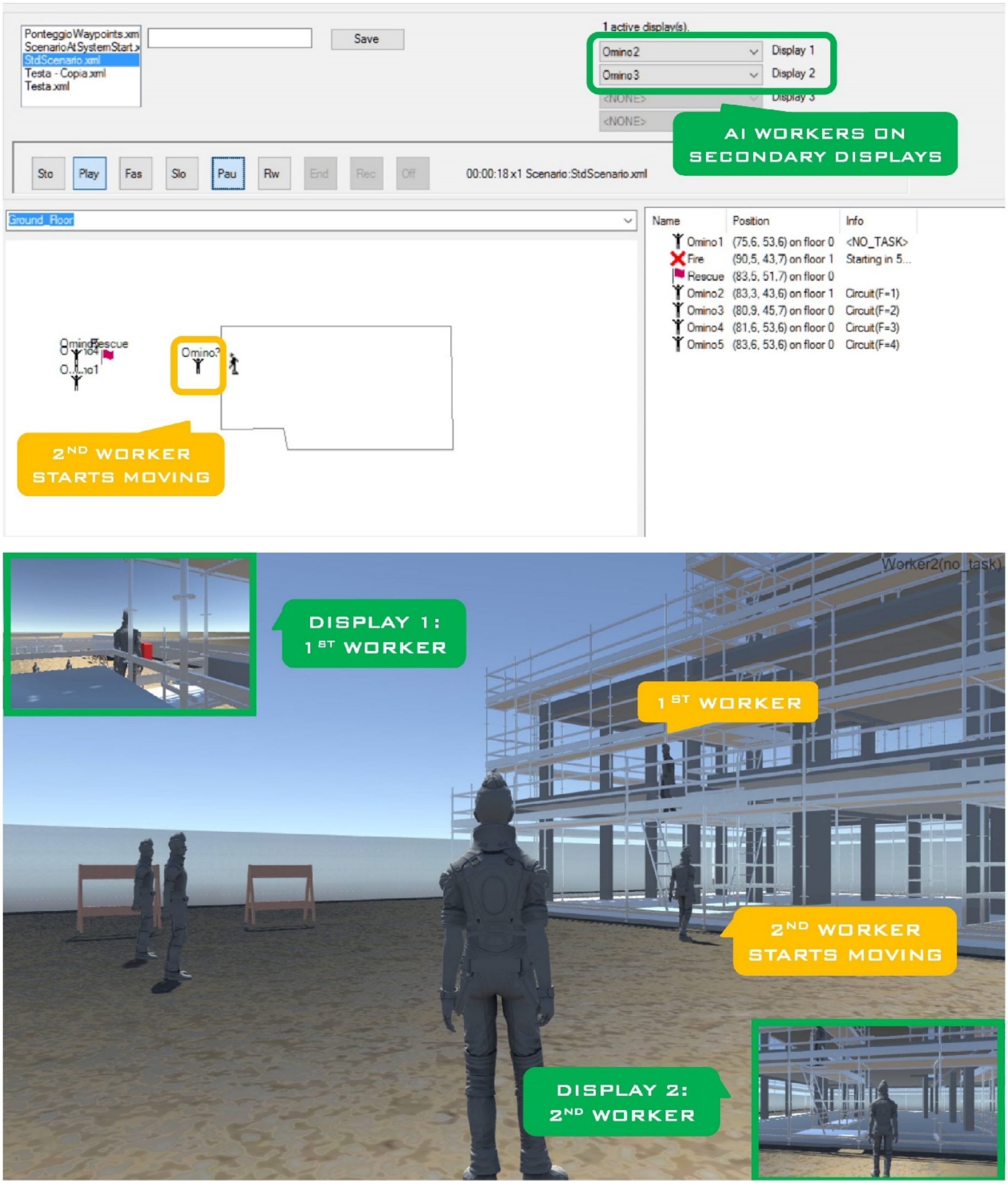



*Figure 5.8 - Multi-user simulation (b)*

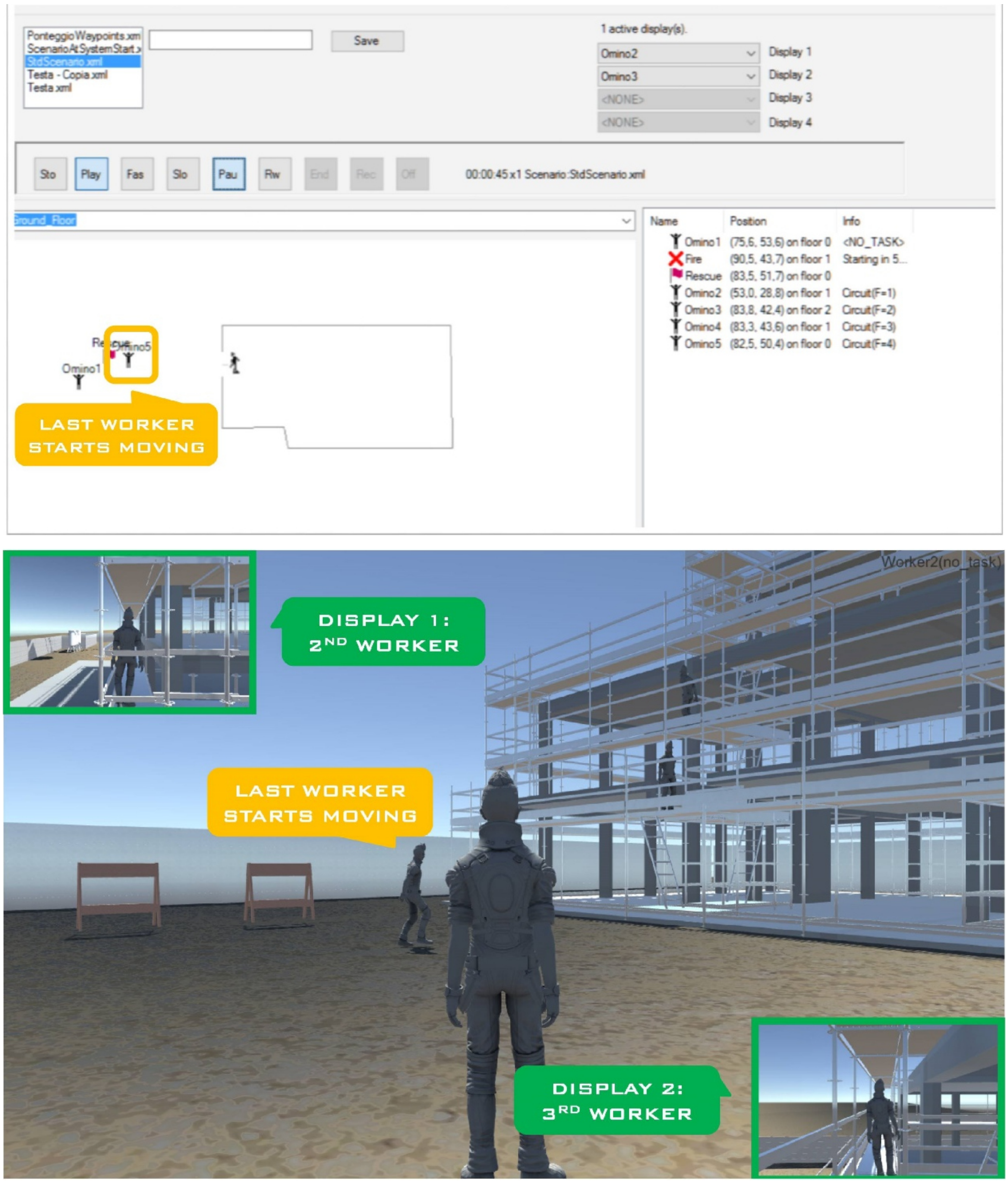



*Figure 5.9 - Multi-user simulation (c)*

Going on to the simulation (precisely, for 2 minutes and 9 seconds) it is possible for the supervisor to trace every user's position throughout the control panel and locate the relative positions in every floor.

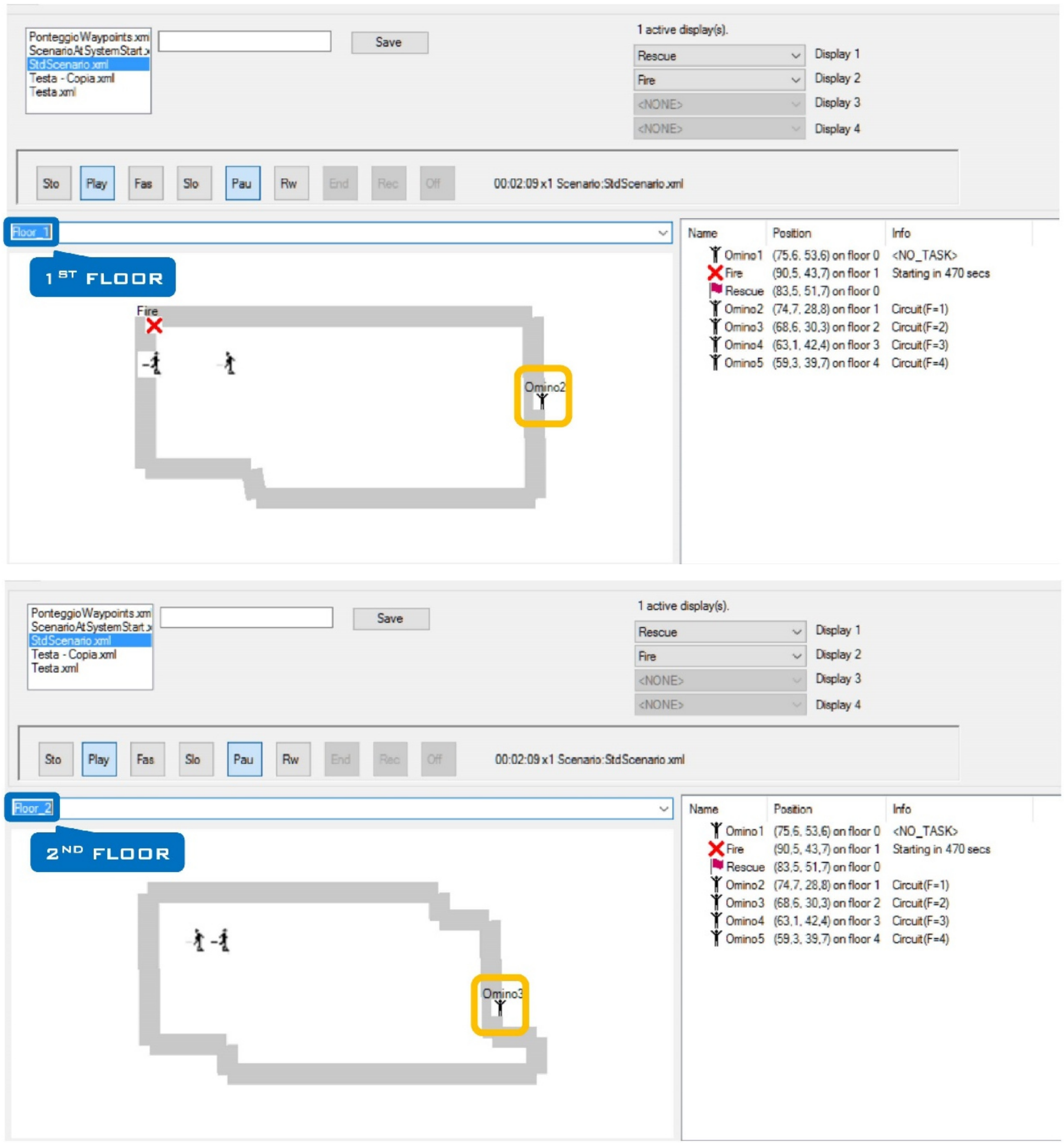



*Figure 5.10 – Floor control (a)*

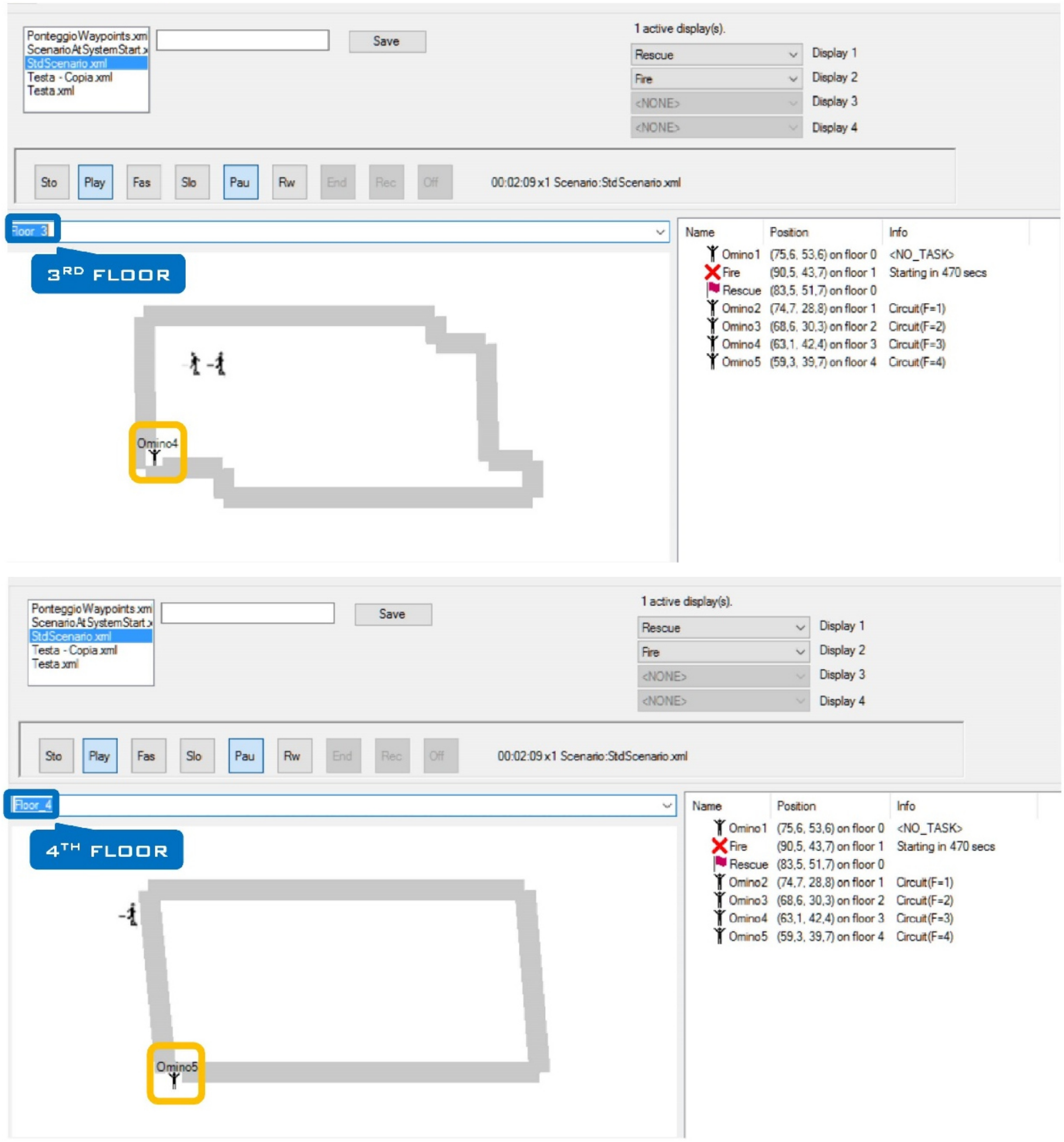



*Figure 5.11 - Floor control (b)*

Now it's time for the fire to finally outbreak and see how the users are capable of quickly reacting. On this occasion, the fire is set on the first floor.

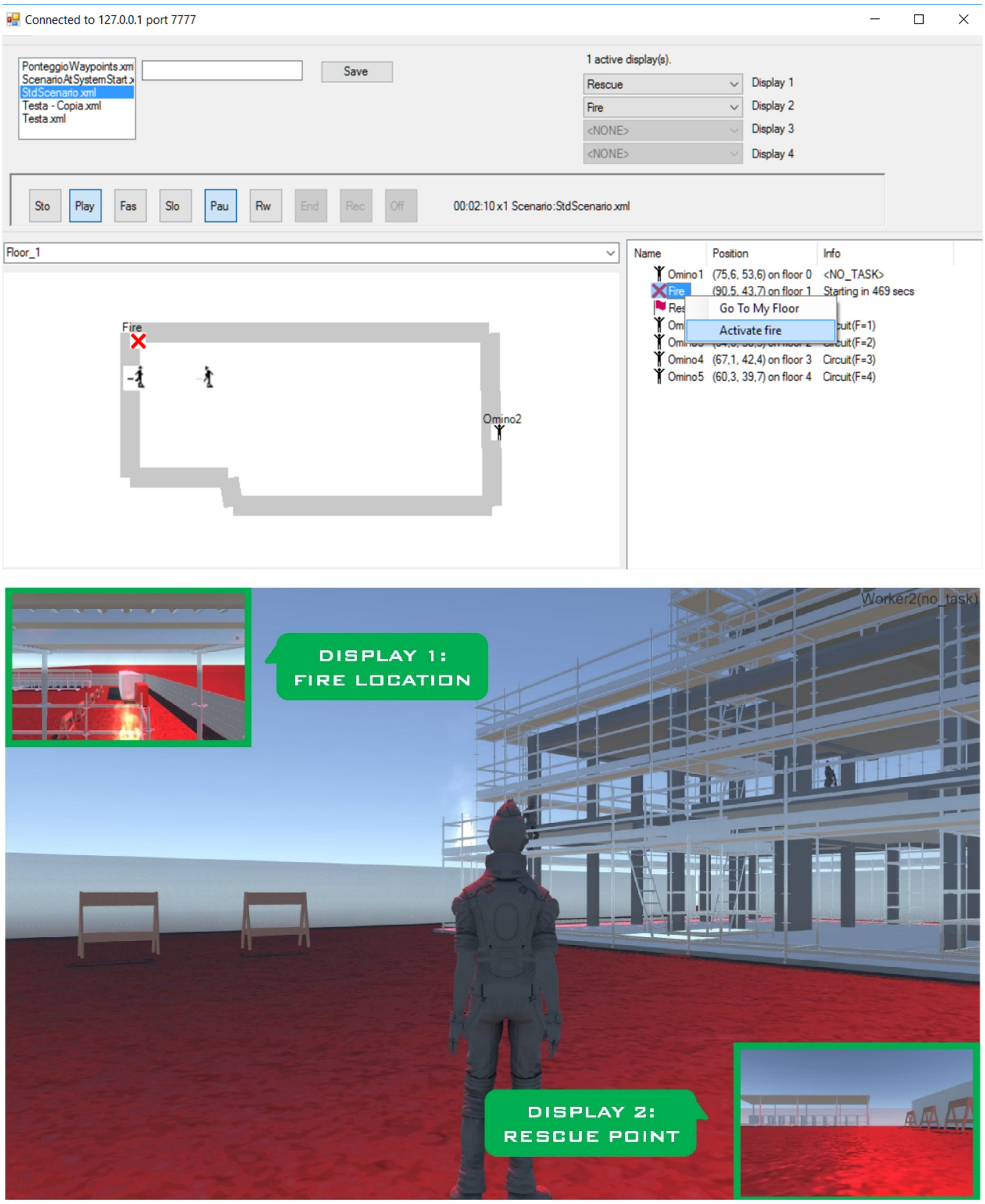



*Figure 5.12 – Fire activation*

Each user then will follow the shortest and safest path to the ground floor in order to avoid the fire and get to the rescue point. The simulation is now over.

