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VR AND AR TECHNOLOGIES IN THE BUILDING CONSTRUCTION INDUSTRY

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Contents

Abstract

VR and AR technologies in the building construction industry

(VR and AR technológiák az építőiparban)

The virtual reality (VR) and augmented reality (AR) technologies are evolving with a tremendous pace, which is acquiring a paradigm shift from the other industries such as gaming, military, medicine etc. into the architecture, engineering and construction (AEC) industry as a catalyst of transformation with unprecedented power, nevertheless at a glacial pace. In a recent survey [1] It is expanded to better track a quickly evolving sector, that immersive space "will aid in all fields of life." This report also showed that only 9% of AR and VR investors are ready to invest in the AEC industry's applications in this field, and many of the investors said it is because of the technology's poor adaption. Hence, engineers and educators are on constant research in order to explore VR technology and how it can be adjusted in other to meet the demands of the future. Even though there are many of its applications in the AEC industries which include construction safety, project implementation, design analysis, detection of errors and AEC worker's education.

Extended reality (XR), which is an emerging umbrella term given to all computer-generated environments including VR, AR and MR [2], is used in this industry for high-realistic rendering, 4D user interaction, total immersive display technology with the person in context serving as an analog interface. The major concern of this research is not XR tech but how it is being used. Problems associated with human analyzing the output from XR technology. Thus, this technology's main usage is for data visualization. Hence, it depends largely on datasets from Humans in other to work. Nevertheless, there are many unavoidable errors made by humans in which we might not be fast to note it, but with the help of other computational algorithms such as artificial intelligence (AI), we might reach a higher level of certainty in our propagation of error. As a way of model improvement, we need to see the possibility of combining these two to achieve viable benefit.

This study is answering questions, through a comparative literature review and analysis, such as Where we have been, where we are and where are we going and the paper includes data gathering, manipulation and optimization techniques to prove the findings. The whole field of XR technologies is too broad to include into a single study, therefore, this scientific work is limited to include hot topics ranging from data management and acquisition of smart and extensive information from the building information modelling (BIM). As others showed VR and XR technology has limitation, this paper indicates that there is no limit to what we can do using this technology when manipulated with the right tools and resources.

1. VR and AR Technologies in the Building Construction Industry

1.1 Introduction

An industry that can particularly take great advantage of the extended reality (XR) technology is the building and construction industry. Construction Industry is one of the most booming industries in the whole world. This industry is mainly an urban-based one that is concerned with preparation as well as construction of real estate properties. The repairing of any existing building or making certain alterations in the same also comes under Construction Industry [3].

As firms all over the world find new ways to compete in 2019, innovation in construction technology is proving to be one of the most important ways to do it. The leading edge seems to move at light speed and it can be hard to keep track of innovations as the next big thing overshadows the impact of tools we have only begun to explore [4].

Digitalization in construction can be said to have started with designers moving away from their drawing boards to computer aided design practice some decades ago and with the constant improvement of digital technologies [5]

Our cities and regions have an important role to play as leaders in the digital transformation process as major enablers of digital transformation all over the world. Furthermore, They orchestrate the development of vibrant innovation ecosystems by bringing together local resources and mobilizing the participation of stakeholders [6].

1.2 Sustainable construction

The Earth has a finite number of resources, a growing population, and a need for sustainable construction [5]. Therefore, the concept of sustainable construction is always in the mind of the AEC industry leaders embracing aspects such as cost management, choice of materials, Life cycle assessment, construction site sustainability, building performance as well as interaction with urban and economic development as a priority.

Sustainable construction can be dynamic between developers of new solutions, investors, the construction industry, professional services, industry suppliers and other relevant parties towards achieving sustainable development [7].

With attention to the aforementioned, true sustainability as a solution should influence our design process and makes us acutely aware of every aspect of the design and implementation [8]. As the world population grows, the AEC industry is up to the task of providing Social and economic spaces for the global population, and for helping maintain restore the buildings and infrastructure already in use. The industry must look to smarter, more efficient ways to design and build not just to keep up with the global demand but also to help create spaces that are smarter and more resilient [9].

1.3 Automation in the construction industry

The impact of technological automation cannot be over emphasize in the AEC industry, hence as buildings become more complex with an increase amount of data collection, over time the need to adjust the trend to meet various demand is vital especially in respect to sustainability.

Fig.1.1 highlight few example of automation in the construction. In addition, Fig. 1.2 shows trend of product technologies in the construction industry until 2010.

Over the years, immersive technology has proven to be a very important and valuable tool in AEC industry, Immersive technology refers to technology that attempts to emulate a physical world through the means of a digital or simulated world, thereby creating a sense of immersion [10]. Extended reality implements this technology and serves as a user interface. End-users rightly demand better value that has to be delivered by achieving higher productivity levels at lower cost whilst not sacrificing quality or safety aspects. This is where automation-enhancement has a role to play in decision making and performance of structures can be improved by removing/reducing human error [11] . Hence, we can say this technology is bringing the world closer.

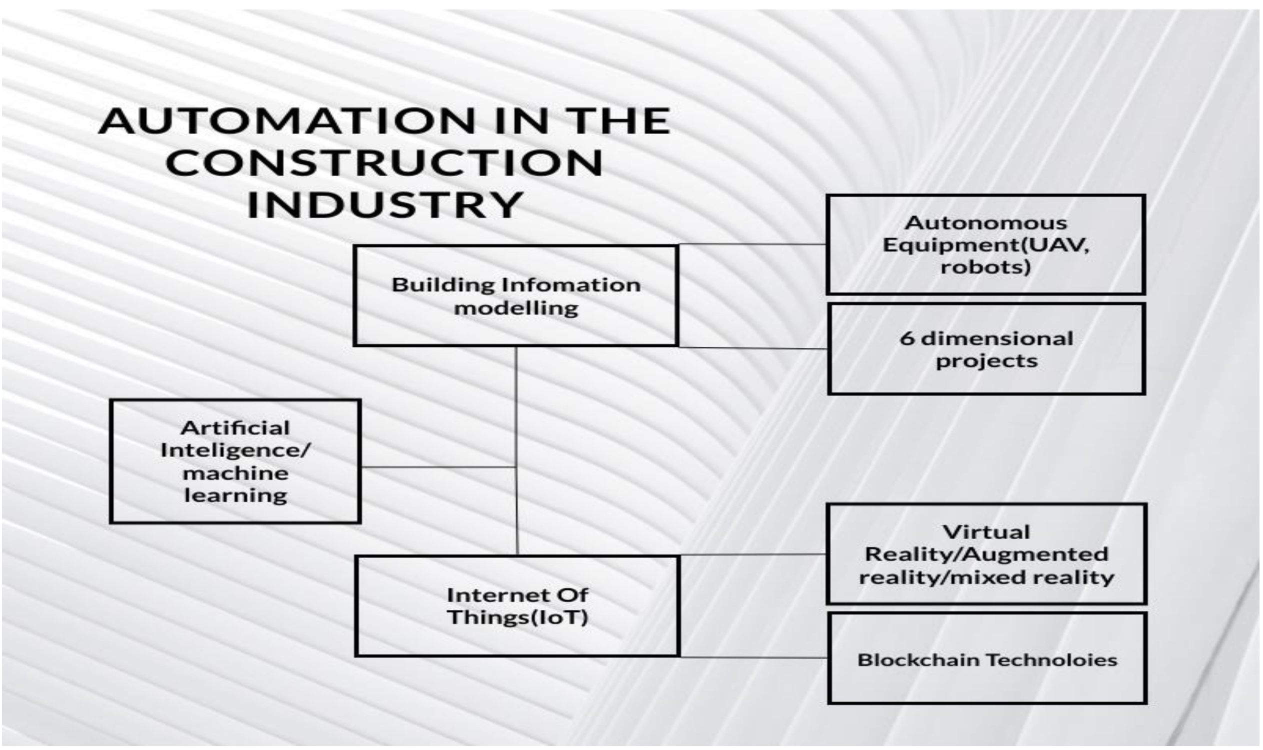


Fig. 1.1 example of automation in the construction

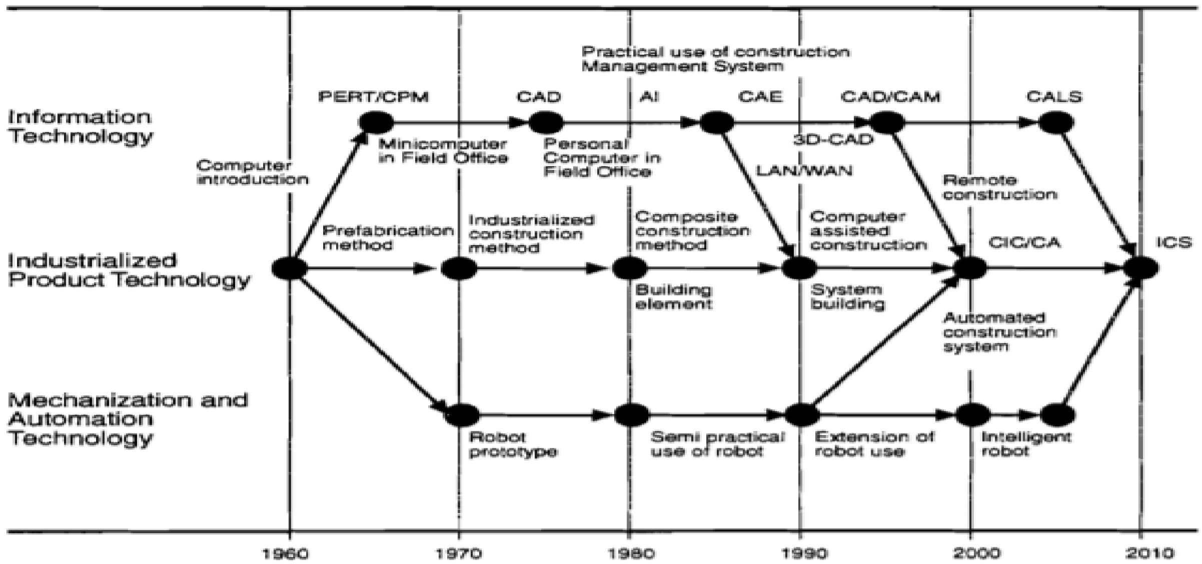


Fig. 1.2 a developing trend of product technologies in the construction industry [12]

1.4 Study case

The scope of technologies applied in the AEC industry is broad and this study will focus on extended reality, and the anticipated technological advancement in this field, which can be of further help to the industry. Exploring and understanding XR broadly – instead of focusing on particular environments – would allow creators to remain flexible and evolve with the types of XR that emerge, rather than being stifled by committing to a single form [13]. In 2025, the global automotive AR and VR market is forecasted to reach about 673 billion U.S. dollars, with a compound annual growth (CAGR) of 175.7 percent from 2018 to 2025. Technological advancement in connectivity is a major reason that drive the fast growth of the market [14].