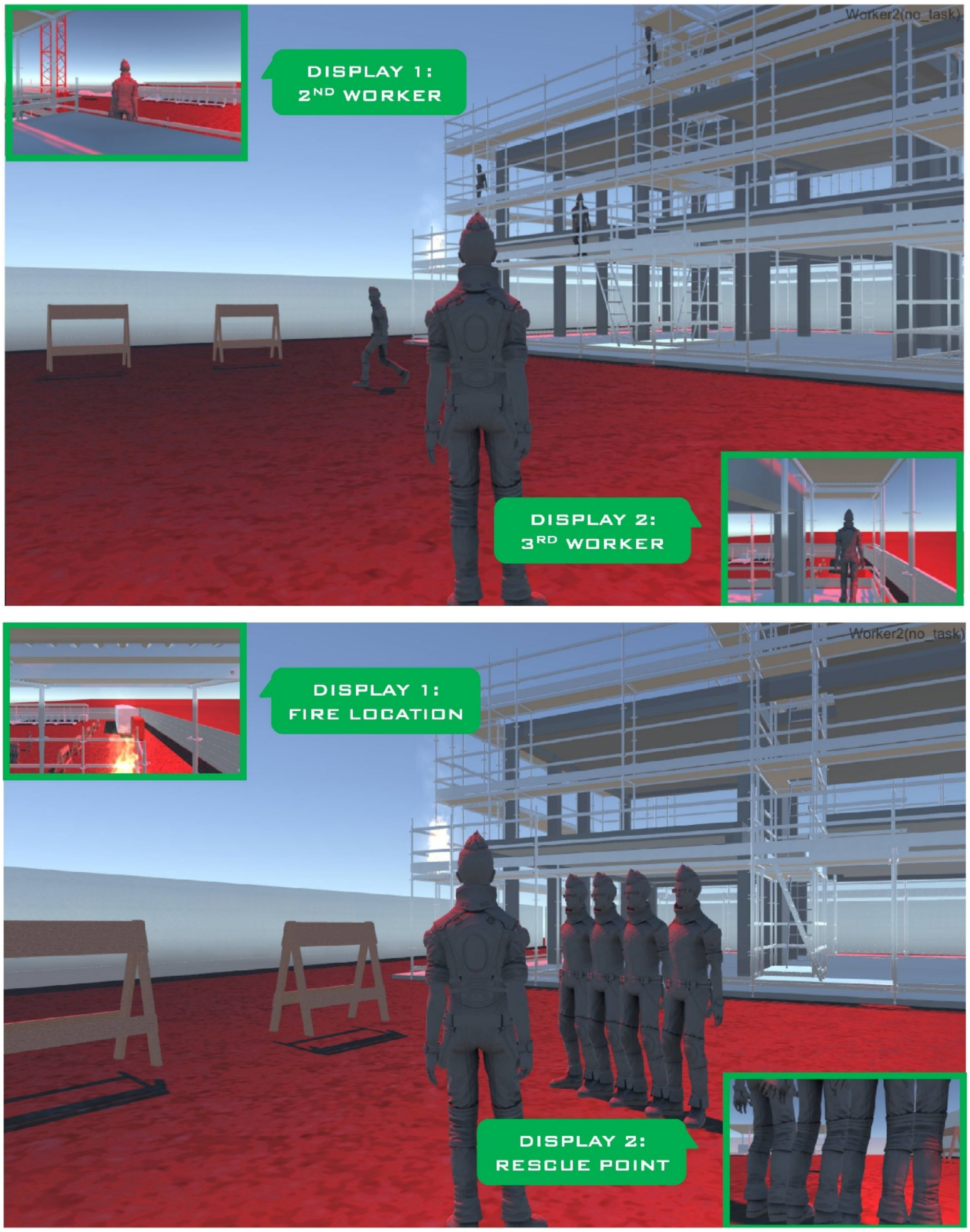



*Figure 5.13 – Gathering to the rescue point*

# 5.3 User types

The picture shows all the professional figures that can benefit from the prototype. Generally, the design approach of such projects consist of starting from the easiest and the more particular kind of user, that is the inspection of the BIM models. However, for this prototype a different strategy was adopted, consisting of the achievement of all the requirements needed by the formation of in-site workers, i.e. the simulation training. Doing so, striving for the obtaining of the highest and more complex user typology, there is the certainty that all the other professional figures can benefit from the system.

The most relevant user types are represented here below:

**In-site workers**: the final and more complex aim of the VR simulation, regarding all the tasks and topics expressed in the previous chapter.
**Safety supervisor**: within the simulation, the figure can take advantage of the system by training on all the issues concerning safety matters. Moreover, he/she is able to evaluate the safety design of the construction site, detecting critical design issues and functionality problems concerning safety matters.
**Rapid response team**: the system offers the possibility to be trained in all the aspects related to rescue and assistance actions. Moreover, after few simulations, the team would be able to detect (and make the designer modify and adapt) functional and technical issues that could affect the promptness of the first responders.
**Teacher**: responsible for the scenarios conception and the evaluation of the users.
**Purchaser**: thanks to the adoption of the prototype it is possible to better understand of course the potentialities of the future construction, but also the hazardousness of the construction site. As a consequence, it would be pretty easier to obtain an estimation of the risk assessment and so facilitate the dealing between developer and banks.
**Inspector**: this role is at the basis of all the BIM projects. The main task is the control and verification of the BIM models, analysing the consistency of all the information, deleting redundancies and improprieties, verifying the connection between model data and supplier data and so on.

# 5.4 Integrations

- **Learning Management System** or **company intranet**: A learning Management System (LMS) is a software application for the administration, documentation, tracking, reporting and delivery of electronic educational technology (also called e-learning) courses or training programs (Ellis, 2009). It basically consists of a software modulus included within e-learning platforms that gather all the functions needed for the management on-line learning/training contents. In other words, LMS as well as company intranet can be seen as the immaterial vehicles through which the prototype can be used by the customers.

- **SCORM Evaluation:** concerning the e-learning field, a central role is played by the SCORM ("Shareable Content Object Reference Model"). It basically contains all the standards and technical specifications that grant the exchange and communication of digital contents with e-learning platforms. SCORM tells programmers how to write their code so that it can "play well" with other e-learning software. It is the de facto industry standard for e-learning interoperability (SCORM.com). This kind of protocol has the power to broadly define all the variables involved within an electronic training system, imposing the syntax and the standards for the data packaging and the internal data cataloguing. In other words, it is the main responsible for the tracking and reporting within the platform. More specifically, concerning the prototype of the thesis under discussion, it allows the major computational operations within the training process, such as:
    - tracking of evaluations and score
    - time of use or time of the session for a given content/task
    - number of trials
    - progress percentage of the user within a course
    - percentage of answers given by the user in a test
    - completion/failure of the test
- **Oculus Rift or other AR/VR devices**: as fully described in *Chapter 6.4*
- **Monte Carlo Simulation in MATLAB**: it's quite easy to understand that talking about safety, training and risk assessment in a construction site generally involves variables. And these variables not only are numerous, but also they always run in random order, bringing so to an extremely hard forecasting of the analytical results. It is just like what happens in the gambling hot spot in Monaco (from where indeed "Monte Carlo Method" takes the name), since games like roulette, dice and slot machines are always subjected to chance and random outcome (Investopedia.com). Then, in order to have a better comprehension how a model responds to randomly generated inputs, Monte Carlo Simulation is adopted, consisting of a wide-ranging class of computational algorithms that rely on repeated random sampling to obtain numerical results. This method can be adopted thanks to the implementation of the MATLAB computing environment, typically involving a three-step process:
    1. Randomly generate "N" inputs (sometimes called scenarios)

2. Run a simulation for each of the "N" inputs. Simulations are run on a computerized model of the system being analyzed
3. Aggregate and assess the outputs from the simulations. Common measures include the mean value of an output, the distribution of output values, and the minimum or maximum output value (MathWorks.com)

- **Sensors and IoT**: at the present stage, the prototype has been developed merely within the e-learning sphere, so consisting of a user immersed in a virtual environment and guided by the supervisor through safety and technical issues. But what if we would like to try to lay down the foundations for a future managing and supervising application? Something that is not constrained by the boundaries of e-learning, both conceptual (the training about given exercise coming from the supervisor or directly from the AI) both physical (the simulation ran within a virtual context that is somehow detached from all the actual events occurred in the real site). This can be achieved by the adoption of sensors, integrated with an implemented logistic power of the AI. In the next future, the prototype could have the potentiality to manage real situations and events, giving automatically a better outcome of what is happening and, more important, what would happen in forthcoming cases. Let's consider the following example: the real site is provided with motion sensors that grant the detection of moves and paths of the workers. These detectors send a series of feedbacks to the prototype system, whose internal processors elaborate the actual scene and store the outcomes in the database. Doing so, the system is able to understand if a particular access or pathway is too overwhelmed or unable to provide all the safety requirements. Again, during an emergency situation (such evacuation protocols due to fire or accident to workers or even terrorist event) the sensors analyse the escape flow, permitting so to detect critical issues and apply improvements to the site for new upcoming events, as well as redirect the stream through audible warnings in order to avoid people getting across particular unsafe ways out.

  This kind of technical integrations falls within the field of the Internet of Things (IoT), which consists of the acquisition of more intrinsic intelligence among the digital objects ("things" indeed) due to the ability of communicating data about themselves and accessing to information from others thanks to the network connection (Magrassi, 2002). Indeed, the main objective of the IoT is ensuring that the electronic/virtual environment tracks a coherent map of the corresponding real one, giving so a concrete identity to things and to locations of the physical environment, generally through the adoption of technologies directly applied on the objects of interest, such as Radio-frequency Identifications (RFID) or QR codes.

  Other special integrations can be incorporated in the site also in order to assist workers with medical issues. An academic study of June 2016, carried out by the University of Chemistry and Technology of Prague, analysed a new method of using Microsoft Kinect sensors for non-contact monitoring of breathing and heart rate estimation to detect possible medical and neurological disorder. Video sequences of facial features and thorax movements are recorded by Microsoft Kinect image, depth and infrared sensors to enable their time analysis in selected regions of interest. The study proves that simple image and depth sensors can be used to efficiently record biomedical multidimensional data with sufficient accuracy to detect selected biomedical features using specific methods of computational intelligence (Procházka, Schätz, Vyšata, & Vališ, 2016).

- **Graphics Libraries:** at present day, the prototype offers a 3D visualization at its basic form. The model is simple and schematic, graphic effects are not fully developed and even the character (used as a demonstration for the non-VR auxiliary application) has the structure of a sci-fi videogame, being it just momentary. For future developments, a better graphic visualization is desirable, and this is achievable implementing the system with an updated OpenGL (Open Graphics Library) technology. It basically consists of a specification that describes an abstract application programming interface (API) for bi-dimensional and three-dimensional graphics. Starting from this specification, hardware developers create new implementations, i.e. new libraries of functions that are designed in accordance with the same OpenGL specification, by making use of the hardware acceleration. There are even nowadays efficient OpenGL implementations, such as for Microsoft Windows, Linux, several Unix platforms, PlayStation 3 and Mac OS. This means that, in the future, the prototype could potentially be integrated in these platform or new ones, typically more user-friendly and even accessible directly from a domestic context. An additional technology adopted for the prototype is WebGL a JavaScript API for rendering 3D graphics within any compatible web browser without the use of plug-ins (Tavares, 2015), then leading the system to a complete integration into all the web standards of the browsers.

## 5.5 Simulator and AI

At this point, it has become quite clear to understand the importance of AI within the simulation. The types of sensors previously described give only an approximate idea of AI's elaboration power. Within the simulation, the user is able to start and restart the process as many times as desired, deciding to focus and improve a particular task or criticality. In addition to this, one can also order the AI to set a random exercise, useful in particular at the end of a defined ensemble of exercises (i.e. "units") in order to test the overall knowledge of a distinct unit. This method can be compared to the classic approach adopted by students: instead of a teacher who decides the topics of the test, there is a virtual AI that independently determine what the user is supposed to accomplish, opting even for more additional exercises concerning those topics where the user found more troubles to solve within the previous simulations (recorded and stored by the AI itself). It is crucial for the AI an efficient prediction of the possible behaviour of the workers, both the passive ones (NPC, “Non Playable Characters” using a video gaming terminology) included in the event simulator and the active ones (PC, “Playable Characters”), i.e. the user itself. This can be achieved throughout not only, obviously, the computational power of the software, but also thanks to the capability of recording and storing all the data inputs given by the trainee during the sessions. Indeed, since the beginnings of the studies related to AI, it has been observed that human behaviour is preferred do be modelled by probabilities determined by prior observation and sampling, rather than by modelling the decision mechanisms of the customer. Doing so, it is possible to allow the AI simulating a sort of adaptive behaviour, where the activity attempted next is determined by some perception of the present state of the system. Indeed, simple decision rules are frequently inadequate (O'Keefe & Roach, 1987). An example of this concept might be Google Maps application, where “follow the shortest route” isn’t always the best choice: distance is not the only factor taken into account by the application during the computing process, but also the road traffic is considered according to several possible events such as car accidents, congested areas because of potential strikes, rush hour traffic. As a consequence, it is exactly this adaptive capacity that makes AI actually more and more “intelligent”. Last but not least, a complete integration of the safety regulation must be included within the AI. The simulation must be executed with due regard to the current legislation, allowing the user to become acquainted with the proper safety procedure, including both national and international references. By now, as seen in *Chapter 4.2*, the highest field of application of AI is related to the military sector; concerning the building engineering context, the implementation of normative within the AI component should be intended as “all the amount of activities and procedures that a worker is required to know”, i.e. technically talking (from a software-programming point of view) consists in the creation of a finite-state machine. It is basically a mathematical model of computation that can change from one state to another in response to some external inputs. Therefore, the implementation of national and international normative within the CGF enables the simulation to behave following the current doctrine for any type of human input, e.g. avoid a dangerous/busy pathway, overcoming a physical obstacle, reaching the rally point in case of emergency, ect.

## 5.6 Boundary conditions

AI and dynamic simulation go hand in hand: the virtual environment risks to lose effectiveness if it doesn’t change according to the existing notional conditions. Among these, environmental conditions can be considered as the most obvious: meteorological changes, for instance, offers the user a great opportunity to deal with weather-related issues, as well as even possible landslides and other terrestrial phenomena. Simulating these events, usual or extreme ones, the system acquires a probabilistic reliance that is strictly connected to the dynamicity of the real environment, and thus obtaining a training apparatus able to strengthen the problem solving skills of workers. The same example can be done considering seasonal variability and day-night alternation, in order to train the user throughout different visibility scenarios. Great importance is assumed also by the political conditions: concerning particularly critic working site, the AI should be able to submit possible issues to the user. Within the simulation, these issues involve the occurrence, for instance, of the military force for areas of strategic interest. Furthermore, working conditions can't be underestimated: often connected to political conditions, they involve the occurrence of changes in the normal working activity, such as the obstruction of emergency exits and ways out caused by, for instance, external massive uprisings due to strikes and protests. These above are just few examples of how the AI is supposed to deal not only with internal working factors, but even more with external boundary conditions, ripping apart the boundaries between these two dimension and bringing to the creation of a system fully integrated with the surrounding socio-political and geographic context.

## 5.7 Fruition

The prototype was born as a Computer Based Training (CBT), i.e. a learning method based on educational platform made accessible by the user through a laptop. It can take shape as an e-learning project as well as a self-taught. However, its fruition potentialities are various, allowing the user to adopt the system throughout other several ways.

- **Web**: Web learning provides effective teaching to workers with the benefits of online courses, such as 24/7 availability of the training system, immediate feedbacks from the supervising authority (AI or human) and potentially countless chances to reiterate a simulation.
- **Intranet**: differing from the web learning, intranet provides the simulation within a distinct working context, thus offering a highly specific formation. Doing this, companies are likely to enrich their employees' profiles with specialized and exclusive training courses, demonstrating also the fulfilment of their technical learning thanks to a tracing and scoring system, useful for instance in the event of settlement of legal disputes.
- **Light/full simulation**: large part of virtual reality simulations is designed with a lack of high-fidelity towards the actual representation of the human reality. This is due mainly to two reasons: first, the most obvious, comes from cost related issues. Indeed, as previously shown in *Chapter 5.1*, the developing of CGF, as well as proper modelling and visualization processes, represents a strong limitation to the creation of a genuine realistic simulation. The second reason is related to the absence of a real high-fidelity

need, thus bringing the software designer to produce a more schematic and "lighter" simulation, with the aim to be promptly deployed and easily adapted to the various application fields. In these cases, the final product is defined as "light simulation" and it is able to offer a fast and pretty user-friendly approach to the virtual environment; however, when accuracy, precision and reality-reflection are strongly required, its use risks to lose efficiency when applied in particularly sensitive applications, such as military and medicine, as well as safety trainings for working sites. Therefore, the lack of hi-fi could result in a too fictional perspective of the simulation, bringing the user to underestimate and minimize its actual potential. To avoid this, it should be better to improve the system with supplementary instruments and sensors (as shown in *Chapter 5.4*) in order to add more realistic scenarios and bringing to a product that can be defined as "full simulation". It's important to note that the latter type of simulation automatically presents not only, obviously, substantial cost issues, but also a target-related issue: this kind of professional software would be gladly accepted by those agencies and figures who require a high performant product and, at the same time, bearing the considerable higher costs. On the other hand, smaller and humbler customers actually won't obtain significant benefits from its adoption, in relation to the excessive cost required and a not needed higher fidelity, preferring thus the adoption of the more accessible light simulation.