However, in an attempt to make findings it is seen that XR also presents new, under-explored risks. The blurring of physical and virtual boundaries unearths urgent new questions around reality [15]. Which this study will aim at providing the answers and solutions through a systematic literature review.

The following questions emerge before and during my research:

What are they limitations of VR, MR, and AR in the AEC industry?

Where we have been, where we are and where are we going?

Ways of effective optimization of data gathering, handling and manipulation?

Available solutions to the industry?

Can they cost of XR be minimized?

What are they Impact of intelligent technologies on XR?

What are they roles of policy makers in ensuring guidelines and codes of conduct for XR?

How does XR affect human sense and mental health?

Nevertheless, I will explore other questions the course of investigation.

1.5 Common abbreviations used in this paper.

XR: Extended reality

MR: Mixed reality

AR: augmented reality

ML: machine learning

VR: virtual reality

AEC: Architecture engineering and construction

CAD: Computer aided design

AI: Artificial Intelligence

BIM: Building Information modelling

HDM: Head mounted display

SHM: structural health monitoring

IoT: Internet of Things

1.6 Extended reality

What is extended reality technology?

1.6.1 Extended reality (*XR*) is a term referring to all real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables [16]. In other terms it is an umbrella term used to describe immersive technologies that can merge the physical and virtual worlds together [17] or create an entirely immersive experience for the user [2].

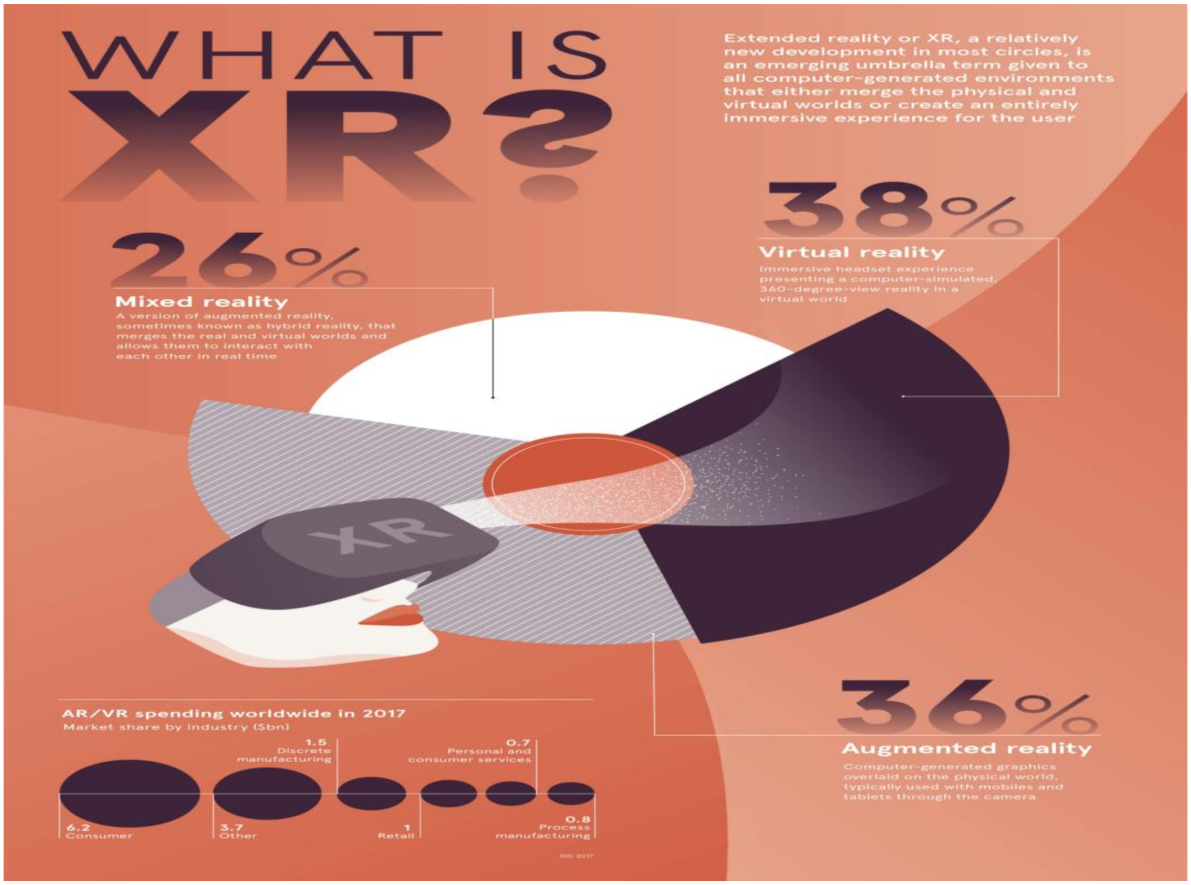


Fig. 1.3 highlight the components of immersive technology in XR [2]

To have a better understanding of the concept of XR the study will review already existing immersive technologies. The Figure below will provide a distinctive highlight of the reality technologies.

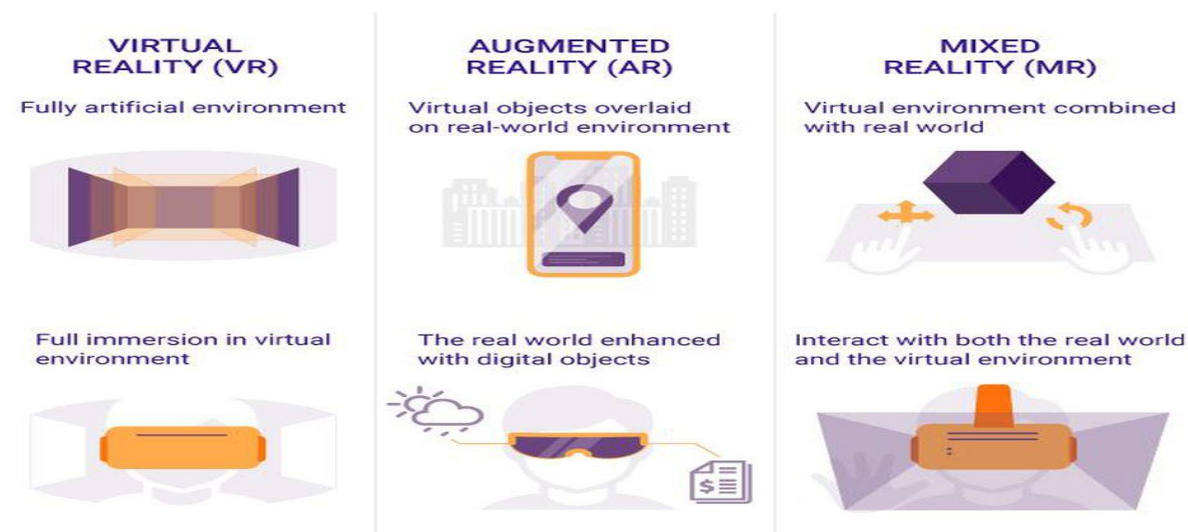


Fig.1.4 difference between AR, VR, AND MR [18].

*1.6.2 Virtual reality (VR)***:** implies a complete immersion experience that shuts out the physical world. Users can be transported into a number of real world and imagined environments such as the middle of a squawking penguin colony or even the back of a dragon.

1.6.3 Augmented reality (AR): adds digital elements to a live view often by using the camera on a smartphone. Examples of augmented reality experiences include Snapchat lenses and the game Pokémon Go.

1.6.4 Mixed reality (MR): in a mixed reality experience, which combines elements of both AR and VR, real-world and digital objects interact. Mixed reality technology is just now starting to take off with Microsoft's HoloLens one of the most notable early mixed reality apparatuses [19].

In design applications, visualizations is not an end in itself. The process of design and visualization should be iterative, with changes, made due to result of insights gained through visualization propagated into the next version of the design. The iterative nature of this process requires adequate support and thought processes should not be interrupted by a requirement to translate the design concepts into software terms for visualization [20].

XR technologies targets to bring the world closer at a very fast rate bridging the Gap between professionals in developing regions and the developed worlds, while this technology in the AEC industry is still in its infancy, other areas of its application has advanced.

2. Methodology

In order to answer the questions asked in the introductory chapter of this study, the research design as illustrated in Fig. 2.1 was employed. Articles used in this study was evaluated based on the selected keywords necessary to broaden our knowledge on the topic. I adopted a systematic literature review method in order to identify, critically evaluate and integrate the findings of all relevant, high-quality individual studies addressing one or more of the research questions [21].