- **Mobile**: as will be discussed in *Chapter 7.2*, mobile applications help the system to be seen and adopted in a more user friendly manner by the customer. Apart from the mere easier and more immediate visualization of projects, information and 3D models, a further use of this technology could be the implementation of spatial sensors within the devices: for instance, let's imagine a site where all the workers are provided with smartphones (or even small personal GPS trackers) able to identify their movements. In this way, spatial and motion feedbacks are sent to the simulation system, allowing the CGF to analyse all the movements and relative operations of the working site. This effect breaks the boundary of the mere "simulation" and leads to the generation of a real "stimulation" from the human presence to the IA component. Above all the benefits, the most relevant one is surely the possibility to instantly trace the actual situation of the site and then understand the presence of critical issues and logistical dysfunctions, such as the blockage of a specific busy pathway, as well as detecting the need of an increased number of workforce in a more unemployed zone.

# SECTION C

## VIRTUALITY CONTINUUM FOR ENGINEERING

# 6. A SURVEY ON AUGMENTED REALITY

*"Will reality be augmented or virtual or some hybrid of the two? In any case, reality will no longer be the only game in town"*

Ced Kurtz

*"**Augmented reality** is a live, copied view of a physical, real-world environment whose elements are **augmented** (or supplemented) by **computer-generated sensory input**. Virtual reality replaces the real world with a simulated one, whereas augmented reality **takes the real world and adds to it with**—in the case of architecture—**a 3D model of your design**."*

*Graham, Zook and Boulton's definition for Augmented Reality, 2012*

## 6.1 The "Virtuality Continuum"

In 1994, the paper "A Taxonomy of Mixed Reality Visual Displays" showed the concept of *Mixed Reality*, consisting on a sub-class within virtual simulation technology, where digitized objects are merged with real world objects to create a hybrid physical and virtual world.

Mixed reality has been an on-going research field that has progressed throughout the past 20 years. The field of research can be considered in terms of a continuum that spans from full simulation (virtual reality) to the simple reproduction of reality through video recording; with augmented reality (AR) and augmented virtuality (AV) being hybrids of the two (Milgram & Kishino, 1994)

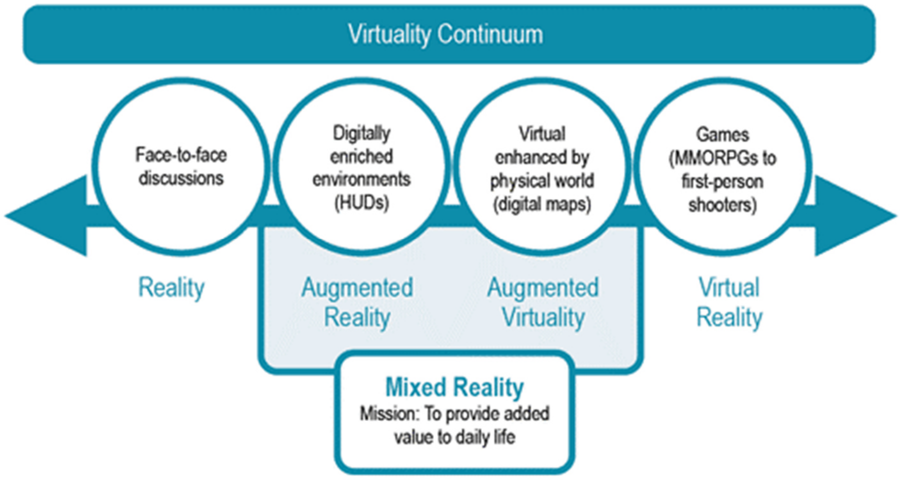



Figure 6.1 – Conceptual map of the Virtual Continuum

Augmented reality can also be defined as *a medium that is experienced*, as explored by Alan B. Craig in his book "Understanding Augmented Reality". Its abstract is reported here below:

*"Augmented reality is not a* ***technology****. Augmented reality is a* ***medium****.*

*Likewise, a book on augmented reality that only addresses the technology that is required to support the medium of augmented reality falls far short of providing the background that is needed to produce, or critically consume, augmented reality applications. One reads a book. One watches a movie. One experiences augmented reality.*

*Understanding Augmented Reality addresses the elements that are required to create* ***compelling augmented reality experiences.*** *The technology that supports augmented reality will come and go, evolve and change. The underlying principles for creating exciting, useful augmented reality experiences are timeless.*

*Augmented reality designed from a* ***purely technological perspective*** *will lead to an AR experience that is novel and fun for one-time consumption, but is* ***no more than a toy****. Imagine a filmmaking book that discussed cameras and special effects software, but ignored cinematography and storytelling! In order to create compelling augmented reality experiences that stand the test of time and cause the participant in the AR experience to focus on the content of the experience - rather than the technology - one must consider how to maximally* ***exploit the affordances of the medium****"* (Craig, 2013)

Compared to Milgram and Kishinos' report, that portrays augmented reality as a technique in mixed realities technology, this is a pretty different definition: the emphasis is on the interactive and experiential aspects of the technology, in contrast to previous traditions of text and film making. "One reads a book. One watches a movie. One experiences augmented reality".

# 6.2 History


Figure 6.2 - The Sensorama Stimulator

The foundations of Augmented Reality are strictly connected to the birth and development of Virtual Reality itself. Therefore, the very beginnings can be traced all the way back to the 1950s and 1960s to Morton Heilig who is now referred to as the "father of virtual reality." Morton was a philosopher, film maker and inventor who applied his cinematographer experience to design and then finally patented the Sensorama Stimulator in 1962. The Sensorama Stimulator used visual images, sounds, fans, scents and vibrations to give the user the sensation of riding a motorcycle down the streets of Brooklyn. Albeit big and bulky, the Sensorama Stimulator was ahead of its time. Unfortunately, Morton was unable to obtain the financial backing necessary to move the invention ahead any farther.

One of the next big milestones in the history of AR was the invention of the first head-mounted AR machine. In 1968, Harvard associate professor Ivan Sutherland worked with his student Bob Sproull to invent what Sutherland termed, "the ultimate display."

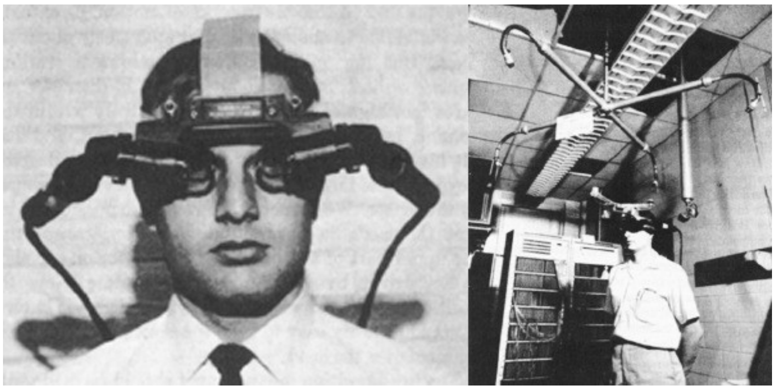


Figure 6.3 - Ivan Sutherland's ultimate display, "The Sword of Damocles"

The system displayed a simple wireframe room that was shown through the head-mounted binocular, and the user's perspective from within that room would change using vision and head tracking. While the user interface may have been head mounted, the entire system was so large and heavy that it could not be placed on the user. It was suspended from the ceiling directly above the user.

This inspired the name that was given to the device, “The Sword of Damocles.”

Even though we now refer to these early incarnations as AR, it wasn't until 1990 when Tom Caudell, a researcher at Boeing, coined the term “augmented reality”. He and a colleague, David Mizell, were asked to come up with an alternative to the large bulky “example” boards that were used then as a guide for factory workers installing the wiring on planes.

Figure 6.4 - Tom Caudell

They proposed replacing the large plywood boards, which contained individually designed wiring instructions for each plane, with a head-mounted apparatus that would display a plane's specific schematics through high-tech eyewear and project them onto multipurpose, reusable boards. These AR displays could quickly and easily be changed with a computer, as opposed to having to manually reconfigure or rebuild the board by hand.

Later that decade, around 1998, AR made one of its first mainstream debuts. The application was created for televised football games. A first-down line was superimposed over the actual view of the football field for people watching on TV. Then we started to see the technology being used in weather forecasts, overlaying computer images onto real-world views and maps. From there, developments in AR really started to explode.


Figure 6.5 - AR superimposed during a football play

In 2000, while in the Wearable Computer Lab at the University of Southern Australia, Bruce H. Thomas created the first mobile, outdoor AR game called ARQuake. Around 2008, smartphones started to use AR in applications such as maps. Then in 2013, Google released Google Glass, which is a head-mounted optical display that resembles a pair of glasses. And just last year in 2015, Microsoft released the HoloLens—an AR headset that blends three-dimensional computer-generated images (holograms) with the real world around you (Heimgartner, 2016).

Figure 6.6 – "ARQuake" AR game (2000)

The couple of figures below is an example of one early augmented reality application for hand held devices, called *The Invisible Train,* as reported on the (Wagner, 2005).

By manoeuvring physically in the real world around the 2D markers set on the table, the user

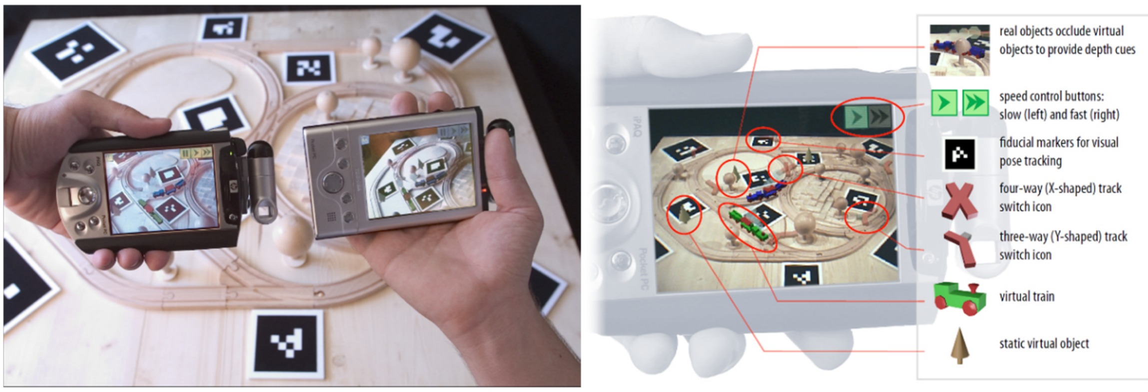



Figure 6.7 - "The Invisible Train" AR game

is able to view a virtual train simulation from different angles in AR. Touching the screen with a stylus enabled the user to interact with the 3D models and re-arranges the train tracks in different formats (Haller, Billinghurst, & Thomas, 2007).

## 6.3 AR Application in real life

The revenue potential seems to be growing just as fast (if not faster) than the developments themselves. While AR revenue is expected to reach $1 billion this year, it's forecasted at $120 billion by 2020 (Heimgartner, 2016). AR has become far reaching, with applications spanning across a myriad of industries. Here are just a few examples:

- Archaeology: Display ancient ruins as they looked at a particular site the way they existed in history.
- Art: Help individuals with disabilities create art by tracking eye movement and turning those movements into drawings on a screen.
- Commerce: Show multiple customization options or additional information for a product.
- Education: Superimpose text, graphics, video and audio onto a student's real-time environment.
- Fashion: Show what different makeup or hairstyle options might look like on a person.
- Gaming: Allow users to experience and interact with a game using a real-world environment.
- Medical: Show patients' internal organs superimposed over their skin via virtual X-rays.
- Military: Use AR goggles in real time to show people and various objects and mark them with special informative indicators and to warn soldiers of potential dangers.
- Navigation: Label road and street names along with other pertinent information on a real-world map or display on your wind shield showing destination direction, weather, terrain, road conditions and traffic information as well as alerts to potential hazards.
- Sports: Show the first-down line on football games, the flight of a golf ball after it's hit or puck tracking during hockey games.
- Television: Display weather visualizations and images.

# 6.4 AR and MR for the masses

Figure 6.8 - Volkswagen's app MARTA

After more than two decades from the first attempts of introducing augmented reality by Tom Caudell, the closest application that amounted to a useful tool was a Volkswagen's iPad app, Mobile Augmented Reality Technical Assistant App (**MARTA** for short). Offering to service workers a new way to see the car's parts and fix problems, MARTA was able to project visual labels and instructions in real time to guide mechanic operators to fix car components.

Almost all early AR innovators, they turned out, focused entirely on industrial applications where usage requirements were exceedingly high. The bulky, expensive, head-mounted display devices didn’t help either.

## Oculus Rift

Developed by Oculus VR, a division of Facebook Inc., **Oculus Rift** is a virtual reality headset released on March 2016. Is is composed of a stereoscopic OLED display, 1080x1200 resolution per eye, 90 Hz refresh rate and 110° field of view (Orland, 2016). It has integrated headphones which provide a 3D audio effect, rotational and positional tracking (The Oculus Rift, Oculus Touch, and VR Games at E3, 2015). As well as gaming and entertaining uses, the Rift has attracted the attention from industrial and professional contexts, in particular regarding purposes such as visualization, advertising and productivity enhancement. These kind of implementations have been experimented by several architecture firms, especially for visualization and design. Indeed, the Rift allows architects to see exactly the final appearance of the building, getting thus a better understanding of the scale that would ne barely comprehensible on traditional monitors. As a review by Dan Stapleton of IGN says, "The Oculus Rift is the first headset available, and it does a fantastic job of not just displaying high-quality VR, but making it easy to use" (Stapleton, 2016). Althought being an efficient and user-friendly device, the Rift received few shortcomings (Dormehl, 2016), generally related to its high cost (in 2016 it was around 600 $ in USA, after a yer it has been dropped to 500 $) and the need of a powerfull PC to run it.

Figure 6.9 – Oculus Rift with Oculus Touch controllers

## Google Glass

In 2013, Google publicized to bring AR to the masses by launching **Google Glass**. Priced at a premium of $1500, however, it was quickly disregarded by consumers against other top-end smartphones. Consumers naturally thought they would see information of all kinds with their gaze fixed upon anything, pulling sources from Twitter to Facebook to Wikipedia. When futurist Robert Scoble first brought home the prized item, his wife asked eagerly, *"Can I look at someone and see something about them?"*.


Figure 6.10 - Google Glass

Predictably, Google Glass fell short of all expectations. The prospect of an underwhelming and unaffordable device, that so invaded privacy also led restaurants, bars, gyms, and hospitals to forbid its usage. The public wasn't ready yet. No wonder the Glass flopped.

## HoloLens

After Google's attempt to introduce augmented reality to the masses, the push by Microsoft with its **HoloLens** technology - as well as new headsets from companies including *Meta* and *Magic Leap* - really shows people how virtual objects can be integrated into real-world surroundings. To the point where users will, for example, see that there's a virtual object sitting on a table and that object will remain where it is with respect to the user's position as he or she moves.

These new technologies are really raising expectations for augmented and mixed reality beyond holding a phone out to see a creature on the street corner. (Greenemeier, 2016).


Figure 6.11 - Microsoft HoloLens

## 6.5 Modern conception and awareness of Virtuality Continuum

Several decades have passed since the first attempts of giving a clear definition of Virtuality Continuum and its main sub-classes. Although the modern market is able to offer more and more examples and application of AR, VR and MR – in engineering fields, but not only there – it is easy to notice an evident confusion concerning the correct terminology applied to that.

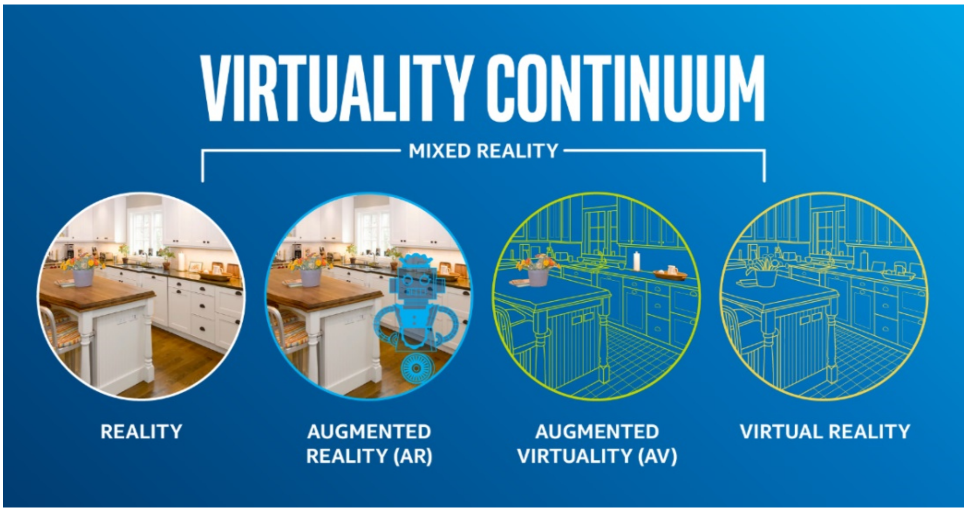



Figure 6.12 - Virtuality Continuum examples

### Movies and VR (The Matrix - TRON - Inception)

In the cinematographic field, for example, one needs only to think of 3 most successful movies that tackled the subject of virtual reality.

In the Wachowskis' **Matrix** series, humans are enslaved in a virtual world created by machines. The ensuing battle does not occur in a physical reality but primarily in the ***artificial reality*** of the Matrix – a digitally manufactured reality experienced by oblivious humans as a dream.

***"[The world] exists now only as part of a neural-interactive simulation that we call the Matrix"***

*Morpheus' (Laurence Fishburne) quote from "The Matrix"*

A likewise concept can be found in **TRON** Series, with the only difference that the main character does not interact with other human users connected in the virtual environment (called "the Grid") but only with ***actual human-like programs***.

Figure 6.13 - Tron (1982) and Tron: Legacy (2010)

An inspiring picture of this virtual environment is depicted within the first speech of Tron: Legacy's prologue, from the character interpreted by Jeff Bridges.

*"The Grid. A **digital frontier**. I tried to picture clusters of information as they moved through the computer. What did they look like? Ships? Motorcycles? Were the circuits like freeways? I kept dreaming of a world I thought I'd never see.*
*And then, one day… I got in."*

Similarly, in **Inception** movie the scene is set into an "oneiric" reality, where the characters live (through their dreams) an experience of total immersion inside their subconscious. Actually, in this case it is possible to talk about a ***multiple virtual reality*** (or multi-level VR) being the user able to interface from a virtual environment into another virtual environment within it; inside of it, the process can be reiterated even further (for a total of 3 sub-levels, in the movie).

Figure 6.14 – Virtual reality in Inception (2010)

***"In a dream your mind continuously does that... It creates and perceives a world simultaneously. So well that you don't feel your brain doing the creating"***

*Cobb's (Leonardo DiCaprio) quote from "Inception"*

In all the previous examples, the characters are totally immersed in a virtual environment so plausible and verisimilar, that it could be compared to a complete real environment. Noticing the previous quotes, it is interesting to observe that during the development of the movies, despite there isn't a clear adoption of the term "virtual reality", all the three movies are undoubtedly talking about the same thing: ***virtual reality***.

A famous dialogue between the two main characters in The Matrix gives an interesting description of this digital context, as well as of the feelings and senses perceived within it.

*Neo: Right now we're inside a computer program?*

*Morpheus: Is it really so hard to believe? [...] Your appearance now is what we call residual self-image. It is the mental projection of your digital self.*

*Neo: This, this isn't real?*

*Morpheus: What is real? How do you define real? If you're talking about what you can feel, what you can smell, what you can taste and see, then real is simply electrical signals interpreted by your brain. This is the world that you know. The world as it was at the end of the twentieth century. It exists now only as part of a neural-interactive simulation that we call the Matrix. You've been living in a dream world, Neo. This is the world as it exists today.*

This term can be considered as correct, if not even "underestimated", being these contexts a clear example of ***fully-immersive virtual reality***.

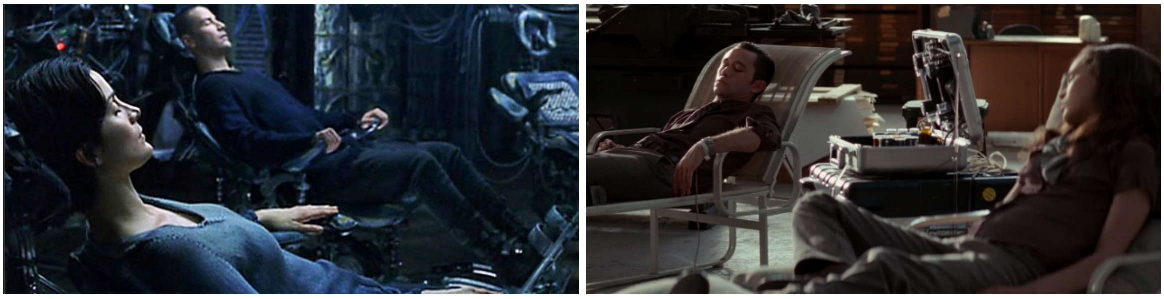


Figure 6.15 – Similarities on the connection modality
between Matrix Series (1999 - 2003) and Inception (2010)

## Movies and Mixed Reality (Minority Report, Iron Man Series)

Clear examples of mixed reality can be found in other movies such as Iron Man or Minority Report. In particular, The Iron Man series is actually relevant for the adoption of both augmented and mixed reality, as it can be noted in the figures above: AR inside the armour, with an accurate identification and analysis of the external environment; on the other hand, Tony Stark starts up J.A.R.V.I.S and can grab and turn virtual objects out of the air using only his hand, giving so a perfect example of MR application.

Figure 6.16 – Augmented reality and Mixed reality in Iron Man Series (2008 - 2010 - 2013)

Though, how he actually sees and has advanced interactions with the virtual objects with no eye wear is one issue, and holographic technology wouldn't allow for what is seen in the film.

A curious fact is that during the whole progression of the movie, not a single explanation or description of the technology adopted has been provided. Consequently, everything is erroneously confused from the spectators (or even worse, from the movie critics) as a simple and vague "virtual reality" or even "augmented reality", whereas in this situation we are dealing with a case of mixed reality.

From a 2016 report of Matt Szymczyk, CEO and founder of Zugara - a Los Angeles-based augmented reality software developer – there is an example of application of this technology made by John Underkoffler (interface designer, Oblong Industries).

*"We're not finished until all the computers in the world work like this"*

*John Underkoffler, Oblong Industries*

Underkoffler was a consultant on Minority Report and his company, Oblong, already has similar interfaces in use by clients. For interaction with virtual objects, HoloLens technology uses gestures within the field of view to point and click within a virtual interface. While gestures can currently be used to interact with and move virtual objects with technology like Kinect, detection and tracking of objects synchronized to finger movements is still a few years away. Decades away is the ability to use a mixed reality system depicted in Iron Man 2 to "create" a new element like Vibranium (Szymczyk, 2016).

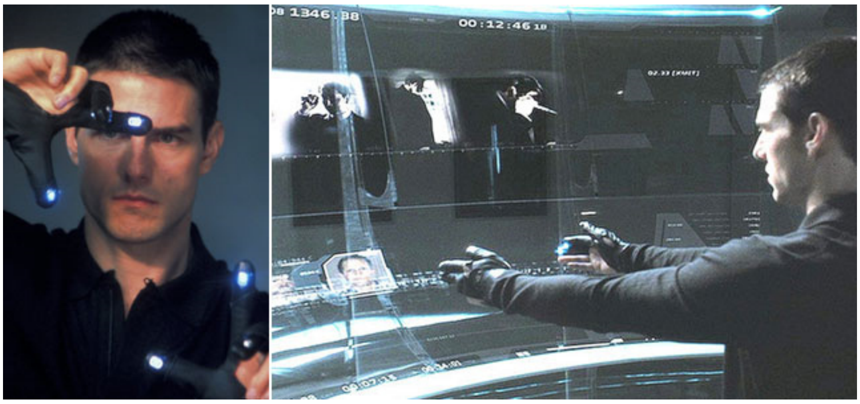


Figure 6.17 – Mixed reality in Minority Report (2002)

These are just two of the latest examples of mixed reality in movies but, if we want to look far behind, a special mention must be done for **Terminator**, which even in the late 1984 anticipated the first elements of AR, like humans and objects recognizing and identification. But of course, in this case the strict terminological classification of AR falls down being the user not a human, but a machine itself.


Figure 6.18 - Augmented reality in Terminator (1984)

As conclusion, after the examples provided it is possible to note a different level of feasibility between the two systems, virtual reality and mixed reality. If in the VR-based movies we are still encountering serious technical limitations for a tangible modern application, on the other hand the movies proposing Mixed Reality models are able to face an easier applicative interpretation, subdued mostly to a necessary technology sector, which we are getting closer and closer to. But then again, it is indeed this feasibility definition the brings to the difference between ***sci-fi*** genre and ***futuristic*** one.

## Books and videogames

Over the past decade, time spent with print media has declined as younger readers have flocked to digital readers, tablets and smartphones. To engage potential readers with print media, some early innovators in publishing have been toying with augmented reality books, giving the possibility not only to play, but also to learn in a more interactive and of course funnier way. As well as books, AR is able to offer through the videogames sector a way to learn more about the everyday context, this just walking on the street and taking a look onto the personal device.

In the following paragraphs, two recent applications of AR within books and videogames are shown as examples, giving for the latter also a demonstration of the typical terminological incorrectness that risk to spread among the market.

## Wonderbook: Book of Spells from J.K. Rowling

Released in November of 2012, “Wonderbook: Book of Spells” for PlayStation 3 is an Augmented Reality book experience that works with the PlayStation Move Motion Controller and the PlayStation Eye Camera. The book-slash-game transforms readers into students of Harry Potter’s Hogwarts.

Figure 6.19 - Wonderbook: Book of Spells from J.K. Rowling

Using the motion sensitive controller as a magic wand, readers can cast spells as they read through pages. “This is an extraordinary device that offers a reading experience like no other,” says J.K. Rowling. Reviews of the book (Brenzo, 2013) suggest that the book not only captures the magical spirit of Harry Potter, but that it is a perfect use of the Move controller.

## Pokémon Go

When Pokémon Go made debut, critics sneered at its user interface, saying that the game should not even be qualified as AR. Immersive visuals are non-existent. The graphics look rudimentary. But it promises nothing more than a game, using your phone’s GPS to detect where you are and make digital monsters “appear” around you. And it’s all free. So even though the servers crashed many times over, casual gamers still can’t get enough of their favourite pocket monsters, and have turned the game into a cultural phenomenon.

Figure 6.20 - Augmented reality mode on Pokémon Go

Basically, the game uses the camera and GPS system on an Android or iPhone handset to digitally superimpose these animated creatures on top of whatever scenery appears on the smartphone's screen when its camera scans one's surroundings. That might sound a lot like augmented reality, but Ken Perlin, a computer science professor and founding director of the New York University Media Research Lab, prefers to call Pokémon GO and games like it ***"location-based entertainment"*** rather than *augmented reality*.

Perlin makes a distinction between simply dropping digital characters onto a screen based on a player's location and integrating those characters into their surroundings so that they seem more real than virtual. Perlin's experience with virtual and augmented reality extends back decades, and he has won several awards - including an Academy Award - for inventing ways to improve computer graphics.

Perlin is not criticizing Pokémon GO, which has introduced a lot of people to the basic idea of augmented reality in a short period of time. Instead, he says interest in the game provides an opportunity to look at where augmented reality could go in the near future.

There are his words from a recent interview: "There is a fundamental difference between just slapping a label in front of something because I'm there and actually altering our perception of reality. If you or I are walking around and we're seeing a creature through a wearable device over our eyes—as opposed to seeing it through our phone screens at arm's length—then that creature has become part of our shared perception of reality. There's a fundamental difference between our brains integrating objects into reality and simply being told that something is part of reality" (Greenemeier, 2016).

Niantic CEO John Hanke said he sees augmented reality as an important complement to his company's guiding philosophy, that games should happen off the couch and outside of the home. In the case of Pokémon Go, players have to travel —

> *"AR is far more interesting and promising — for technology and, really, for humanity"*
>
> *John Hanke, Niantic CEO*

including to places they may never have visited before — to find and catch all the Pokémon in the world.

"From the very beginning, our games were about encouraging people to go outside and see interesting places," Hanke said. "So [I have] mixed feelings about people looking at their screen while we're trying to lead them out into the park where they can see the statue and trees and nature."

Much like Apple CEO Tim Cook, Hanke predicted that AR will reach greater heights than virtual reality, which employs headsets such as the Oculus Rift or HTC Vive to surround players in an all-virtual environment.

"It is the direction that I think is far more interesting and promising — for technology and, really, for humanity," Hanke said. "In a VR situation, you're isolating yourself from everyone around you and entering this completely virtual space. AR is designed to add, enhance the things you do as a human being: being outside, socializing with other people, shopping, playing, having fun. AR can make all those things better." But, he acknowledged, convincing AR is "significantly more challenging" to create (Johnson, 2016 )

## 6.6 Final considerations on AR

Therefore, nowadays the term augmented reality is mainly used in relation with the technology adopted, rather than its real former application, influencing then also the choice of particular commercial names. Names that regularly bring to a misleading ambiguity. Just to take an example that can be analysed in *Chapter 7.1*, the ARToolKit software offer an instance of how the technologic definition is able to declass the applicative one: seeing the figure, the 3D model is projected, through a marker, onto a device's screen, offering the possibility to analyse the plant with a 360 degree prospective. This procedure at the present time is universally acknowledged as AR. Yet, after a better examination from a conceptual point of view, this is not properly correct: the AR technology should namely offer an "augmented perspective of reality", proposing a wealth of additional information onto a real context. However, in a marker it's impossible to find this supporting reality, i.e. the room from which extrapolate the plant system, but just a mere virtual representation of a real environment (located at kilometres away or maybe even not designed yet) in a simple piece of paper of few square centimetres.

Let's now compare this example with a more practical AR application (BIM Anywhere): differing from the first case, now in the device it's possible to find surely a representation of the virtual environment, but in a context that is totally real. When in the first case the plants are bounded purely to a fictitious marker, without any connection to the real environment, in the second case the plants are actually observed in relation to the existent and physical space, delimited by walls, slabs, partitions and building elements; the real environment is concretely implemented with virtual information, whereas the first example basically consists of a three-dimensional visualisation bound to the space purely from a graphic/prospective point of view.

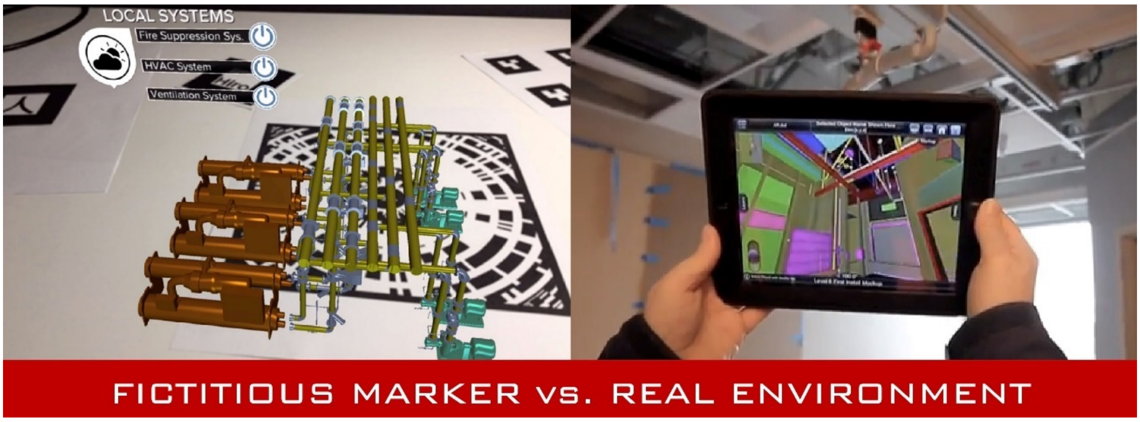



*Figure 6.21 – Comparison between ARToolKit and BIM Anywhere*

ARToolKit is then just one of the many software currently on the market that improperly adopt the term "AR", evidently due to a higher terminological appeal from a marketing standpoint.

During the development of this thesis, however, there will not be any further focus about terminological inconsistencies of the individual software, despite further studies could be desirable in order to ensure a better obviousness in the field of the theoretical definitions within the virtuality continuum. This not only for technical purposes, but also for the protection of the users. Instead it will be emphasized the application fields and the potentiality of the AR and MR systems, delegating elsewhere the reliability and pertinence of the respective commercial names.

# 7. AR AND VR IN BUILDING/CIVIL ENGINEERING AND ARCHITECTURE

*"After decades of gestation ... VR and AR [have] finally gone mainstream. In short, people are now comfortable with the idea of interacting as pixels, and it is changing the way they want to work"*

Catherine McIntyre

The evolution of modern microprocessors and computer memories during the past decade has made the acquisition, recording and manipulation of virtual 3D data technically affordable, even with standard personal computers and handheld devices. Application of augmented reality for 3d model presentation can be used in all field of engineering where we use virtual three dimensional models in process of projecting.

Augmented reality is used for the presentation of different type of 3D elements in civil engineering. In *Figure 7.1* a virtual steel structure model is shown, registered and superimposed in an outdoor location, using AR application and portable device. User is first located at a distance from the CAD model.

Figure 7.1 - AR presentation of steel structure model

When he eventually starts moving towards the structure to look at the inside from different angles, CAD model of the steel structure stays fixed in the user's field of view, and so the user had complete freedom of movement in the site to observe the augmented scene from different perspectives (Amir, Brian, & Vineet, 2008). Using the design model, created by the architect as a background for AR, it is possible to coordinated the complex interior detailing.

In *Figure 7.2* we can see an AR presentation of the stairs model created from the structural steel, glass and railing detailers. The complex nature of the stairs and its immediate context required unorthodox sequencing, in which field welds had to take place directly adjacent to already installed feature glass.

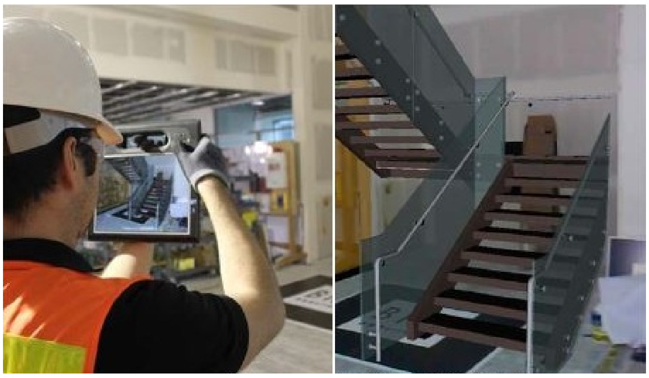


*Figure 7.2 - AR presentation of stairs*

This led to intense study of the means and methods to solve the problem by using augmented reality applications.

Augmented Reality can be used as visualization tool for building's mechanical systems. In the process of reconstruction of Fraunhofer's new Boston headquarters (LaMonica, 2013 ) AR was used as novel visualization tool for building's mechanical systems.