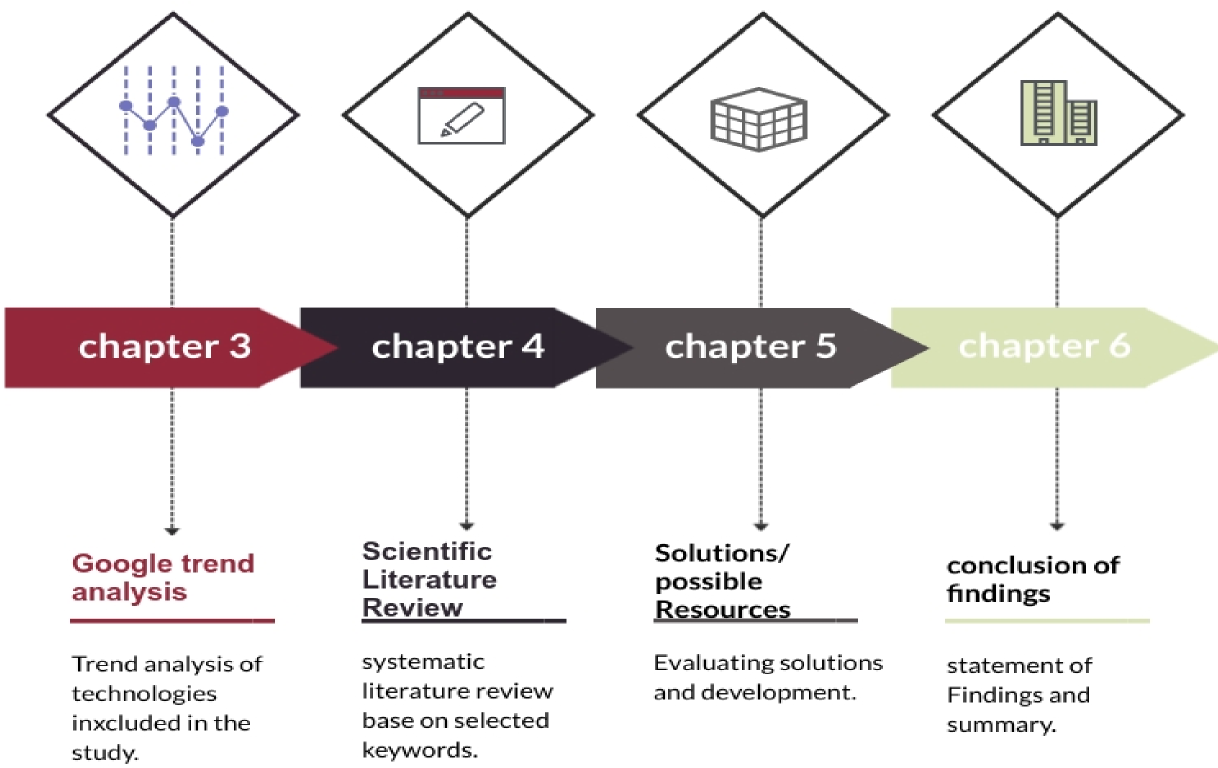


Fig. 2.1 schematic representation of the research process

2.1 TREND ANALYSIS

In order to analyze future trends in the AEC industry, which is necessary for influencing future outcome. I made a historical data analysis with respect to the keywords in focus; hence, the aim of this analysis is to give us a sense of direction to where we are and where we are going, engagement of researchers and industry expert in the domain of XR technology. I mainly sourced data for this trend analysis from Google Trend and SCOPUS within a range of 10 years (2004 - 2019). which I selected because it has a wide range of scientific publication and about 69 million records [22]. This is to establish connection between keywords and published journals related to the AEC industry, I achieved this by filtering using search terms linked to the AEC industry. (As illustrated in the Fig. 2.2).

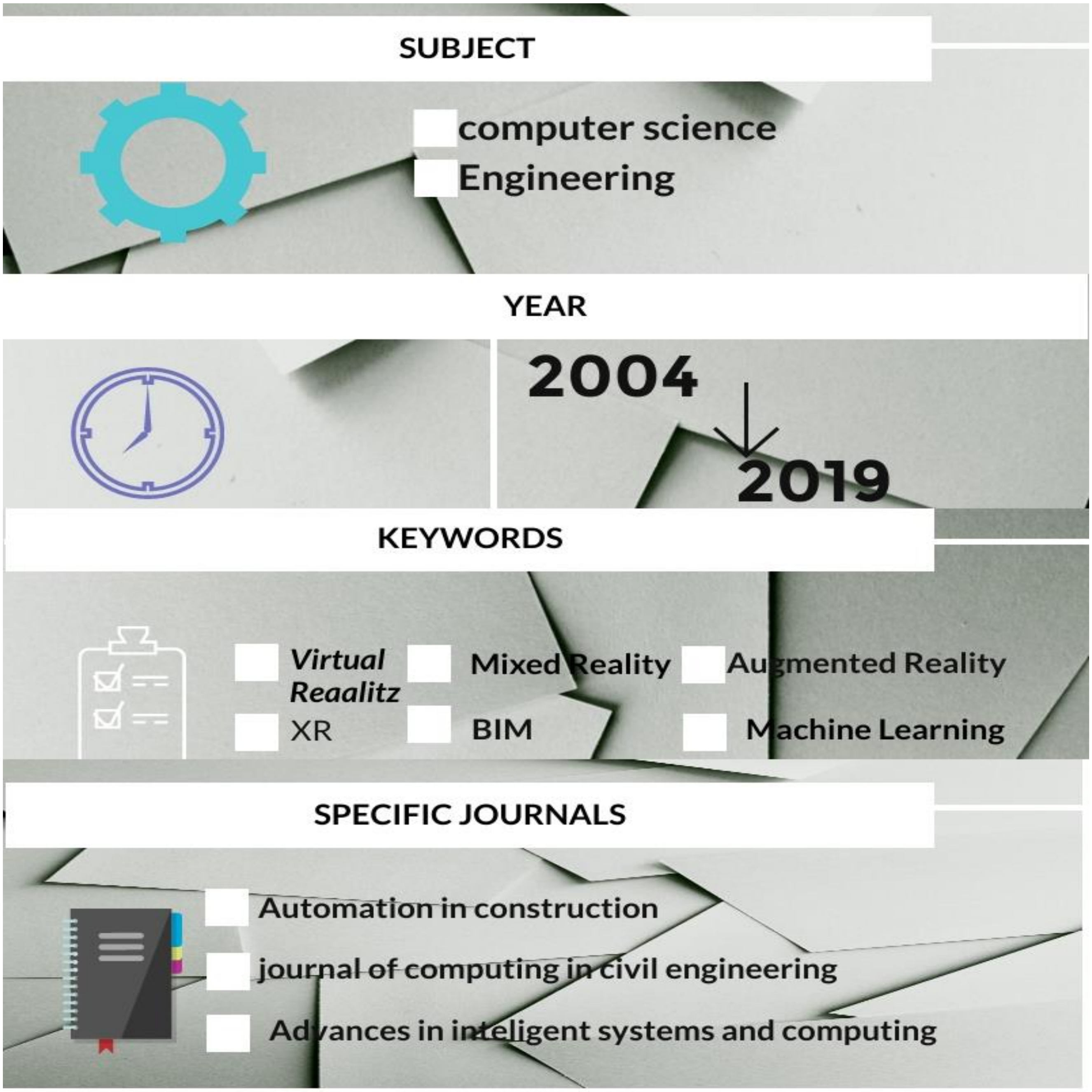


Fig. 2.2 schematic representation of filtered key terms on Scopus database.

2.2 DATA ACQUISITION

Data acquisition of existing literature is fundamental in this research since it determines the scientific articles from which I will draw my conclusions. Hence, the database and searching strategy are generally base on searches through selected science publishing sites base on included keywords. Nonetheless, I carried out a general google search to get unpublished work and articles from the industry experts, which will be very important to this study. I carefully evaluated and screened via citation manager contents of the downloaded articles, journals, and web pages through their titles and abstract in order to identify work that is more relevant and suitable for inclusion in this review.

Subsequently, after selecting relevant studies, I organized it in their consecutive order according to written year; furthermore, I read them in order to extract all relevant information for potential inclusion base on my questions and topics.

3. Google trend analysis

In recent years, numerous studies have been made on technologies used in the AEC industry. Most of the studies on XR technologies have presented some remarkable findings. However they seem to require further test in order to be regarded as being accurate or not and decipher how far we have gone into research and determine areas that need further research.

Firstly, I made an analysis on VR, AR and MR, which are the major keywords. Subsequently, I observed the drift in BIM, IoT, ML, and construction automation.

3.1 VIRTUAL REALITY

Applying the technique stated in the previous chapter, search results were filtered base on the interest over time, related topics to the search term and regions with the most interest (as in Fig. 3.1.a).