There is an iPad application that lets people point the tablet at a wall or floor and see an animation of the pipes and ducts underneath (*Fig. 7.3*). Augmented reality can be used by civil engineering, transportation, and urban planning professionals to create, evaluate, and communicate infrastructure proposals. AR help to drive stakeholder buy-in and inform decision making with visually rich proposals for transportation, land, water, and energy infrastructure projects (*Fig. 7.4*)

*Figure 7.3 - AR presentation of street pipeline*

*Figure 7.4 - AR presentation of building mechanical systems*

Augmented reality in architecture is used for presentation of an existing architectural facility. Most often it is done because of its historic significance or design values of presented buildings. The augmented reality presentation of existing facilities involves use of an appropriate hardware (a computer, a tablet, a mobile phone), software (Augment, AR Media...) and markers (2D graphics).

It offers the possibility to see 3D models in a realistic environment, just like a scale model does (where by physically moving and rotating a marker you move and rotate the facility, looking at it from the perspective chosen by the user, as shown in *Figure 7.5*). This enables an intuitive view of the 3D facility model and it is more suitable for users with no experience in the manipulation of three-dimensional digital facilities (Krasić & Pejić, 2014).

*Figure 7.5 - AR presentation of existing building*

In architecture, AR can be used for presentation of no longer extant buildings. The research showed that reconstructions of no longer existing historic structures are most commonly used for presentation or research purposes of large buildings or city models (Münster, 2013). This approach can be used for creating non-invasive presentation of an object. The use of the AR presentation which provides generating hybrid environment, i.e. a mixture of the real and virtual environment, influences the viewer impressions. A potential user of the AR presentation can see a no longer extant object in its real size and they can look for its relationship with both real time and space.

Augmented reality can be used for presentation of building project on real location (*Figure 7.6*). This feature allows users to use GPS coordinates to locate a 3D model on the earth's surface. The software then tracks the 3D model coordinates in the real space using a suitable sensor fusion technique.

*Figure 7.6 - AR presentation of building project*

This makes it possible to display virtual models in the real world without any marker. The Geo-localization feature extends the spectrum of visualization possibilities for the AR users in many application domains, including architecture, engineering and cultural heritage.

# 7.1 Authoring platforms for augmented reality

Within the book *Emerging Technologies of Augmented Reality: Interfaces and Design,* (Haller, Billinghurst, & Thomas, 2007) the authors identify distinct development platforms that are available for creating and authoring AR simulations. These platforms include the ARToolKit, Studierstube and DWARF. The popularity of such programs comes from their ease of use, without any need of advanced programming skills. There are numerous software platforms that are capable of authoring augmented reality simulations; though, it is preferable now to focalize the analysis on those platforms that provide construction/architectural based applications. In particular, two remarkable platforms will be discussed: ARToolKit and Unity 3D.

## ARToolKit

Developed by Dr Hirokazu Kato, the ARToolKit is a widespread authoring platform used for the creation of strong augmented reality applications. Currently, it is maintained as an open-source project hosted on GitHub (GitHub.com, 2016). Its popularity is strongly proved by the amounts of software downloads - more than 750.000 (Sourceforge.net, 2016) since its release on 2004 - most of which come from Japan (Italy is the 13$^{th}$ in the download ranking). Computer vision algorithms are used to track 2D target markers, while C or C++ programming languages are adopted for the creation of interfaces and additional functionality. AR is supported through direct video feed of the real world with a 3D object overlain or alternatively can support designing environments for AR on Head Mounted Displays. The toolkit has a few limitations that are common for most AR authoring tools, such as the influence of 2D marker size and pattern. The more distinct the pattern is with colour/shape, the easier the camera will register it from a distance. If parts of the 2D marker are covered, the 3D model will not superimpose (Elgohari, 2015).

Figure below shows how the ARToolKit camera technology tracks a 2D target (sheet of paper) and how a 3D object is superimposed over video stream of the real world (Elgohari, 2015).

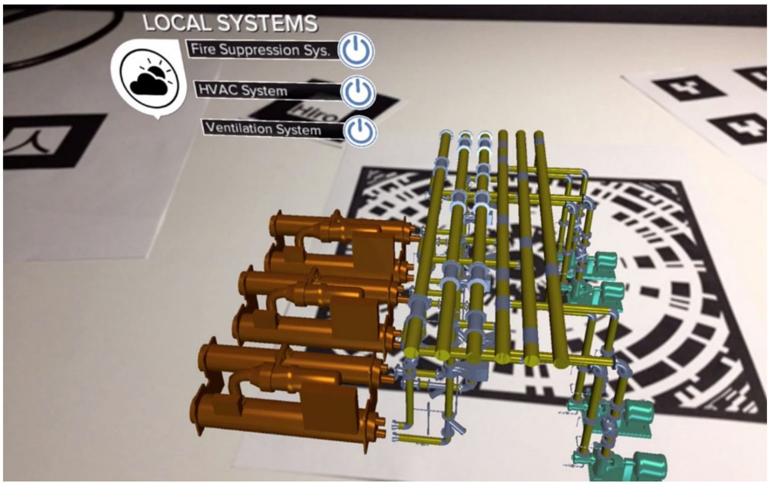



*Figure 7.7 - Mechanical system on ARToolKit*

## Unity 3D

Unity 3D, differing from ARToolKit, has the peculiarity to go beyond the mere creation of augmented reality applications. Its adoption is focused mainly to the production of video games and to some extents entertainment. Unity 3D is also a common platform for the development of serious games, which are simulated environments for training and learning. These include simulations such as army personnel training, construction safety situations and lifesaving real time environments developed with Unity 3D. A serious game precedent where employers are trained to visualize life on an **oil rig environment** will be discussed further in the chapter. Unity 3D would appear to be the ideal platform for the capacity to build sophisticated user interfaces. Unity 3D also has well-documented dictionaries of scripting commands that are available online on the main Unity 3D website and also on a variety of independent developer websites. In addition, all scripting commands can be written in either C# or JavaScript. Unity 3D is one of the easiest authoring platforms to use since it has such a diverse range of precedents and uses in gaming and entertainment ("Fear", 2009). It was important to find research precedents that demonstrated application development for construction uses and could simulate a vast amount of 3D content while maintaining performance. Unity 3D, among all authoring platforms, delivered this with its numerous online precedents of 3D modelling simulations and training examples. Documented resources show the limitations of scripting and key performance criteria for 3D performance and content. Many tutorial resources generated by the creators of Unity 3D are available on online alongside hundreds of other avid developers who have posted free resources and training.

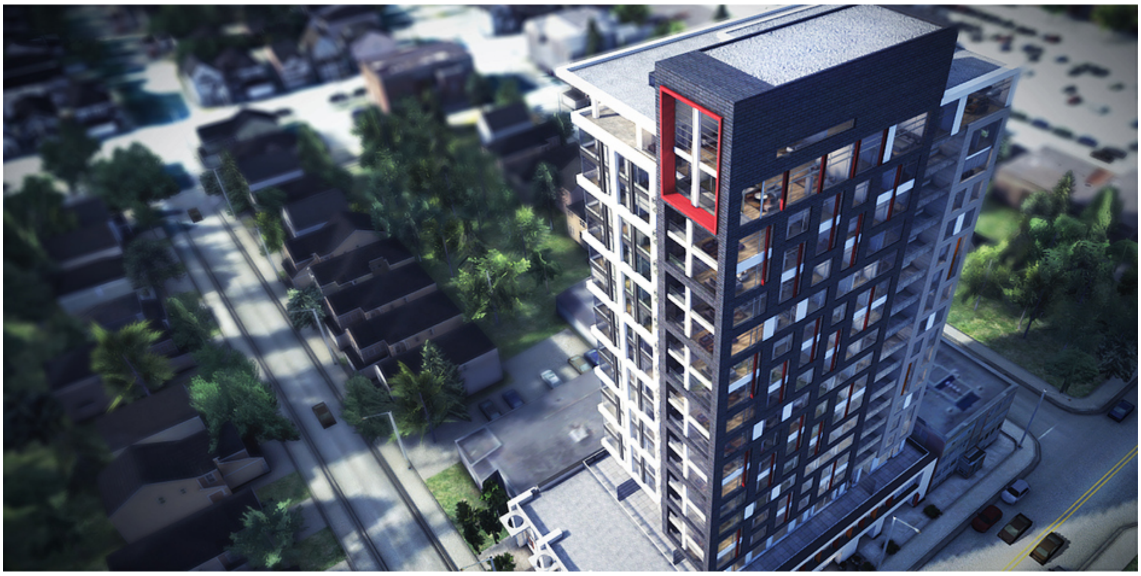


*Figure 7.8 - Unity 3D: visualization of a new building in Ottawa, Canada*

Most importantly within these resources are scripting samples that contain C# and JavaScript which can be easily manipulated to serve a different function. In addition, Unity 3D has a diverse community of developers that share knowledge on forums. This ability to access various development forums allows any user to analyze methods that other developers have used to achieve similar goals/functions.

A separate extension package called **Vuforia** enables augmented reality to be integrated with Unity 3D. The extension is easy to install and has a simplified set of tools. Porting an application for a mobile smart device is relatively straightforward and there are not many programmatic complexities to deal with (Qualcomm, 2012). The complexity of AR controls within Unity 3D are limited compared with AR specific platforms such as the ARToolKit. Developing an AR application with Unity 3D also requires added software development kits (SDKs) and mobile platform licenses which are not free. Despite this added complexity, Unity 3D provides a sophisticated platform and it is well supported in terms of documentation and examples.


*Figure 7.9 – Vuforia application with Unity 3D*

# 7.2 Computer software applications

The aim of this chapter is to identify functions/aspects that can inform the design of the prototype application. The chosen software platforms are well established desktop computers applications that are capable of 4D BIM integration. Also discussed are recent mobile platform precedents such as smart reality and BIM 360 which are lightweight mobile versions of two desktop computer applications. Applications such as Navisworks and Synchro both have abilities that enable users to integrate a Gantt chart with 3D building models from BIM platforms such as Revit. This section also discusses desktop computer research projects such as the VCS project in which a different development path was used to integrate MS project with a 3D model. From this review of 4D BIM, a final section examines an oil rig simulation that illustrates the interaction and visualization capabilities of Unity 3D called the Oil rig simulation. These areas of precedent – commercial 4D BIM, examples from academia and a large-scale simulation – will inform the subsequent development of the prototype applications.

## Navisworks

Developed by Autodesk, Navisworks enables the integration of common scheduling Microsoft software project (MS Project) with a wide range of specific 3D models from mainstream Autodesk BIM programs. Navisworks also has integrated file size reduction tools, making it a well-established tool for multi sized BIM projects, and is also valued for its ease in filtering and grouping objects with similar object properties (Morkos, Macedo, Fischer, & Somu, 2012). Navisworks can also integrate with other scheduling tools such as Asta and Oracle Primavera (AutodeskNavisworksHelp, 2013). It operates by cross referencing components in a 3D model back to tasks listed within the respective Schedule/Gantt chart. This link can then enable the user to control the project visually using tools that graphically identify clashes and 3D timelines (AutodeskNavisworks_website). These clash detection tools identify conflicts not only in the schedule but also components that are in the 3D model as shown in figure below.

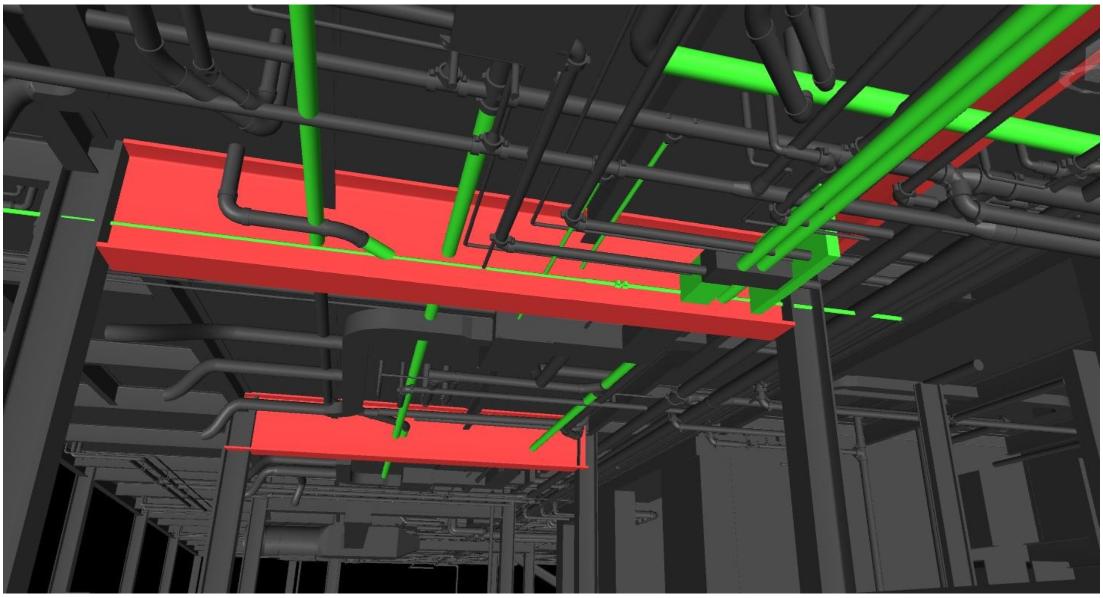


Figure 7.10 – Clash detection in Navisworks

Therefore, any Autodesk native 3D models such as Revit, which are integrated into Navisworks can be analyzed for modelling clashes using the clash detective. Navisworks is an important precedent among other 4D BIM precedents since it is the industry standard program used in practice. Navisworks has the capacity to simulate projects with relatively large file sizes and has a well-established system for identifying project clashes using the clash detective function. The clash detective function is very useful for identifying and resolving potential convergences between various servicing components such as structural beams and piping in a 3D model as seen below. By identifying these clashes early, the risk of cost overruns and potential conflicts is reduced hence improving the coordination amongst key stakeholders (AutodeskNavisworks_website)

## BIM 360 Glue

Similar to Navisworks it gives the user a 360-degree view of the project in 3D on a tablet computer. It can identify clashes with a variety of tools on screen whilst on the move. This is particularly useful for practitioners that want to take a portable version of a 3D model on site and access it virtually with any other key stakeholders (AutodeskBIM360_website). BIM 360 is important not just for being an extension of Navisworks for mobile devices but also an application that can simulate the complexities of large 3D model content. This is important in this precedent review as this will be a challenge during development to simulate large amounts of 3D content on devices with lesser computing power. This is a challenge in many mobile application platforms that intend to simulate complex 3D content, as optimization plays a key role during development (Jie, Yang, & Haihui, 2011). BIM 360 also enables online collaboration of a singular 3D model on a cloud based system increasing the practice of teamwork and partnership between project participants. A variety of tools enable users to pinpoint issues and save the view they were in for different users to find. Comments and arrows can be drawn and saved on the 3D model and the application is able to communicate this information with a main Navisworks desktop computer program (Schwaiger, 2013).

*Figure 7.11 - BIM 360 GLUE*

## Synchro

Synchro is relatively similar in function to Navisworks in the ability to merge project management information from MS project and provide virtual simulation tools that graphically show clashes in both schedule and 3D model. Apart from interface design, navigation methods and selection tools in both Navisworks and Synchro have clash detection tools that highlight 3D components that are conflicting (SynchroProfessionalProductVideo, 2012). The two applications have different workflows but both strive for the same objective of integrating task based information and 3D components in simulation. Small differences such as methods of selecting objects and navigating the interface using the mouse and keyboard set these applications apart. Synchro and Navisworks integrate and import similar 3D model files from Autodesk products.

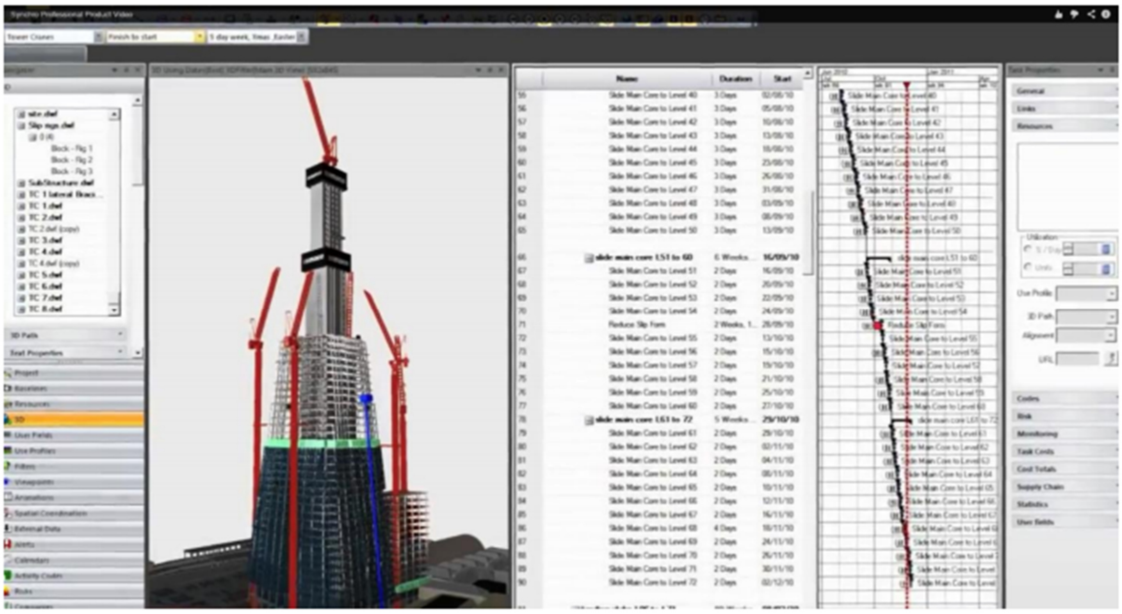


*Figure 7.12 - SYNCHRO application in 3D model and schedule*

## Smart Reality

Synchro, through collaboration with software developers JBKnowledge, has also released an application for smart devices which adopt augmented reality. This precedent is the most important of all examples that have been discussed in this chapter as it is one of the few precedents that display construction management information using augmented reality. Smart Reality is a 4D AR BIM application which simulates a Revit based 3D model in AR using the 2D building plan as a target marker. The application smart reality is by far the closest example of mobile 4D AR BIM that has been found through research at this stage in time. Smart reality is a particularly important precedent since it is one of the few applications that is operating on an android device and has a video demonstration of functions (smartreality.com). Although developers have released a Beta version for testing they also stress that it is still a work in progress among many other research projects that are carrying out 4D AR BIM. The application has features that allow the user to simulate an augmented reality 4D model of a Revit model onto a 2D plan acting as the target marker (Benham, 2014).