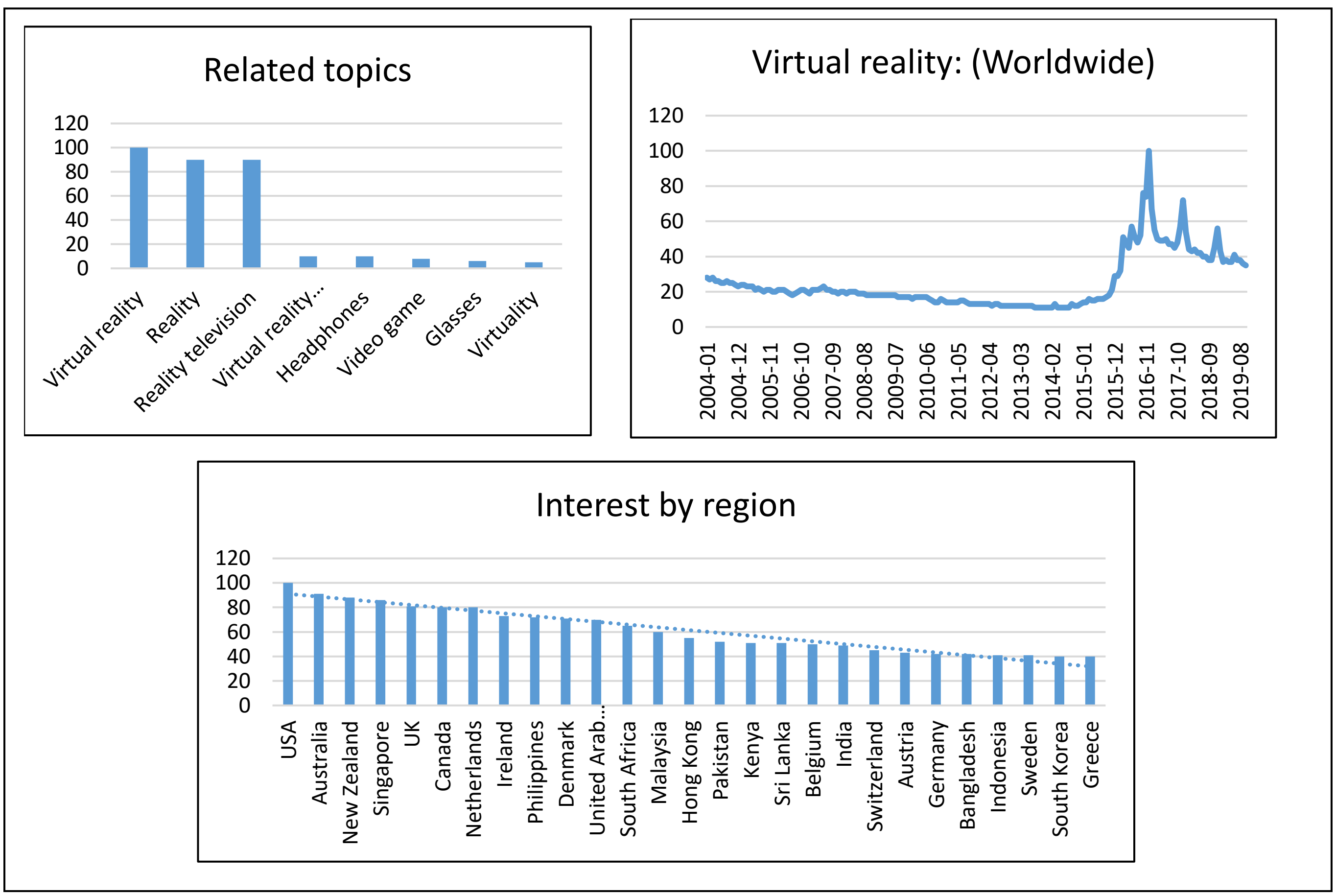


Fig. 3.1.a. google trend analysis of virtual reality

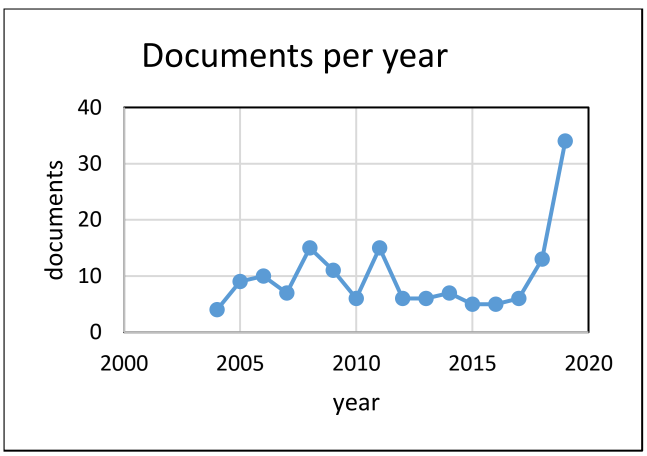
They Values are calculated on a scale from zero to 100, a value of 100 is the peak popularity or commonly searched topic or interest by region for a term. A value of 50 means that the term is half as popular. A score of zero means there was not enough data for the term [23].

In December 2016 VR reached the peak value base on the search, United States of America (USA) was the most interested region with the peak value of search term. The related topic search query is not linked to the construction industry.

From the data, English-speaking countries have advanced in the VR technology, followed by countries in Asia and the Middle Eastern states.

Subsequently, I made an analysis of the available resources from SCOPUS database; I captured key facts relevant to the study topic and related to the google trend analysis. After filtering the datasets base on the steps outline in chapter 2, I analyzed the datasets based on documents per country or region and documents per year.

From the google trend analysis, USA was the most interested region. Hence the produced the most papers in VR in relation to the AEC industry. I obtained One-hundred and forty-six (146) papers related to the search filter.



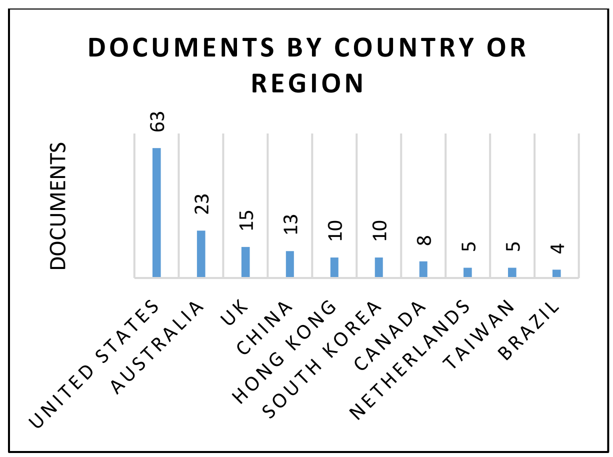


Fig. 3.1.b Scopus analysis of Virtual reality

3.2 AUGMENTED REALITY

I used the same procedure as above in the analysis of AR and subsequent keywords.

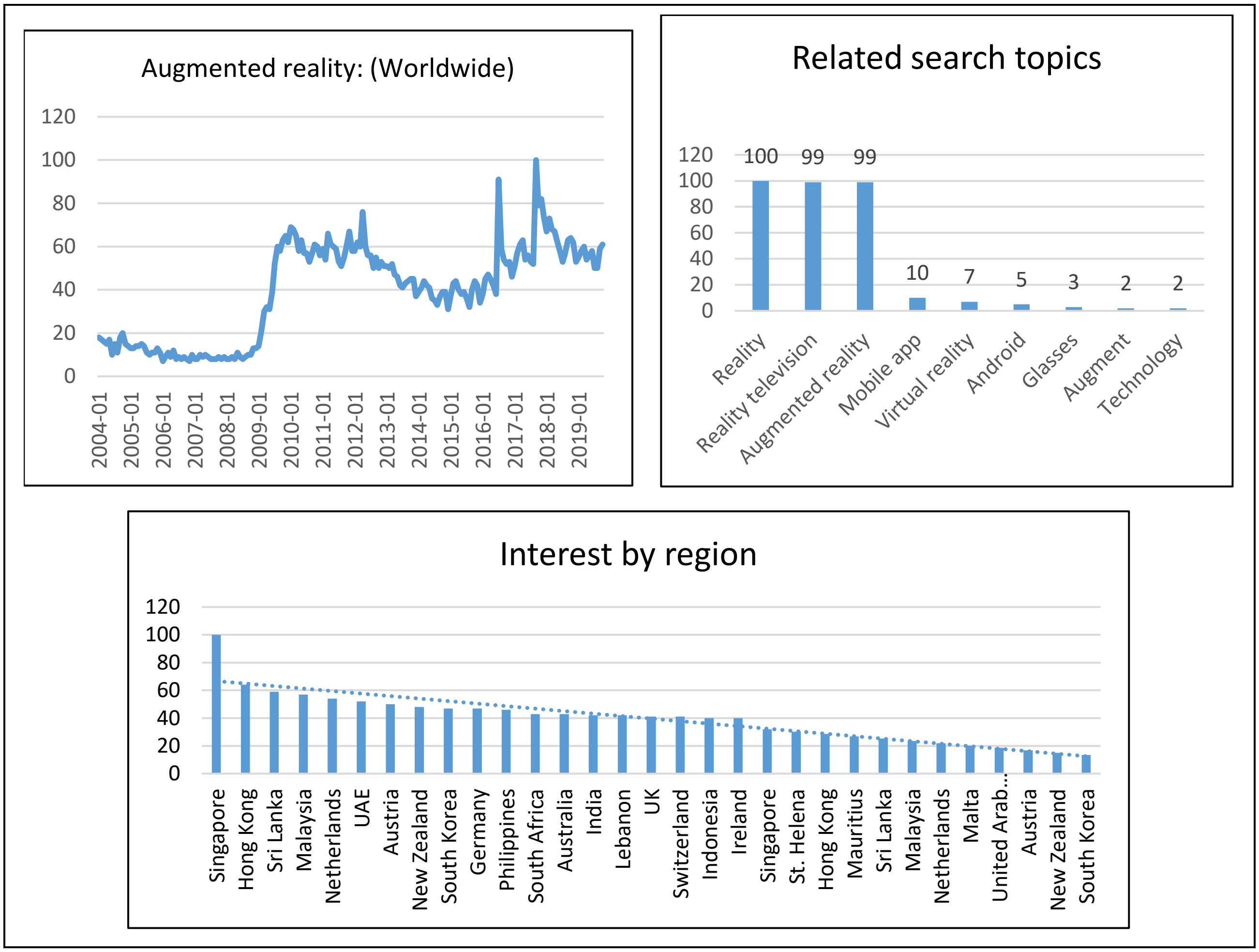


Fig. 3.2.a. *google trend analysis of augmented reality*

The search term first reached its peak in July 2016 after Microsoft announced its pre-production version of the HoloLens[24] and also the HTC vive announced it sales in June 2016 [25]. It later reached a peak value in 2017, most search query are linked to a developmental trend. The most interested regions were Singapore, Hong Kong, Sri Lanka. From the trend line of these countries, it is observed from the study that, it is mostly countries with high-rise buildings.

2013 recorded the year with highest documents per year; USA and Australia are leading in published materials with 25 and 21 documents respectively (Fig. 3.2.b).

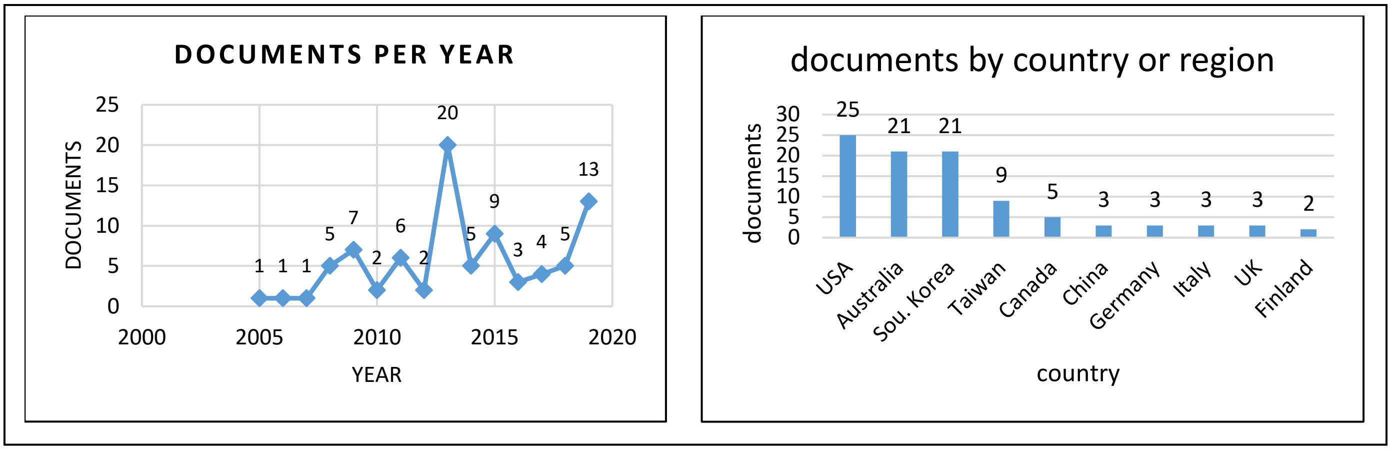


Fig. 3.2.b. Fig. 3.1.b Scopus analysis of augmented reality

3.3 MIXED REALITY

Similarly, MR reached its peak value in 2017 with a growing trend from April 2016,

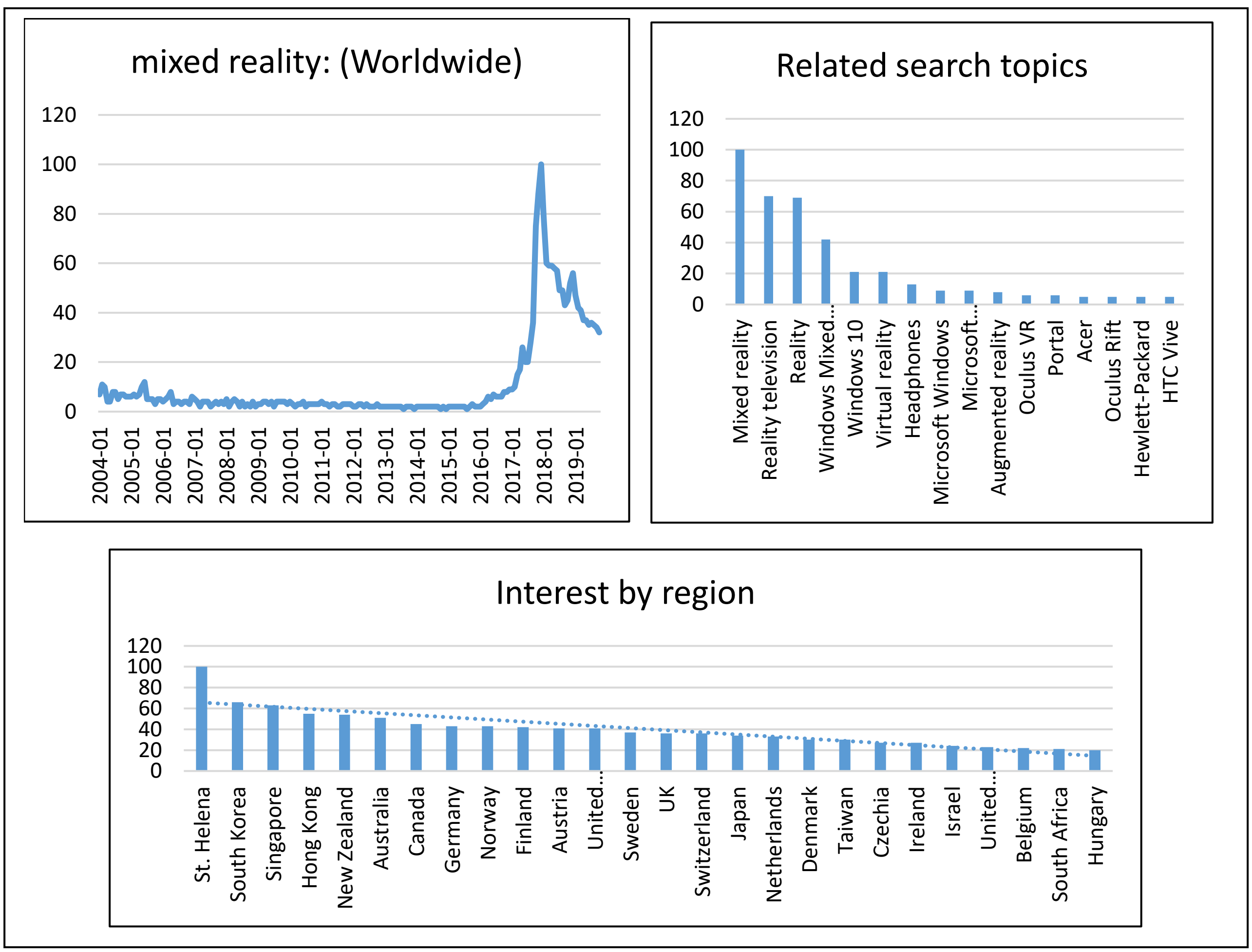


Fig. 3.3.a. google trend analysis of mixed reality

Whereas, most search related topics are focused towards MR hardware, which include Oculus VR, HTC vive, Microsoft HoloLens. Recently after HoloLens began its sales in November 2016 [24] MR search term started gaining an insight and by December 2017 it reached the highest peak.

The related search topic was linked to the Microsoft cooperation including hardware such as HoloLens, HTC Vive, oculus VR, and oculus rift.

Similarly, countries with an advancement in high-rise buildings are mostly interested in this technology. From previous charts in VR and AR, the occurrence of European countries are less, but as seen in the MR technology the statistics of these countries is on the rise.

The analysis of the available documents in this area is less than average with only twenty-one documents found after the search filter based on required parameters.

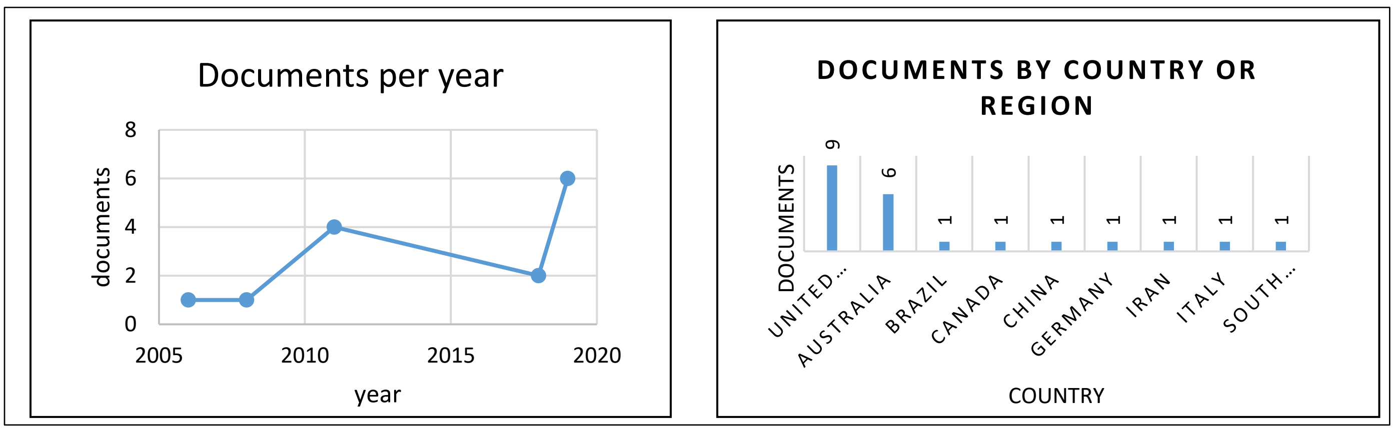


Fig. 3.3.b. Fig. 3.1.b Scopus analysis of mixed reality

3.4 Extended reality

The search query for XR included VR, MR and AR in other to compare all the three fields to see the already established work.

From the google trend analysis, this keyword term has been prominent since 2004 with Jamaica as the most interested region, but nevertheless the contribute less to this study as the search in that region is not directed to the scope of XR we are discussing in this study. In USA, the search term is mostly in the area of California which is one of the global center for high technology. Subsequent related topics to the keyword includes other terms of the immersive technology, field of artificial intelligence, Accenture(company that provides services in strategy, consulting, digital, technology and operations [26][27]).

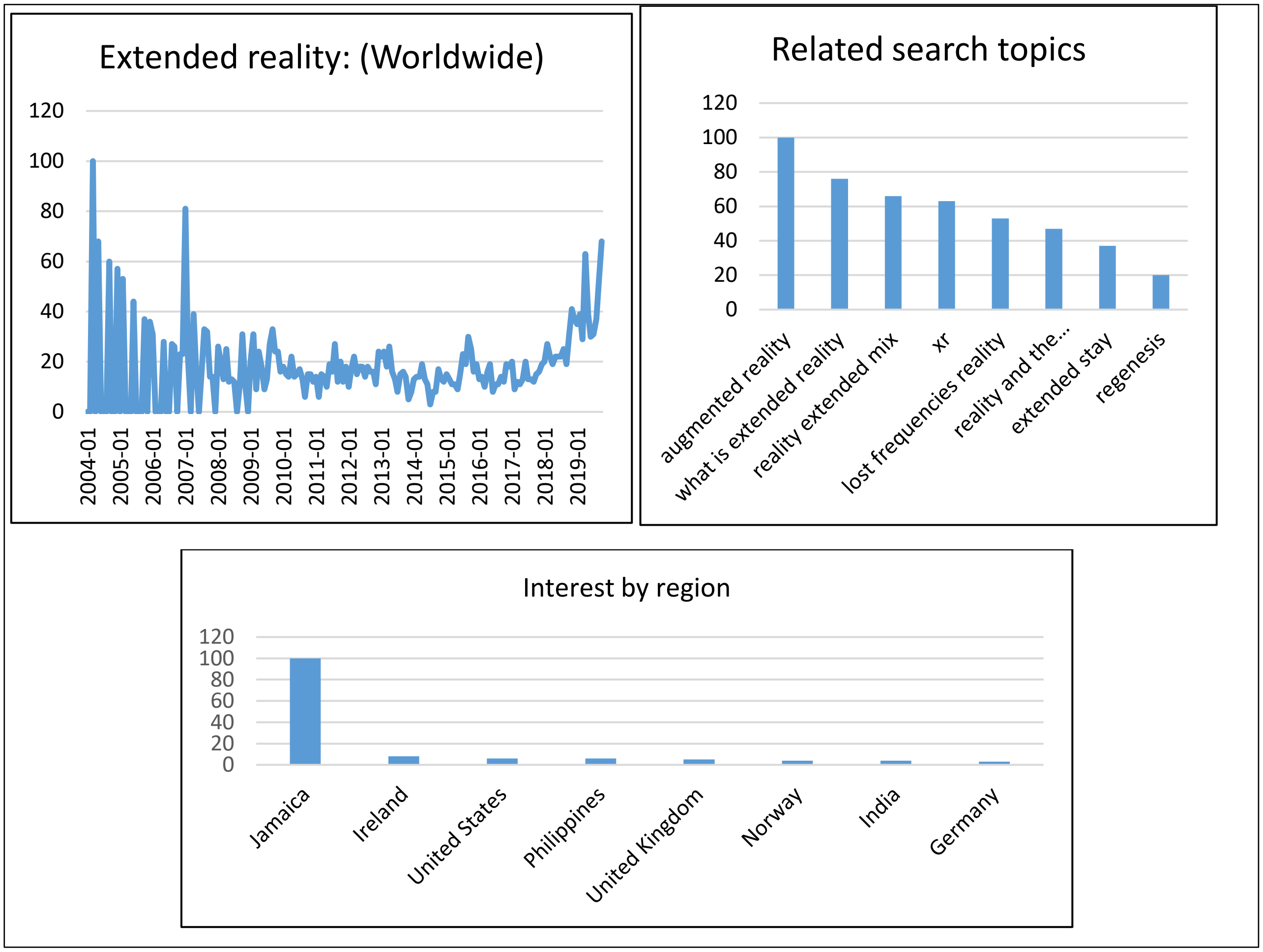


Fig. 3.4.a. google trend analysis of extended reality

To elaborate further they available documents on XR on the SCOPUS database are linked to what we have discussed in the analysis above, in addition, there are insufficient documents particularly in the domain of this keyword to make a rational conclusion about already published work.