*Figure 7.13 - Smart Reality demonstration*

# Virtual Construction Simulator

The virtual construction simulator is a research project which aimed to integrate a MS project Gantt chart with a 3D building model as shown in figure below. The Gantt chart reacted to changes made in the schedule and was further referenced on the 3D model in visual representation. The goal of creating this project was for improving engineering education in planning and construction management amongst students at Penn State University. This was done by exposing them to playing the simulation as a type of game where players had to test different construction scenarios (Messner, et al., 2011).

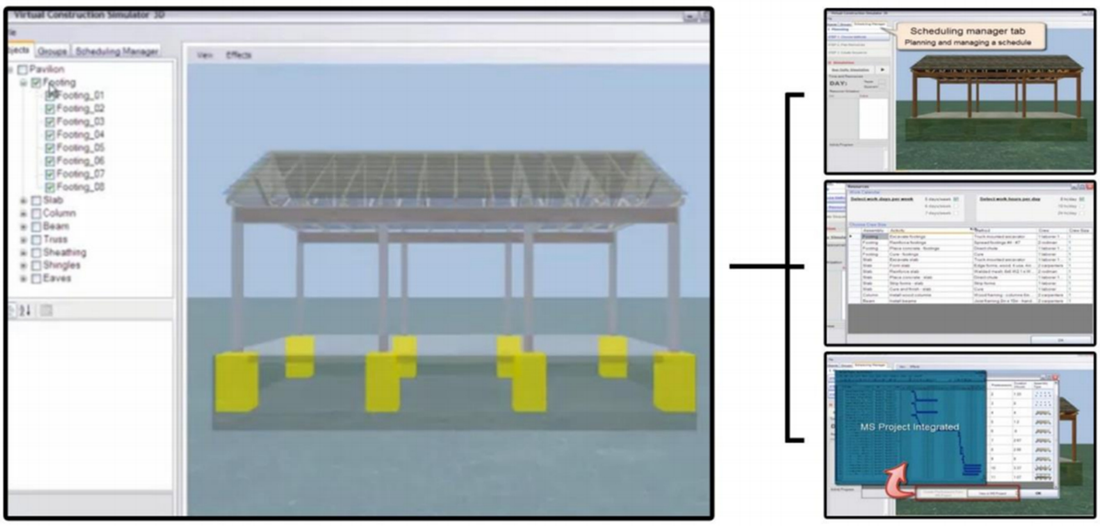



*Figure 7.14 - Virtual Construction Simulator*

This project was significant as a research precedent as it recorded a workflow showing an attempt at the same concept for this research through developing 4D BIM integration with a development engine called Irrlicht (Nikolic, 2006). The complexity of this project was sufficiently larger, since the programmed MS project was fully integrated into standalone platform and there were multiple developers. The aspects from this precedent were significant with the method in which the application uses colour coordinated changes that were triggered by changes in the schedule. Although the 3D content simulates a simple building model, it is simple enough to display the idea that the Gantt chart has a direct link with the 3D model and any changes made to it is registered in the 3D model via colour highlights.

## Oil Rig Serious Game (Spatially Immersive System)

This precedent was important for showcasing a complex 3D project created using Unity 3D. Aspects such as detail of 3D content and textural quality will be important in the design of the prototype. Most importantly for this precedent was assessing how the user interface functions.

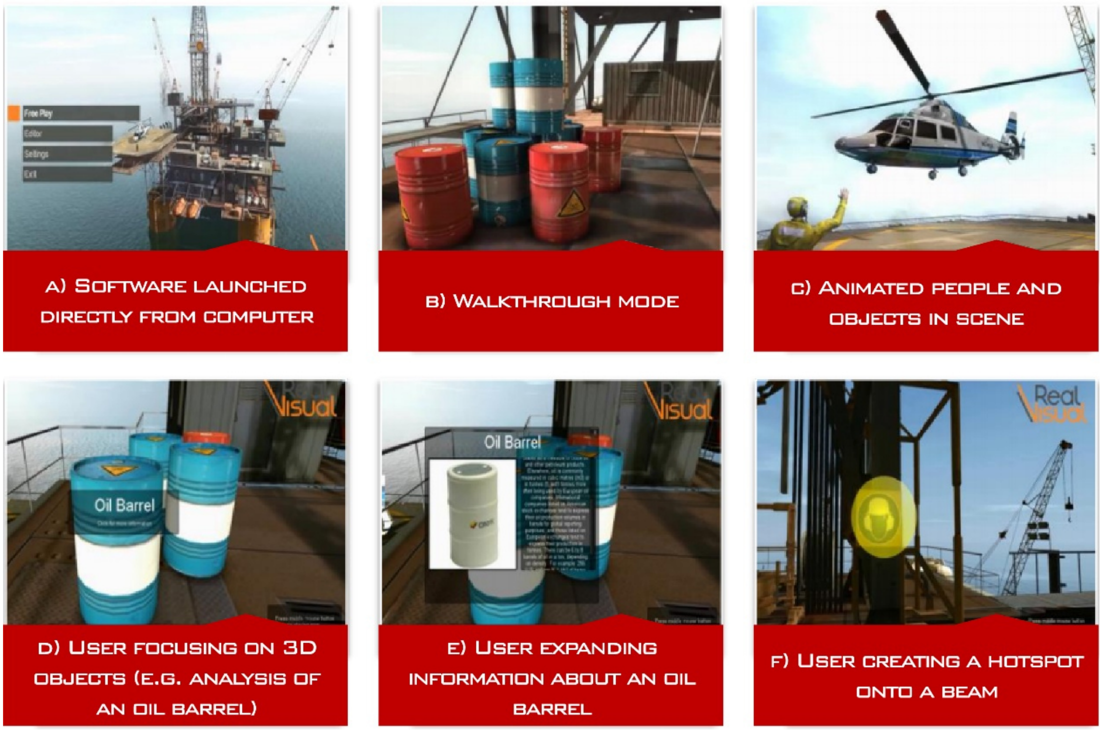



*Figure 7.15 - Potentialities of Oil Rig Serious Game*

With the authors limited programming experience, it was important to observe the extents of the user interface and to ascertain an idea of functions that can be designed with Unity 3D. The Oil rig simulation created by Real Visual is a serious game application for standalone aimed to enable potential employees for an oil rig to visualize how operations occur on an oil rig. These include samples of daily tasks, common objects found around the site and emergency procedures.

Figure below shows the application in operation and a few of the features that help train participating users in understanding information. Image B clarifies where the user is able to explore the entire oil rig using a walkthrough mode. Image C shows the enhanced user experience through animated 3D content such as co-workers and sophisticated vehicles such as cranes and helicopters. Images D/E are unique on screen features that help the user ascertain information about a particular object which in this image is manufacturing information on an oil barrel. If there are areas of concern that pose a potential risk to the personnel on the rig, the user can virtually create a virtual hotspot on the area of concern, as shown in image F. This allows another user in the simulation to enter and view what has been labelled as a potential risk from the previous participant enhancing the sense of collaboration amongst employees (RealVisual, 2014).

# 7.3 Mobile Applications

This section discusses precedents of mobile applications that are important precedents for informing the design of the prototype. There are numerous applications for Architectural, Engineering and Construction (AEC) use. Applications such as such as AutoCAD 360 and Magic Plan are rated as one of the top performing applications for Architectural practitioners in the world. The focus of this review is to analyse functions and special features of applications aligned to construction management or augmented reality. In this context, four applications have been selected for analysis: AutoCAD360, BIM Anywhere, 3Don Architecture and MagicPlan.

## Autocad 360

This application is relatively similar to BIM 360 in that it was also made by Autodesk and enables online 3D model collaboration. As opposed to integrating Revit based drawings/3D models AutoCAD 360 enables users to turn the drawings/3D models made with AutoCAD into portable resources that can be viewed on a tablet computer as shown in the demonstration figure below. Traditional methods of checking 2D building plans against a real building on site involved printing them out and taking them on site as seen in image 1. With AutoCAD 360 the user views a 2D plan on site without the hassle of unrolling large A1 sized rolls of paper as seen in image 2. In image 3 the user can present findings from on-site visits to virtually any audience with ease since the application ties information found on site with the tablet computer back to the original AutoCAD desktop computer program. AutoCAD 360 has received a lot of attention on both social networks and in general practice as an application that has been used extensively amongst Architects.

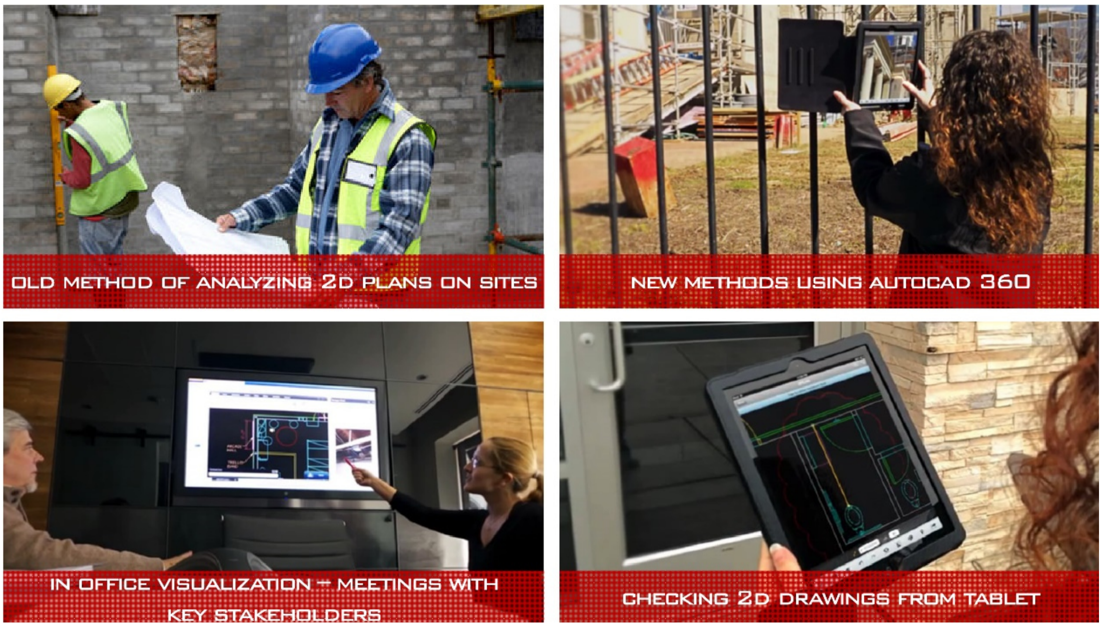



*Figure 7.16 - AutoCAD 360*

## BIM Anywhere

This application has relatively identical features to the last one by enabling the user to visualize 3D models. This application however is different in that it utilizes a form of augmented simulation by using QR codes that are glued to surfaces within the building. This method along Milgram and Kishinos virtuality continuum is referred to as augmented virtuality. Although a QR code is used the 3D environment simulated on the tablet is mostly 100% virtual and relies on sensors such as the gyroscope and accelerometer within the tablet to guide the user. This is different from augmented reality which is a mixture of both real and virtual objects on screen.

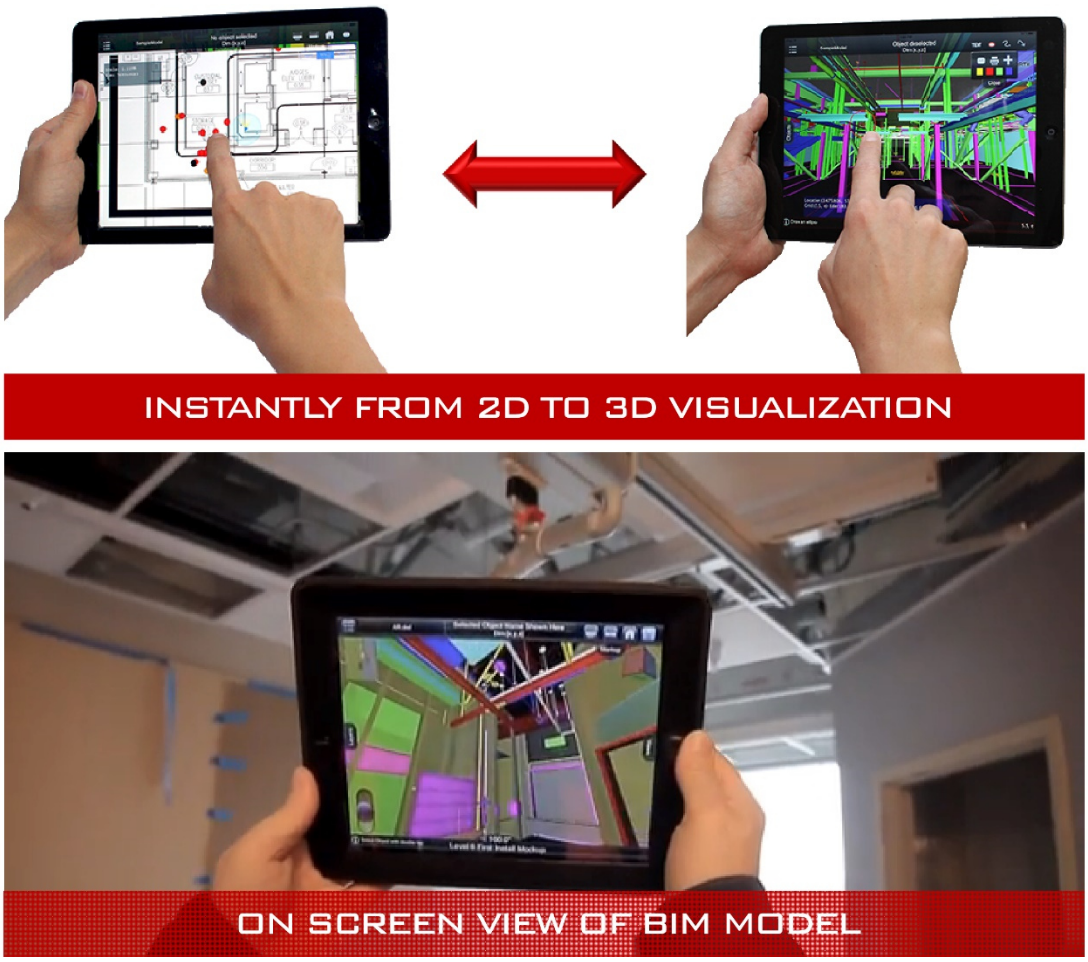



*Figure 7.17 – BIM Anywhere*

By activating this application, the tablet computer camera is switched on and directs the user to focus the tablet onto the QR code. Once the camera has focused onto the QR code the BIM model is superimposed virtually into position on screen which can be in front or anywhere around the user (BIManywherePro.com). This application contains similar functions to Autodesk 360 and BIM 360 in its ability to share files online using cloud sharing services where office personnel can communicate with on-site personnel using a singular digitized 3D model.

## 3DOn Architecture

The mobile application 3DOn is unique in that it utilizes both virtual and augmented reality for on-site simulation of 3D models created using Google Sketch Up. Google Sketch Up is a 3D modelling program which is commonly used amongst a large range of design related disciplines for its ease of use. 3Don contains 3 different modes that change the user perspective for visualizing a 3D Model. Preview mode enables the user to examine the model using virtual reality on the tablet screen. Walkthrough mode is relatively identical to any other virtual game application where the user can examine both inside and outside the building. On site mode is a special mode that enables the user to superimpose the 3D model using augmented reality. This application however does not use a 2D target marker but instead uses GPS and wireless internet systems that are installed within the mobile device (Vaay, 2014). This application from these demonstrations only superimposes the building in augmented reality on site but has limited interaction functionality.


*Figure 7.18 – 3DOn Architecture*

## Augment

There are also some third-party AR providers that have software and applications for download: Augment is one of those with apps available for both Android and iOS platforms. Augment is labeled as a user-friendly turnkey solution that you can upload your 3D models to, and if you don't have your own 3D models, they have an in-house team that can create them for you or you can browse their gallery of pre-made 3D models (Heimgartner, 2016).

*Figure 7.19 - Augment*

## MagicPlan

MagicPlan takes advantage of the devices camera and augmented reality to create floor plans of rooms. All the user has to do is stand and point the device and then the software does the rest of the work. It is then possible to export these drawings as a PDF, JPG, or DXF. It takes a bit of getting used to at first but, once mastered, is quite accurate.


*Figure 7.20 - Usage and potentialities of MagicPlan*

## 7.4 Considerations on future developments of AR

According to Digi-Capital fundamental "Augmented/Virtual Reality Report Q2 2015", the AR/VR market is going to expand up to $150 billion by 2020. Moreover, the augmented reality has got the lion's share of the market in $120 billion (VR gets only $30 billion, though).