3.5 BIM, IoT, ML

A very important topic or term to discuss and analyze is the BIM, IoT and machine learning, BIM is was a topic which was trending 15 years ago and it still has a growing trend line, thus as we buildings get complex and dynamic the need to integrate this form of tech with other system is necessary for maximum optimization.

In the analysis in Fig. 3.5.a, I directed a search query comparing the three technologies and all three have a growing trend. There is a great future if we explore these technologies in the AEC industry.

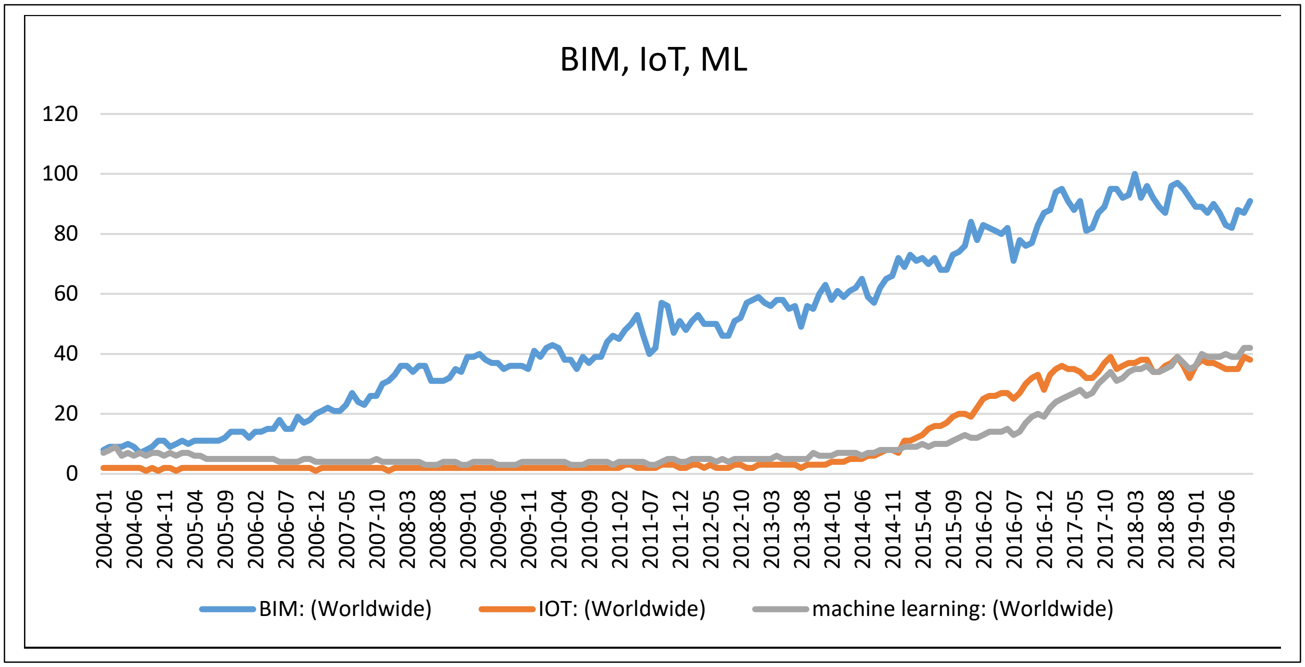


Fig. 3.5.a. google trend analysis of BIM, IoT, ML

It is likewise important to note the number of available literatures that are available in this field, I directed a search on the SCOPUS database and analyzed the above terms additionally including VR, AR, and MR which are they major keywords for this study.

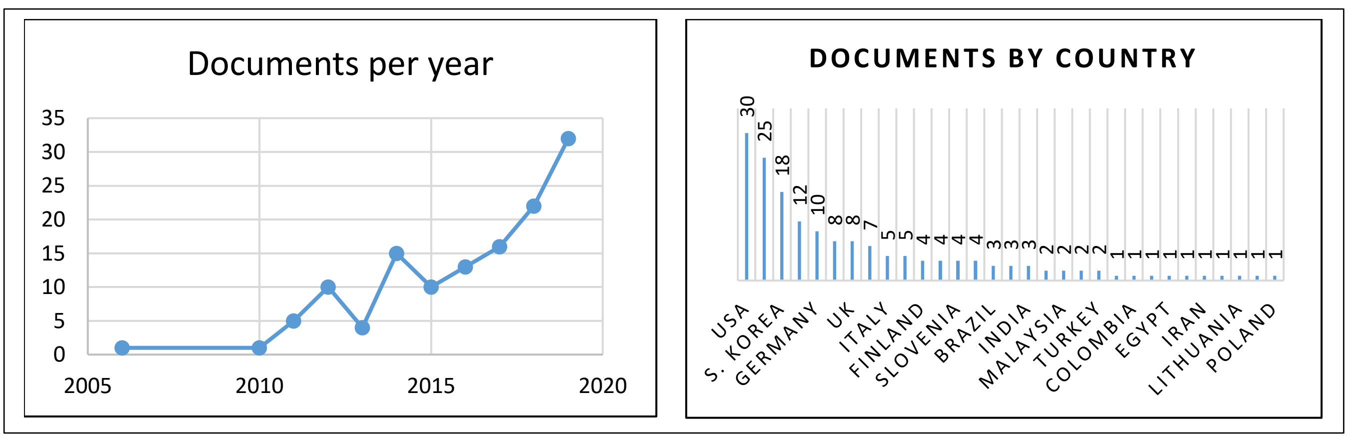


Fig. 3.5.b Fig. 3.1.b Scopus analysis of BIM, IoT, ML

I sourced 129 documents from the search query, as seen in the analysis the terms are on the rise; in addition, the number of documents written in this field is also rising. Which shows a progressive trend in the industry's adaptation to these technologies as illustrated in Fig. 3.5.b.

3.6 Summary of trend analysis

From the analysis it show that, virtual reality is the most advanced term in the immersive technology with 156 documents sourced from SCOPUS. Furthermore, extended reality is on the rise, which indicates great potential for all the forms of immersive technology and advancement in these fields.

Similarly, comparing the google trend analysis and the datasets from the SCOPUS database, it follows, that these countries (in Fig. 3.6.a) are on the lead in the technological applications of XR in the AEC industry, undoubtedly, these regions have an increasing number of high-rise buildings and buildings with a much expensive construction cost.

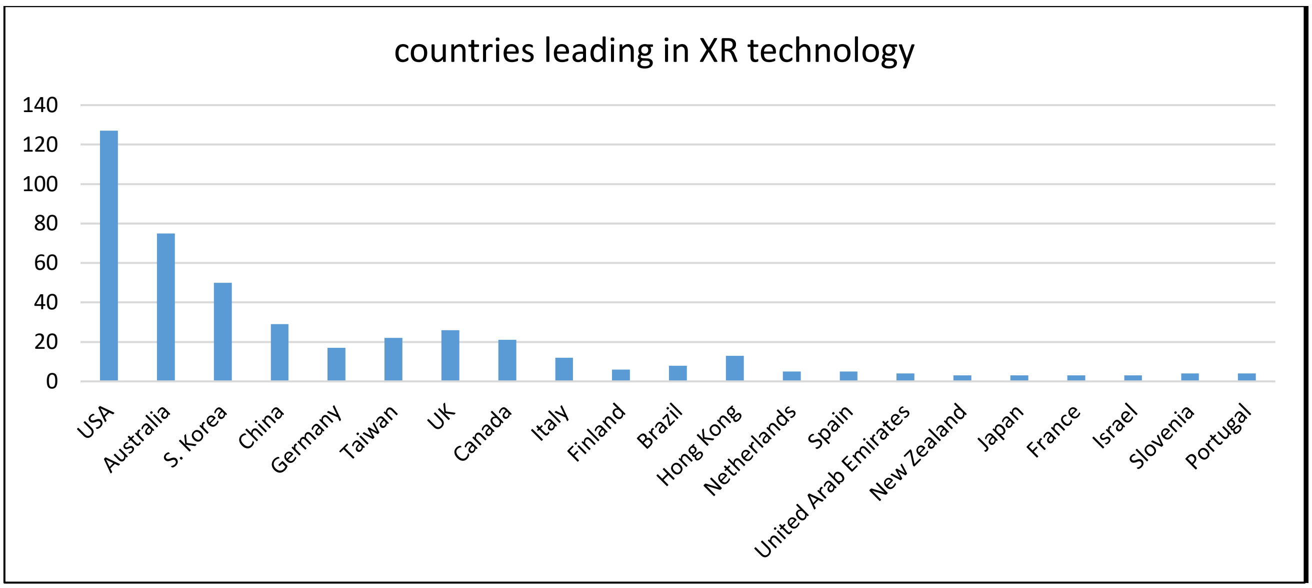


Fig. 3.6.a. countries leading in XR technology

I also present a comparison between a report made by A.Storchi on the insights from then next generation's technology, these report matches with this study's analysis on the components of XR technology as shown in the Fig. 3.6.a, despite sourced from different database as in Fig. 3.6.b (web of science 2018) [28].

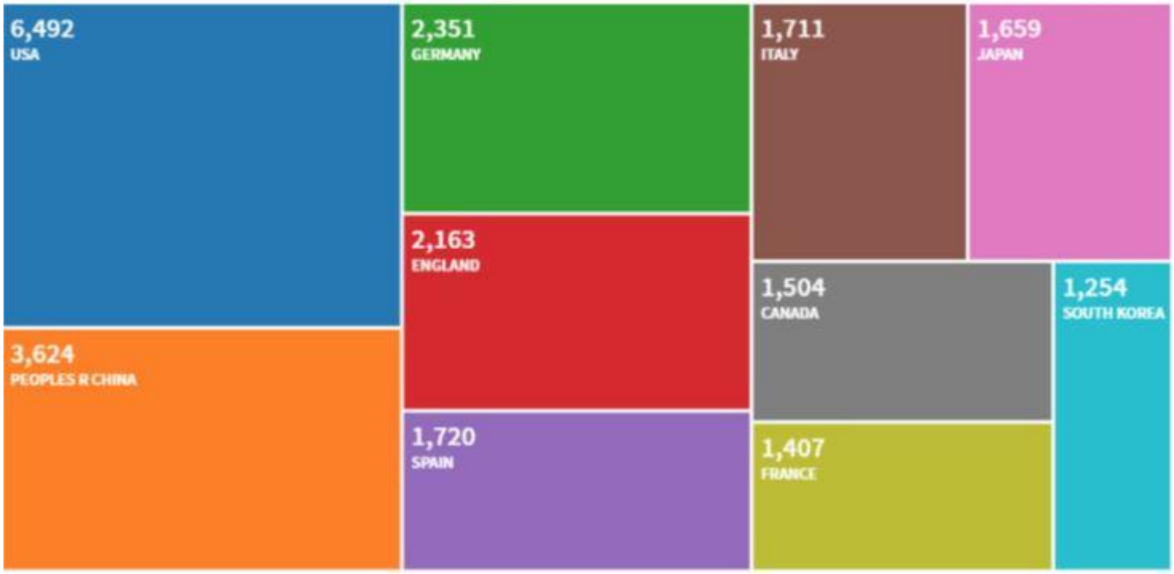


Fig. 3.6.b. publications made on XR (web of science). [28]

Fig.3.6.c. market cap analysis of XR [28]

However, the above analysis (Fig.3.6.c) also seem to match with the regional revenue forecasts made by Digi-Capital (2018) that estimates Europe, North America, and Asia as leading regions, with Asia being the biggest market of all [28].

4. Review OF VR, AR, and MR Literature

4.1 Virtual reality

VR is one of the earliest form of the immersive technology, which dated back to the early 1970s [29], Virtual reality is the term used to describe a three-dimensional, computer generated environment which can be explored and interacted with by a person. That person becomes part of this virtual world or is immersed within this environment and whilst there, is able to manipulate objects or perform a series of actions [30].

The needed data required for a VR system to function is from the CAD software and BIM used during the early stages of design. Thus, in this field, 4D models combine 3D models with the project timeline, and VR technology has been used to render 4D models more realistic allowing interaction with the environment and representing the construction site. This concerns essentially economic and administrative benefits, in addition 4D models are being used to improve the production, analysis design and management and construction information in many phases of construction project [31].

A recent Design News article claims in its title "There is no excuse for not designing virtually…" (Atwell & Gretlein, 2013). Yet the use of virtual reality in design will be different in specific design sub disciplines. Beyond allowing the addition of virtual entities to real-world views, VR technology enhances collaboration among members of design teams (Wang, 2007) [32].

The construction industry also has adopted VR-based simulators for various types of training programs. Simulators are used in such areas as safety training, construction management and planning, and equipment training. Many of the major construction equipment manufacturers nowadays provide training simulators that represent the design and characteristics of their equipment [33].

VR provides a safe, immersive and realistic experience for users, some of which are hard to recreate in real world settings. One of the focuses in Industry 4.0 is the bridging of the digital, virtual and physical worlds, which are called cyber-physical systems. VR (and all related mixed-reality technologies) offers great potential to support this endeavor [34].

4.2 AUGMENTED REALITY

Augmented Reality (AR) creates an environment where digital information is inserted in a predominantly real worldview. It originated from marker-based tracking toolkits (e.g., AR Toolkit, AR Tag) which are used to determine tracking and registration (where to display the digital contents) and the media contents (what digital content to display) [35].

Sebastjan et al analyzed the potential areas for the application of AR the analysis of the results showed that AR would be most useful in identifying and locating the existing building component locations and in the control of the compliance of the design and the actual building (Shown in Fig. 4.1) [36].

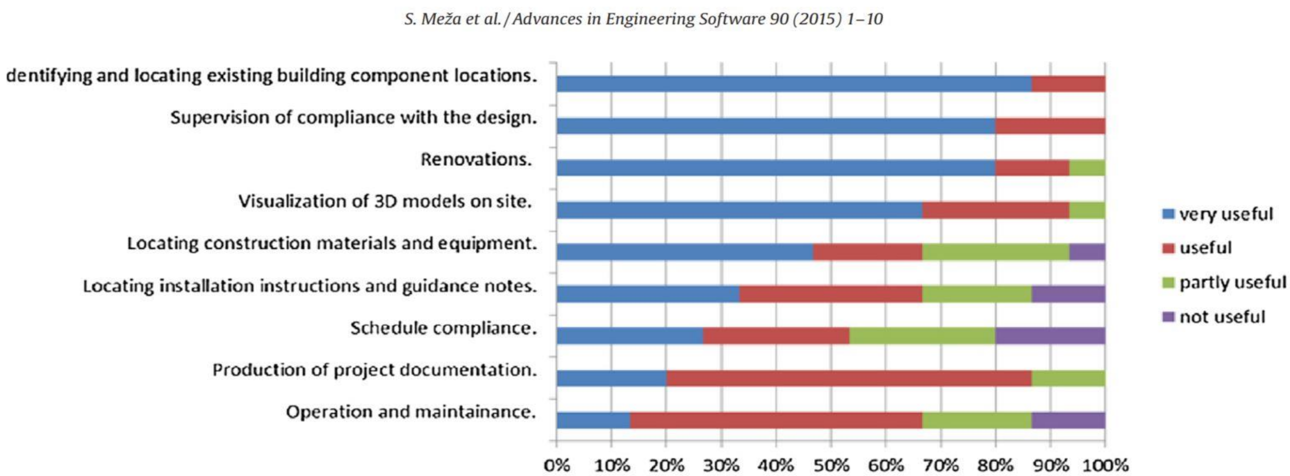


Fig. 4.1 applications of AR [36]

The added visualization benefits of AR technologies allow for better communication between parties when commenting and making suggestions for a particular project. The introduced visualization features and facilitates construction management to deal defects that are probably unnoticed in the inspection process and save time to do so. A marker-based AR technology is used for the quality improvement and defects management of construction project, and the output is very satisfactory [37].

The study (Kwon et al. 2014) concluded as the AR technologies enhance the current manual-based defect management to reduce site managers' workloads and prevent construction work defects proactively by utilizing BIM and AR technologies [38].

From a research carried out for integrating as-built BIM tools, construction data In order to effectively integrate AR and BIM engine. Three issues to be addressed was located: (1) the virtual objects used in AR should come from those in BIM, either directly or indirectly; (2) given an on-site image, locate its corresponding virtual objects in BIM, i.e., authoring; and (3) the storage of the overlay information.

4.3 MIXED REALITY

Milgram states, "The most straightforward way to view a Mixed Reality environment is one in which real-world and virtual-world objects are presented together within a single display, that is, anywhere between the extrema of the virtuality continuum" Fig. 4.2 shows a Milgram spectrum [39].

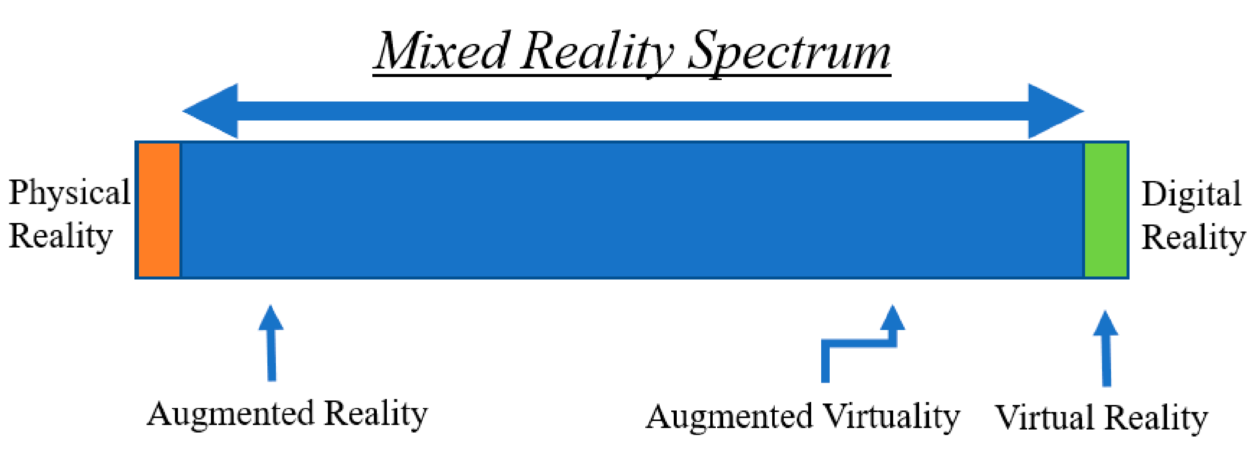


Fig.4.2 MILGRAM MR SPECTRUM [39].

MR allows digital content to be interactive with real-world content. The key term for MR is "flexibility." This aspect makes MR more marketable and "less geeky" than its cousins. By using MR, a construction company can interact with the 3D BIM information model on top of the physical space by either superimposing the different design options within the existing job site condition or reading additional information, which does not exist in the real world [40].

A research at Cambridge has led to a Microsoft HoloLens application, which automates progress inspection. The application then automatically compares the as-built status with the as-planned data to provide instant progress information as the inspector moves around the site. This information allows inspectors to detect any schedule or specification discrepancies at the earliest opportunity, enabling early corrective action to be taken[41].

Adjusting existing or establishing new regulations is necessary to pave the way for a successful implementation and usage of MR systems and technologies within real work environments [42]

4.4 Building Information modelling.

Understanding the difference between concept of BIM and CAD is fundamental Building Information Modeling (BIM) is defined as "a digital representation of the physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition [43]; hence, the term "CAD" is used more for drafting programs. In terms of building design, CAD is essentially using a drafting tool, such as AutoCAD, to create lines and arcs to represent a building design [44]. With BIM, AEC professionals can move towards more collaborative, automated and more successful ways of working during the entire lifecycle of a project (plan, design, build, operation and maintenance) [9]. BIM is the future of building design and construction. BIM is a 3-D, object oriented, CAD approach for architects and engineers. One of the most valuable function of BIM is its ability to improve the coordination between multiple design disciplines, thus reducing errors [45].

Currently, BIM refers to the use of a shared digital representation of a built object to facilitate the design, construction, and operation processes and to form a reliable basis for decision making [46]**.** This technology allows members of the project team to generate a virtual model of the structure and all of its systems in 3D and to be able to share that information with the entire project team. Likewise, the drawings, specifications, and construction details are fundamental to the model, which includes attributes such as building geometry, spatial relationships, quantity characteristics of building components, and geographic information. This allows the project team to quickly identify design and construction issues and resolve them in a virtual environment well before the construction phase in the real world, which encompasses 4D. BIM is now used widely all over the world such as the United States, United Kingdom, France, Germany, Finland, Denmark, Australia, Malaysia, china, and Singapore. Moreover, internationally it is increasingly gaining the attention of the building industry and organizations involved in AEC in addition to the owners and operators of building projects and other structures [47].