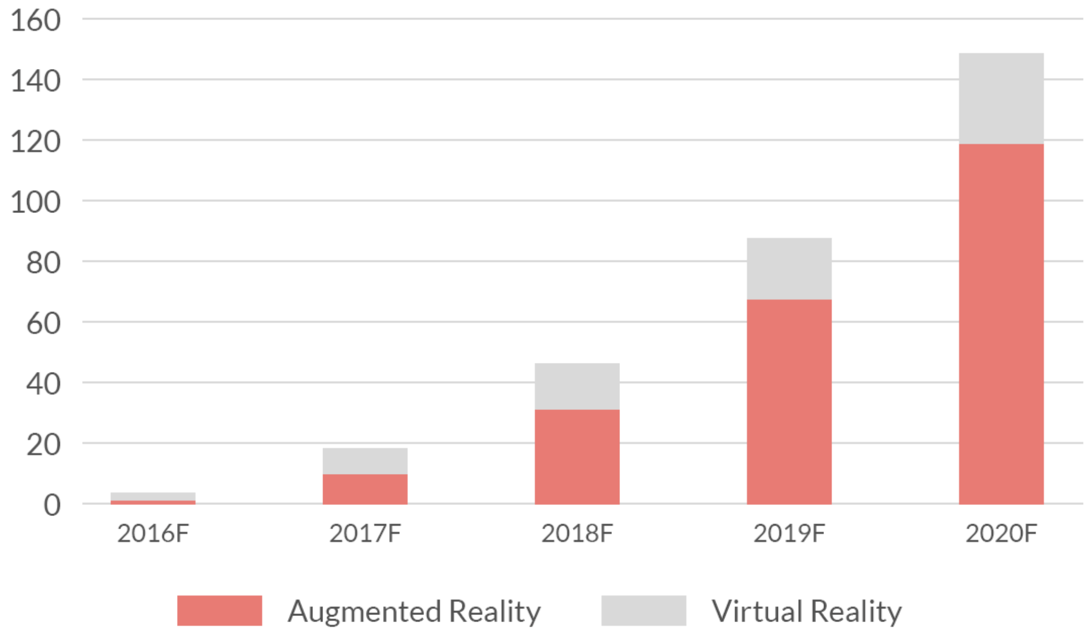



*Figure 7.21 - Augmented/virtual reality revenue forecast (B$)*

The latest market study provided by Juniper Research shows that enterprises and industrial markets are going to bite the $2.4 billion piece of pie in 2019. Compared to $247 million in 2014, the difference is quite impressive.

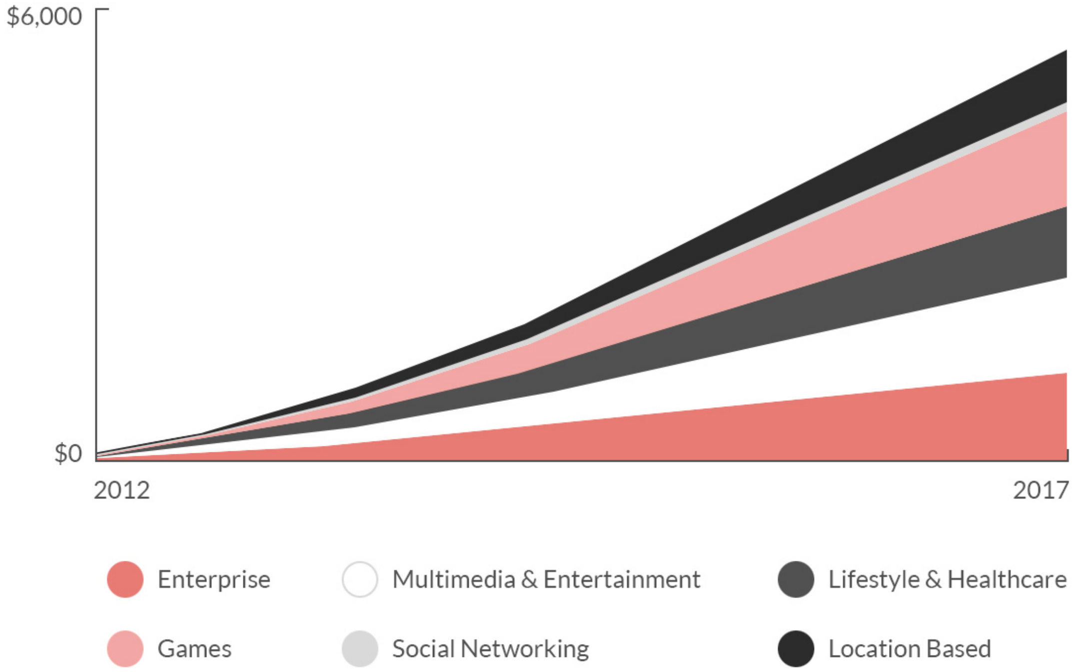



*Figure 7.22 - Total mobile AR revenues (5.2 B$) on mobile devices split by category – 2012 to 2017*

Because of the global technology explosion, software improvements and preponderance of wearables, Juniper predicts extending interest in AR among businesses. Though, until the end of the decade, the adoption won't be so fast.

## Benefits of AR

As seen in the previous chapters, here below is summarized a list of the main benefits of using augmented reality (and, indirectly, the BIM technologies) on building and architectural engineering:

**Higher appeal for the real estate**

Thanks to the innovative software products provided with AR contents, it is possible to offer the costumer a better and more direct visualization of the final product.

**Immediate feedbacks on site progress**

Designers are able to check the evolution of a building projects directly on the construction site.

**Enhance the plant system**

Obtain a clearer perspective of the mechanical systems (hydronic, HVAC, electric, etc.).

**Provide the designer a reliable clash detection**

Avoiding the late recognize of design issues, saving thus money and time

**Managing the on-site phase**

Help the workers to managing the construction site, giving real time information on stocking, cataloguing, monitoring the project phases, etc.

Also, it is important to consider the influence that AR brings to the **marketing** sector:

**Technology is unique and noticeable**

For now, there are much more chances to surprise your customers and create a necessary buzz because you can give your consumers something your competitors don`t have yet.

**Augmented reality gets more virality**

Speaking about the buzz. The word of mouth and social sharing increase the acquisition of new customers.

**AR opportunities for personalization**

A chance to create something unique and thereby to express one's individuality is way more engaging than standard media content.

**Content quality improvement**

With AR you give users a tool for creating the content that they couldn`t do before by themselves.

**Interactivity maintains the retention**

Not in vain the entertainment trend stays in leaders list. The highly exciting content motivates users to interact with your mobile application again and again.

## Limitations

Of course, the augmented reality technology is a bit crude yet and still in its infancy. But we foresee its fast development and evolution because of some key drivers as an increasing number of phones and tablets and their extended functionality or increasing internet speed. Today is the best time to get started with an app that will draw your customer's attention to the product or can become a part of brilliant marketing campaign (theappsolutions.com, 2016).

Taking the technology to the next level, where engineers can display hidden items such as underground utilities using a small tablet or smartphone, for instance, is a lot trickier and a lot more difficult.

The problems center on accuracy. In the demanding fields of engineering or medicine, where research is also taking place, fractions of centimeters or inches make a big difference. "The potential for augmented reality is great but achieving it is extremely difficult," says Stephane Cote, a research director and fellow at Bentley Systems in Quebec. "For engineering, accuracy is extremely important. You're having an impact on people's lives. You need accurate data."

# 8. CONCLUSIONI

*"The dawn of a new era is upon us - one of full immersion into the digital world. It's an era that will be founded upon the technological revolution that's been silently brewing for more than a decade. Our once-dreamed-up reality of wedding the digital world with the physical world is no longer the stuff of fabled fairytales; it's happening, right here, right now"*

R. L. Adams

Nella sintesi introduttiva di questa tesi di laurea specialistica, si è voluto proporre un nuovo punto di riflessione, quasi provocatorio, dicendo che "nel giro di pochi decenni, la realtà virtuale diventerà una tecnologia diffusa e accessibile al pari di un frigorifero o un tostapane". Tuttavia, quando si parla di progresso tecnologico occorre analizzare la differenza tra sviluppo e applicazione. È indubbio che l'implementazione hardware e software stia seguendo una crescita esponenziale in ogni tipo di mercato, accompagnata da una progressiva diminuzione dei costi di sviluppo e da una conseguente maggiore accessibilità da parte degli utenti. Spesso però è necessario che questo sviluppo venga accompagnato anche da una corretta attenzione nei confronti dei fabbisogni e delle limitazioni dell'utente finale o più in generale, in campo aziendale, della committenza. Il settore delle simulazioni in realtà virtuale costituisce un esempio concreto di come questo deficit in passato abbia influenzato possibili potenziali acquirenti, e di come si stia cercando di superare in maniera propositiva il problema dell'accessibilità. Nel corso della tesi, infatti, si è visto l'esempio del sistema VirtuSphere, un ambiente immersivo di simulazione VR decisamente innovativo dal punto di vista tecnologico, ma ostacolato principalmente dalla complessità dei sistemi hardware e dalle dimensioni, fattori che lo hanno escluso da contesti domestici e aziendali limitandolo a sporadiche applicazioni in ambito militare. Nel corso degli ultimi anni, questo muro tra sviluppo e utenza si sta progressivamente abbassando, in parte grazie anche ad un sempre maggior quantitativo di modelli 3D disponibile tra i professionisti del settore, nonché una interoperabilità più efficiente tra i diversi software di progetto.

E qui, dunque, si arriva al BIM. L'esistenza di un database via via più fornito e aggiornato permette l'utilizzo di modelli sempre più completi e complessi, favorendo le imprese ad investire nel BIM. Come si è dimostrato, questo passaggio dalle tecnologie CAD tradizionali al BIM deve essere incentivato anche a livello normativo, tramite l'emanazione di linee guide chiare ed efficienti e col fine ultimo, in sintesi, di offrire un migliore sistema di progettazione digitale. In questo modo, il BIM assume un ruolo centrale in tutto il ciclo di vita dell'edificio: la reale potenzialità del BIM infatti consiste non solo nella fase di progetto (preliminare, definitivo o esecutivo che sia), ma anche nelle fasi di operabilità cantiere, gestione e manutenzione del bene costruito. La creazione del prototipo preso in esame si prefigge come obiettivo proprio la formazione sulla sicurezza per tutte le operazioni in cantiere, e si è dimostrato come il suo futuro sviluppo possa determinare un addestramento degli utenti più sicuro e meno costoso, pur mantenendo un alto livello di efficienza senza inficiare sulla qualità di apprendimento. Naturalmente, come si è riscontrato durante le interviste condotte dall'autore, è impossibile allo stato odierno ottenere un livello di "realtà" comparabile alla vera esperienza di cantiere: il pericolo di un chiodo di troppo lungo il percorso delle impalcature, l'instabilità dovuta agli sbalzi di vento, la caduta accidentale di mezzi e utensili sono solo pochi esempi che testimoniano il livello di variabilità di eventi e situazioni che possono essere riscontrati. Difatti, l'intento del prototipo non è affatto quello di sostituire l'apprendimento diretto, bensì quello di proporsi come mezzo integrativo, in modo tale da offrire all'utente la possibilità di apprendere preventivamente (o potenziare ulteriormente) tutte quelle abilità pratiche e conoscenze teoriche necessarie per un'attività lavorativa in piena sicurezza. È bene chiarire un concetto fondamentale. La nozione di realtà virtuale, così come quella di realtà aumentata, non è nulla di nuovo. Come si è visto, i suoi sviluppi sono stati delineati nel corso degli ultimi decenni partendo da mere supposizioni teoriche fino a raggiungere i primi risultati applicativi. Quindi si può intendere la "tecnologia" del prototipo come un naturale proseguimento degli studi in materia di simulazioni in realtà virtuale. Il lato innovativo nel prototipo sta invece non tanto nella tecnologia, quanto nello "scopo", ovvero il suo campo di applicazione e il target di utenza. Fino ad ora, le VR Simulations si sono limitate al settore militare, aeronautico e in piccola parte al settore di formazione medico, con ottimi risultati deducibili all'interno di questa tesi. Il passo in avanti che il team di professionisti ha voluto compiere nella creazione di questo prototipo è stato dunque quello di estendere, per la prima volta, il concetto di VR al mondo della sicurezza cantiere.

Il prototipo costituisce inoltre un utile strumento di verifica e monitoraggio, permettendo di analizzare criticità funzionali nei percorsi di evacuazione, sia tramite l'osservazione diretta (modalità multi-user) sia tramite il controllo dell'Intelligenza Artificiale (analisi Monte Carlo). Come sviluppo futuro dunque si auspica un'implementazione del comparto software e hardware, in particolare migliorando la struttura del modeling e integrando un sistema di sensoristica per l'utilizzo dell'applicazione in remoto. Per ora il prototipo offre una dimostrazione relativa alle vie di fuga in situazioni di incendio; nuovi tipi di simulazioni sarebbero utili in futuro per dimostrare l'efficacia della simulazione in realtà aumentata, mantenendo sempre un chiaro riferimento alla normativa sulla sicurezza. Inoltre, uno step successivo potrebbe essere costituito dall'implementazione del prototipo all'interno di un contesto di realtà mista, unendo dunque benefici e potenzialità di realtà virtuale e realtà aumentata. Questo è forse il passo più ostico, anche perché a livello sociale il virtuality continuum rimane tuttora un campo oscuro e carico di forti dubbi. Risulta curioso pensare alle parole di Paul Saffo, esperto di tecnologie digitali e docente presso la Stanford University della Silicon Valley, che nel 1991 espresse chiaramente le sue critiche nei confronti degli scetticismi.

> *"Virtual reality is a technological curse that will drive the real world from our lives. This is the conclusion being advanced by a growing number of information-age Cassandras who warn that we will become passive electronic junkies, addicted to synthetic experience served up by virtual reality "fantasy amplifiers." Others welcome what the pessimists fear, convinced that virtual reality will deepen our appreciation of the natural world."*
>
> *PAUL SAFFO, InfoWorld, September 30, 1991*

In conclusione, si è dimostrato come il virtuality continuum possa trovare efficienti spunti di applicazione nel contesto BIM, offrendo nuove possibilità di sviluppo a un tipo di metodo progettuale in continua evoluzione. Perché è proprio questo il concetto più importante del BIM: esso non costituisce solamente uno strumento, come spesso viene erroneamente inteso (anche dagli operatori stessi del settore ingegneria e architettura), ma un vero e proprio metodo. Esso consente di associare ad ogni elemento costruttivo tutte le sue informazioni progettuali, offrendo ai progettisti un ventaglio di strumenti digitali utili al monitoraggio di interferenze costruttive. Non esiste semplificazione più sbagliata dell'accostare il BIM alla mera rappresentazione 3D dei componenti costruttivi. Pertanto è auspicabile una consapevolezza maggiore da parte di tutti gli attori del processo edilizio, prestando la dovuta importanza alla "I" di Information ancor più che alla "M" di Modeling.

# 9. BIBLIOGRAPHY


*"Applications Of Virtual Reality", Virtual Reality Society Web page*. (n.d.). Retrieved from Virtual Reality Society Web page: http://www.vrs.org.uk/virtual-reality-applications/

*"The Benefits of Virtual Reality and 3D Simulation", Skills2Learn Web site*. (2016). Retrieved from Skills2Learn Web site: http://www.skills2learn.com/index.html

*"Virtual Reality in Construction", Virtual Reality Society Web site*. (2016). Retrieved from Virtual Reality Society Web site: http://www.vrs.org.uk/virtual-reality-applications/construction.html

(2016). Retrieved from Skills2Learn Web site: http://www.skills2learn.com/index.html

(2016). Retrieved from Campfire Union Web site: https://www.campfireunion.com/towercranevr

(2017). Retrieved from Cyberith Web site: http://cyberith.com/product/

(2017, March). Retrieved from Google Trends Web Site: https://trends.google.it/trends/

(2017). Retrieved from ICMQ Web site: http://www.icmq.it/pers_esperti_bim.php

*ABC shows, SharkTank Season 1 Episode 9*. (2009, December 10). Retrieved from Abc Web site: http://abc.go.com/shows/shark-tank/episode-guide/season-01/109-episode-109

Abdellaoui, N., Taylor, A., & Parkinson, G. (2009). *Comparative Analysis of Computer Generated Forces' Artificial Intelligence*. Ottawa.

(June 2015). *AEC (UK) BIM Technology Protocol v2.1.1*.

AIA. (June 2013). *AIA Contract Document G202-2013, Building Information Modeling Protocol Form*. American Institute of Architects.

Alessandro Febretti, A. N. (2013). CAVE2: A hybrid reality environment for immersive simulation and information analysis. *Engineering Reality of Virtual Reality 2013*. Burlingame, CA, United States: The International Society for Optical Engineering.

Amir, B., Brian, T., & Vineet, K. (2008). General Purpose Modular Hardware and Software Framework for Mobile Outdoor Augmented Reality Applications in Engineering. *Advanced Engineering Informatics*, pp. 90 - 105.

ANCE-RLST. (2013). *BILANCIO SOCIALE: L'attività realizzata e i risultati ottenuti nell'anno 2013.*

AutodeskBIM360_website. (n.d.). Retrieved from http://www.autodesk.com/products/bim-360/overview

AutodeskNavisworks_website. (n.d.). Retrieved from Autodesk Web site: http://www.autodesk.com/products/autodesk-navisworks-family/overview

AutodeskNavisworksHelp. (2013, January 5). Retrieved from Autodesk Web site: http://www.autodesk.com/support/navisworks-products

Azhar, S., Hein, M., & Sketo, B. (2015). *Building Information Modeling (BIM): Benefits, Risks and Challenges.* Auburn University, Alabama (USA): McWhorter School of Building Science.

Banca Dati Statistica. (2017). Retrieved from Banca Dati Statistica Web site: http://bancadaticsa.inail.it

Benham, J. (2014). *A new way to visualize your construction projects. Retrieved January 28, 2014, from Smart Reality Beta: http://smartreality.co.* Retrieved from • Benham, J. (2014, January 26). A new way to visualize your construction projects. Retrieved January 28, 2014, from Smart Reality Beta: http://smartreality.co

BibLus-net. (2016, September 1). *UNI 11337, dopo le BS e le PAS inglesi arrivano le linee guida BIM italiane.* Retrieved from BibLus-net Web site: http://biblus.acca.it/uni-11337-dopo-le-bs-e-le-pas-inglesi-arrivano-le-linee-guida-bim-italiane/

BIC Cloud Web site. (2017). *Business Process Reengineering with BIC Cloud.* Retrieved from BIC Cloud Web site: http://www.gbtec.de/bpm-software/bic-cloud/

BIM4M2. (2015, February 3). *BIM4M2.* Retrieved from http://bim4m2.co.uk/

*BIM9.* (2017). Retrieved from DFourInc. Web site: http://dfourinc.com/bim9/

BIManywherePro.com. (n.d.). Retrieved from BIManywherePro Web site: http://bimanywhere.com/features.php

Bimforum.org. (n.d.). *Level of Development Specifications.* Retrieved from Bimforum Web site: http://bimforum.org/lod/

BimTalk.co.uk. (n.d.). *Levels of BIM maturity.* Retrieved from BimTalk Web site: http://bimtalk.co.uk/bim_glossary:level_of_maturity

Boughriet, R. (2016, April 12). *BIM : le numérique au service de la transition énergétique du bâtiment.* Retrieved from ACTU-Environnement Web site: http://www.actu-environnement.com/ae/news/bim-numerique-batiment-transition-energetique-maquette-26588.php4

Brenzo, J. A. (2013, August 30). *5 Augmented Reality books that delight and engage.* Retrieved from Marxent VisualCommerce website: http://www.marxentlabs.com/5-augmented-reality-books-that-delight-and-engage/

BuildingSmartItalia.org. (n.d.). *I Livelli di Sviluppo (LOD) nel progetto digitalizzato: La misura dell'informazione all'interno del percorso BIM*. Retrieved from BuildingSmartItalia Web site: http://www.buildingsmartitalia.org/2016/04/22/i-livelli-di-sviluppo-lod-nel-progetto-digitalizzato-la-misura-dellinformazione-allinterno-del-percorso-bim/

CADServicesIndia. (2015, April 21). *Medium*. Retrieved from https://medium.com/@cadservicesindia/bim-is-rapidly-getting-adopted-by-most-of-the-countries-in-the-world-9c562645839a#.4eu83esrp

Chatziandreu, D., & Kostopoulou, M. A. (October 2012). *Bim and Greek Construction: Research and detailed analysis for potential implemention*. Volos, Magnisia, Greece: Department of Architecture, University of Therraly.

Craig, A. B. (2013). *Understanding Augmented Reality*.

D.lgs. 50/2016 art. 23 comma 13. (2016, April 18). Livelli della progettazione per gli appalti, per le concessioni di lavori nonché per i servizi. *Codice Appalti*.

D.lgs. 50/2016 art. 31. (2016, April 18). *Codice Appalti*.

designingbuildings.co.uk. (2016, July 21). *BIM maturity levels*. Retrieved from DesigningBuildings Web site: https://www.designingbuildings.co.uk/wiki/BIM_maturity_levels

Dormehl, L. (2016, March 28). *Oculus Rift Review: VR's Rising Star Isn't Ready for the Mainstream*. Retrieved from Wall Street Journal Web site: https://www.wsj.com/articles/oculus-rift-review-vrs-rising-star-isnt-ready-for-the-mainstream-1459173888

dpr-review.com. (n.d.). *The Four Levels of BIM: Taking Virtual Design and Construction to a Higher Level*. Retrieved from dpr-review Web site: http://dpr-review.com/fall-winter-2010/story/the-four-levels-of-bim

DrillingContractor.org. (2011, October 25). *Transocean's new Kuala Lumpur facility to train more than 1,200 a year*. Retrieved from DrillingContractor Web site: http://www.drillingcontractor.org/transocean%E2%80%99s-new-kuala-lumpur-facility-to-train-more-than-1200-a-year-11534

DrillingContractor.org. (2011, December 13). *Well intervention simulator tops off Shell's new advanced well control course*. Retrieved from DrillingContractor Web site: http://www.drillingcontractor.org/well-intervention-simulator-tops-off-shell%E2%80%99s-new-advanced-well-control-course-12260

EdilTecnico.it. (2017, January 17). *BIM obbligatorio dal 2019: le fasi di attuazione del decreto*. Retrieved from Edil Tecnico Web site: http://www.ediltecnico.it/51786/bim-obbligatorio-2019-decreto/

Elgohari, T. (2015, December 9). *The integration between 4D simulation, Mobile technology and Augmented reality for automating construction progress monitoring and communication*. Retrieved from LinkedIn Web page:

https://www.linkedin.com/pulse/integration-between-4d-simulation-mobile-technology-reality-elgohari

Ellis, R. K. (2009). Field Guide to Learning Management Systems. ASTD Learning Circuits.

GitHub.com. (2016). Retrieved from GitHub Web site: https://github.com/artoolkit

Greenemeier, L. (2016, July 13). Interview to Ken Perlin. *Scientific American magazine*.

Haller, Billinghurst, & Thomas. (2007). *Emerging Technologies of Augmented Reality: Interfaces and Design, p.108*. Idea Group Pub.

Harpaceas.it. (n.d.). *Il BIM e il concetto di dettaglio e LOD*. Retrieved from Harpaceas Web site: http://www.harpaceas.it/il-bim-e-il-concetto-di-dettaglio-e-lod/

Heimgartner, J. (2016, April 13). *"What Is Augmented Reality and How Can Engineers and Designers Use It?"*. Retrieved from www.engineering.com

Heiskanen, A. (2016, July 11). *Virtual Reality for Construction*. Retrieved from aec-business Web site: http://aec-business.com/virtual-reality-construction/

Inail. (2016). *Tabelle regionali con cadenza mensile Regione Lombardia*.

IntelligentDecision. (2011, November 28). *Intelligent Decisions, Inc., to Present and Demo First-Ever, Fully Immersive Virtual Simulation Training for U.S. Soldiers at Top Industry Conference*. Retrieved from Intelligent Decision Web site: http://www.intelligent.net/news/press-releases/intelligent-decisions-inc-present-and-demo-first-ever-fully-immersive-virtual

Investopedia.com. (n.d.). *Monce Carlo Simulation*. Retrieved from Investopedia Web site: http://www.investopedia.com/terms/m/montecarlosimulation.asp

ISO 19650-1. (2017). *BS ENISO 19650-1 Organization of information about construction works - Information management using building information modelling. Part 1: Concepts and principles*. B/555/-/6 - Steering panel for ISO 19650 Specification for information management for the capital/delivery phase of construction projects using Building information modelling.

ISO 19650-2. (2017). *BS ENISO 19650-2 Organization of information about construction works - Information management using building information modelling. Part 2: Delivery phase of assets*. B/555/-/6 - Steering panel for ISO 19650 Specification for information management for the capital/delivery phase of construction projects using Building information modelling.

James, P. (2015, April 18). *The Gulf Between High End Military VR and Consumer VR is Rapidly Shrinking*. Retrieved from Road To Vr Web site: http://www.roadtovr.com/the-gulf-between-high-end-military-vr-and-consumer-vr-is-rapidly-shrinking/

Jie, J., Yang, K., & Haihui, S. (2011). Research on the 3D Game Scene Optimization of Mobile Phone Based on the Unity 3D Engine. *International Conference on Computational and Information Sciences. Chengdu: IEEE Computer Society*, (pp. 875-877). Chengdu.

Johnson, E. (2016 , September 19). Retrieved from Recode.net: http://www.recode.net/2016/9/19/12965508/pokemon-go-john-hanke-augmented-virtual-reality-ar-recode-decode-podcast

Knutt, E. (2015, February 12). *France And Germany Move Forward On Bim Adoption*. Retrieved from Bim+ Web site: http://www.bimplus.co.uk/news/france-and-germany-move-forward-bim-adoption/

Krasić, S., & Pejić, P. (2014). The application of augmented reality in the presentation of existing architectural facilities. *4th International Scientific Conference on Geometry and Graphics, moNGeometrija 2014* (pp. 74-81). Vlasina, Serbia: Faculty of Civil engineering and Architecture in Niš, Serbian Society for Geometry and Graphics SUGIG.

LaMonica, M. (2013 , January 21). *Putting Building Science into Practice*. Retrieved from MIT Technology Review: http://m.technologyreview.com/view/510131/pu

Lawrence, W. K. (2015 ). *Learning and Personality: The Experience of Introverted Reflective Learners in a World of Extroverts*. Cambridge Scholars Publisher.

Lento, G. (2013, March 18). Intervista a Graziano Lento, Autodesk su Ingegneri.cc. (Ingegneri.cc, Interviewer)

Magrassi, P. (2002). *Supranet in "Dizionario dell'economia digitale"*. Milano: V. Di Bari, Sole 24Ore Pirola.

MÄK. (2016). *VR-Forces: Computer Generated Forces and Simulator Development*. Retrieved from MÄK Web site: http://www.mak.com/products/simulate/vr-forces

MarketsandMarkets. (May 2016). *Augmented Reality and Virtual Reality Market by Device Type (HMD, HUD, Handheld Device, Gesture Tracking, Projector and Display Wall), Component (Sensor, Display, Camera, and Software), Vertical, and Geography - Global Forecast to 2022*. MarketsandMarkets.com.

MathWorks.com. (n.d.). *Monte Carlo Simulation in MATLAB*. Retrieved from MathWorks Web site: https://www.mathworks.com/discovery/monte-carlo-simulation.html

McGrawHill. (2014). *The Business Value of BIM for Construction in Major Global Markets*. Bedford, MA: McGraw Hill Construction.

Merel, T. (2015, April 6). *Augmented And Virtual Reality To Hit $150 Billion, Disrupting Mobile By 2020*. Retrieved from Tech Crunch Web site: https://techcrunch.com/2015/04/06/augmented-and-virtual-reality-to-hit-150-billion-by-2020/

Messner, J., Riley, D., Horman, M., Otto, G., Wang, L., Jaruhar, S., & al., e. (2011). *The Development of the Virtual Construction Simulator 3 – An Interactive Simulation Environment for Construction Management Education. Proceedings of the 2011 ASCE International Workshop on Computing in Civil Engineering (pp. 454 - 461).* . (pp. 454 - 461). Miami: American Society of Civil Engineer.

Milgram, P., & Kishino, F. (1994). *A Taxonomy of Mixed Reality Visual Displays, 1994.*

Morkos, R., Macedo, J., Fischer, M., & Somu, C. (2012). Quantifying effects of specific tool functionalities on 4D modelling productivity. *CIB W78 2012: 29th International Conference*, (pp. 17-19). Beirut. Retrieved from • (2012). y. CIB W78 2012: 29th International Conference, (pp. 17-19). Beirut

Münster, S. (2013). *Workflows and the role of images for virtual 3d reconstruction of no longer extant historic objects,*. Dresden University of Technology.

Nieler, P. (2016). *Investing Into Virtual Reality: Making Sense Of It All.* CoFounder Magazine.

Nikolic, D. (2006). *The Virtual Construction Simulator. Retrieved December 02, 2013, from Penn State University - Computer Integrated Construction:.* Retrieved from http://www.engr.psu.edu/ae/cic/vcs/index.aspx?p=4

Nikolic, D., Jaruhar, S., & Messner, J. (2011). Educational Simulation in Construction: Virtual Construction Simulator. In D. Nikolic, S. Jaruhar, & J. Messner, *Journal of Computing in Civil Engineering* (pp. 421-429).

O'Keefe, R. M., & Roach, J. W. (1987). Artificial Intelligence Approaches to Simulation. In *The Journal of the Operational Research Society* (pp. 713-722). Palgrave Macmillan Journals on behalf of the Operational Research Society.

Orland, K. (2016, March 29). *The Ars review: Oculus Rift expands PC gaming past the monitor's edge.* Retrieved from Ars Technica Web site: https://arstechnica.com/gaming/2016/03/the-ars-review-oculus-rift-expands-pc-gaming-past-the-monitors-edge/

Pavan, A., Daniotti, B., Cecconi, F. R., Maltese, S., Spagnolo, S. L., Caffi, V., . . . Pasini, D. (2014). INNOVance: Italian BIM Database for Construction Process Management. *ICCCBE2014 International Conference on Computing in Civil and Building Engineering*. Orlando.

Pavan, A., Daniotti, B., Cecconi, F. R., Spagnolo, S. L., Maltese, S., Chiozzi, M., . . . Caffi, V. (2014). Gestione informativa delle costruzioni, INNOVance per il processo costruttivo. *Energy, sustainability and building information modelling and management*. *Energia, sostenibilità e dematerializzazione operativa*. Bari.

perspectives.3ds.com. (n.d.). *BIM Level 2 vs. Level 3.* Retrieved from Perspectives 3D Web site: http://perspectives.3ds.com/architecture-engineering-construction/what-is-bim-level-3/

Procházka, A., Schätz, M., Vyšata, O., & Vališ, M. (2016). *Microsoft Kinect Visual and Depth Sensors for Breathing and Heart Rate Analysis.* Prague: Department of Computing and Control Engineering, University of Chemistry and Technology.

Qualcomm. (2012). *Augmented Reality (Vuforia).* Retrieved from Qualcomm Developer Web site: https://developer.qualcomm.com/mobile-development/add-advanced-features/augmented-reality-vuforia

RealVisual. (2014, January 7). *Unity 3d: Hotspots. A presentation by Real Visual.* Retrieved from https://www.youtube.com/watch?v=xJXqk4hex_o&list=PL7HmpJN3LvQpWYY8AZLzjGMbnywKngffB&index=2

Rizzarda, C. C. (2016, February 5). *BIM e normative in Europa: cerchiamo di essere lucidi.* Retrieved from LinkedIn Web site: https://www.linkedin.com/pulse/bim-e-normative-europa-cerchiamo-di-essere-lucidi-chiara-c-rizzarda

Rizzarda, C. C. (2017, January 13). *Pas 1192-2 is under revision.* Retrieved from LinkedIn Web site: https://www.linkedin.com/pulse/pas-1192-2-under-revision-chiara-c-rizzarda

Sampaio, A. Z., Cruz, C. O., & Martins, O. P. (2011). Didactic Models in Civil Engineering Education: Virtual Simulation of Construction Works. In J.-J. Kim, *Virtual Reality* (p. January). 8: InTech.

Schwaiger, T. (2013, October 18). Retrieved from http://beyonddesign.typepad.com/posts/2013/10/how-to-use-bim-360-a

SCORM.com. (n.d.). Retrieved from SCORM Web site: http://scorm.com/it/scorm-explained/technical-scorm/sequencing/sequencing-pseudo-code/

SharkTankBlog. (2017). *SharkTankBlog Episodes.* Retrieved from SharkTankBlog Web site: http://sharktankblog.com/business/virtusphere/

Shelidon. (2015, August 28). *Canta che ti PAS 1192 (2): specifiche per l'information management.* Retrieved from Shelidon Web site: http://www.shelidon.it/?p=3496

smartreality.com. (n.d.). Retrieved from Smart Reality Web page: http://smartreality.co/

Sourceforge.net. (2016). Retrieved from Sourceforge Web site: https://sourceforge.net/projects/artoolkit/files/stats/map?dates=2004-08-05%20to%202017-02-19

Stapleton, D. (2016, April 7). *Oculus Rift Review.* Retrieved from IGN Web site: http://in.ign.com/oculus-rift-1/90822/review/oculus-rift-review

Stewart, M. (2011). *BIM: Getting Past the Hype.* Retrieved from Planting Acorns Web site: http://plantingacorns.com/construction-trends/bim-getting-past-the-hype/

SynchroProfessionalProductVideo. (2012, April 12). *SynchroSoftware.* Retrieved from from Youtube.com: http://www.youtube.com/watch?v=gL-tjMCwfgg

Szymczyk, M. (. (2016, May 21). *Augmented Reality and Virtual Reality Tech From Movies: Fantasy vs. Reality.* Retrieved from Zugara Web site: http://zugara.com/augmented-reality-and-virtual-reality-tech-from-movies-fantasy-vs-reality

Tavares, G. (2015, May 18). *WebGL Fundamentals.* Retrieved from HTML5 Rocks Web site: https://www.html5rocks.com/en/tutorials/webgl/webgl_fundamentals/

*The Oculus Rift, Oculus Touch, and VR Games at E3.* (2015, June 11). Retrieved from Oculus Web site: https://www3.oculus.com/en-us/blog/the-oculus-rift-oculus-touch-and-vr-games-at-e3/

theappsolutions.com. (2016). *Benefits of Using Augmented Reality for Business*. Retrieved from http://theappsolutions.com/blog/development/ar-benefits-for-business/

unimersiv.com. (n.d.). Retrieved from Unimersiv Web site: https://unimersiv.com/

Vaay, J. (2014). *4D Building Information Modelling With Augmented Reality onMobile Devices toSupport Construction Management: Applicationsand key performance criteriafrom a stakeholder perspective*. Victoria University of Wellington.

*Virtual Heroes' Portfolio*. (2016). Retrieved from Virtual Heroes Web site: http://www.virtualheroes.com/sites/default/files/VHPortfolio_2016.pdf

VirtualSociety. (2016). *Virtual Reality in the Military*. Retrieved from Virtual Reality Society Web site: http://www.vrs.org.uk/virtual-reality-military/

VirtuSphere. (2016). *VirtuSphere FAQ*. Retrieved from VirtuSphere Web site: http://www.virtusphere.com/FAQ.html

VirtuSphere. (2016). *VirtuSphere Product Description*. Retrieved from VirtuSphere Web site: http://www.virtusphere.com/Product.html

VR Focus. (2014, July 22). *First Cyberith Virtualizers to Cost $599*. Retrieved from VR Focus Web site: https://www.vrfocus.com/2014/07/first-cyberith-virtualizers-cost-599/

VR Gamer. (2014, August 2). *Cyberith Virtualizer: nuovi dettagli e progressi*. Retrieved from VR Gamer Web site: http://www.vrgamer.it/2014/08/02/cyberith-virtualizer-nuovi-dettagli-e-progressi/

Wagner, D. P. (2005, May). Towards massively multi-user augmented reality on handheld devices. *International Conference on Pervasive Computing* (pp. 208-219). Springer.

Wikipedia. (n.d.). *Live, virtual, and constructive*. Retrieved from Wikipedia Web site: https://en.wikipedia.org/wiki/Live,_virtual,_and_constructive

Wilkinson, P. (2013, October 30). *BIM = Better information mobility?* Retrieved from Professional Constructor Central Web site: http://www.professionalconstructorcentral.com/bim/mobility/?open-article-id=2454430&article-title=bim---better-information-mobility-&blog-domain=extranetevolution.com&blog-title=extranet-evolution

ZukunftBAU. (2013). *BIM-Guide for Germany*. München: Martin Egger, Kerstin Hausknecht, Thomas Liebich, Jakob Przybylo.