As a generalization, BIM, XR and IoT data offer complementary views of the project that together supplement the limitations of each. A large number of applications using the combination of VR and AR can support effective information flow and display. For example, using AR, BIM and sensors can be beneficial to automatic schedule update, safety inspection, smart building design, facility management, construction lifecycle management, smart learning environment for educational institutions [48]. The building information involved in the BIM approach can include both geometric data as well as non-geometric data. BIM is one of the important areas in current Virtual Reality (VR) research and is expected to envision efficient collaboration, improved data integrity, intelligent documentation**,** distributed access and retrieval of building data and high quality project outcome through enhanced performance analysis, as well as multidisciplinary planning and coordination [49].

4.5 Internet of things (IOT)

The later lifecycle stage of a project is operation and maintenance, to explore further the benefits of technology in the AEC industry, and how it will help in the these phase; it is fundamental to highlight the benefits of integrating IoT in the industry to optimize how we use our buildings, help identify areas that need future supervision and analysis. Briefly, the Internet of Things is the concept of connecting any device (so long as it has an on/off switch) to the Internet and to other connected devices. The IoT is a giant network of connected things and people – all of which collect and share data about the way they are used and about the environment around them [50].

The number of connected devices have already overtaken connected human beings and are estimated to be around 9 billion. The sensor nodes are being deployed in various application areas such as the industrial or building automation. The number of sensor installation is increasing at an exponential rate and some estimates suggest that there will be around 50 billion connected devices by 2020 [51].

The integration of Building Information Modeling (BIM) with real-time data from the Internet of Things (IoT) devices presents a powerful paradigm for applications to improve construction and operational efficiencies [48]**.**

IoT is used in areas such as for Structural health monitoring (SHM)**,** AR can be integrated into equipment visors and vehicle windshields to provide a virtual map. Environmental and contextual data collected from IoT sensors can be displayed in real-time and overlaid onto a real-world view of the job to be done or journey to be made [52].

Object recognition is a promising technology with the potential to replace optical codes on object, driven by advances in scene understanding and deep learning. Object recognition uses the camera of XR devices to identify an object based on its visual features. This means that it can work instantly without any tags or special preparation of the object in question. Based on the learnings from a Munich study, they proposed field-of-view interactions - a new type of interaction suitable for AR - IoT systems. Field of view (FOV) interactions use a hybrid approach combining object recognition with contextual cues. It overcomes the range limitation of optical codes while still being able to provide high identification accuracy. The interaction becomes more naturally since it is tied to the area of attention of the user – defined by the field of view. It provides a seamless way of supporting multi-user interactions [53].

This technology is important and essential to achieve smart and sustainable buildings and infrastructure.

4.5.1 Structural health monitoring

Structural health monitoring uses an assortment of sensors to collect and analyze data pertaining to any damage or deterioration that a structure may receive over the course of its life. Structural health monitoring is used on structures such as bridges, skyscrapers, stadiums, wind turbines, and many others [54].

Structural Health Monitoring (SHM) is becoming a crucial research topic to improve the human safety and to reduce maintenance costs [55].

In the IoT, each sensor is equipped with processing capacities and data transmissions. The information is transmitted using an Internet connection in the Cloud and are elaborated by distributed systems managed by a paradigm of Big Data. This allows the interaction between different correlated data in time that have been acquired by different types of sensors [56].

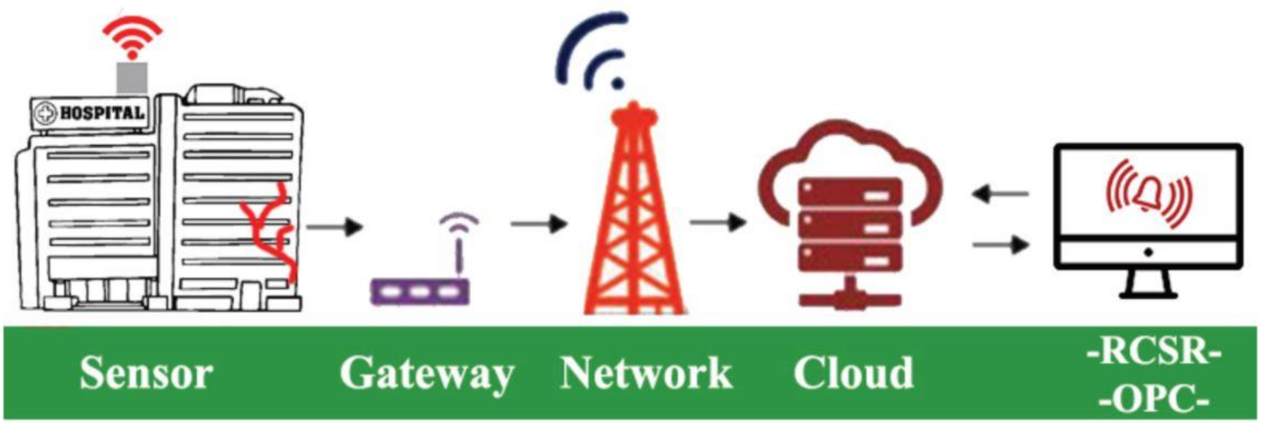


Fig. 4.4. Diagram showing integration of IoT into SHM source [56]

Fig.4.4 shows how IoT is integrated into SHM, in addition further research efforts must be devoted to enhance sensor virtualization [56].

4.6 Big data

Big data analytics is the use of advanced analytic techniques against very large, diverse datasets that include structured, semi-structured and unstructured data, from different sources, and in different sizes from terabytes to zettabytes. Big data is a term applied to data sets whose size or type is beyond the ability of traditional relational databases to capture, manage and process the data with low latency. Big data has one or more of the following characteristics: high volume, high velocity or high variety. Artificial intelligence (AI), mobile, social and the Internet of Things (IoT) are driving data complexity through new forms and sources of data Analysis of big data allows analysts, researchers and business users to make better and faster decisions using data that was previously inaccessible or unusable. The AEC industry can use advanced analytics techniques such as text analytics, machine learning, predictive analytics, data mining, statistics and natural language processing to gain new insights from previously untapped data sources independently or together with existing enterprise data [57].

Han and Golparvar-Fard investigate the potential of big visual data used in conjunction with building information modeling (BIM) for Construction Performance Analytics. The authors address the gaps in-knowledge in current practices and research efforts in big visual sensing and analytics. They also provide a comprehensive picture about the future direction of big visual data analytics. A model-driven visual analytics using images and BIM as a potential solution for solving inefficient communication and poor project controls is introduced [58].

Machine learning (ML), a sub-field of Artificial Intelligence (AI), focuses on the task of enabling computational systems to learn from data about specific task automatically. ML tasks can be categorized into: (i) classification (or supervised learning); (ii) clustering (or unsupervised learning); (iii) association; (iv) numeric prediction [59]. Fig. 4.3 highlight some of the important ML-based tools that have been developed.

Big Data Big Data and new data analytics enable new approaches to data generation and analyses to be implemented that make it possible to ask and answer questions in new ways. Rather than seeking to extract insights from datasets limited by scope, temporality and size, Big Data provides the counter problem of handling and analyzing enormous, dynamic, and varied datasets. The solution has been the development of new forms of data management and analytical techniques that rely on machine learning and new modes of visualization [60].

Tool name	Description	Supported languages	ML at scale	Supported algorithms
Apache Mahout [167]	Mahout is an open-source machine learning framework for quickly writing scalable and high performance ML applications	– Java – Scala	Yes	– Collaborative Filtering – Classification – Clustering – Regression
R [168]	R is an open-source programming language for statistical analysis. R is extremely extensible. With huge developer base, thousands of R packages are available to provide variety of functionalities. The graphics supported by R are highly polished and very powerful	Many languages	Yes	– Collaborative filtering – Classification – Clustering – Regression
MLbase [169]	Spark has constituted a novel ML platform called MLbase, which has brought together highly robust ML components, such as *ML optimizer*, *MLI*, and *MLlib*, to support the full lifecycle activities, required to implement as well as use ML algorithms. ML optimizer automates the tasks of ML pipeline construction to efficiently search algorithms of MLI and MLlib. MLI is the API to develop ML algorithms using high-level constructs. MLlib is the Spark distributed ML library	– Java – Scala – Python	Yes	– Collaborative filtering – Classification – Clustering – Regression
Oryx [13]	Oryx is an open-source ML library that has evolved over time out of the libraries and toolkits developed by Cloudera. Based on the distributed input from HDFS, it builds predictive models that are written to output in predictive model markup language (PMML). An interesting feature of Oryx is its ability to keep the model updated under emerging streams of data from Hadoop	– Java	Yes	– Collaborative filtering – Classification – Clustering – Regression

Fig.4.3 ML tools used in data analysis [59]

4.7 Machine learning

As stated in the introductory chapter of this study it will investigate the possibilities of combing XR technology with other computational algorithms, based on BIM and IoT devices collected data, big data techniques can be applied to automated decision making that enables intelligent monitoring and actuation. Current research is focusing on how the massive AEC data can leverage artificial intelligence algorithms and big data techniques in potential areas such as generating the optimal solution based on sensor data, assisting real-time operation and problem identification. Future research should also focus on real-time big data analytics, cloud based big data management solutions for extensive real-time data from IoT devices, and AEC data resides in BIM [61].

Machine learning, seen as a subset of artificial intelligence, is the scientific study of algorithms and statistical models that computer systems use to perform a specific task, making predictions or decisions without using explicit instructions, relying on patterns and inference instead. Machine learning algorithms build a mathematical model based on sample data, known as "training data" [62]. Its Application in AEC can range from computer vision to analyzing structural anomaly and making other analysis on the available data lake[63] sourced from sensors, BIM, and the XR hardware.

Computer vision is an interdisciplinary scientific field concerned with the automatic extraction of useful information from image data in order to understand or represent the underlying physical world, either qualitatively or quantitatively. Computer vision methods can be used to automate tasks of the human visual cortex, These algorithms have achieved remarkable success in building perception systems for highly complex visual problems [64]

Anomaly detection is the identification of rare items, events or observations, which raise suspicions by differing significantly from the majority of the data. Typically, the anomalous items will translate to some kind of problem such as a structural defect or errors in a text [65].

Applying these techniques of machine leaning it is easier to analyze big data, automatically detect, extract and discover vital information from large-scale data lake and can additionally train and deploy AI models [66].

5. Technologies

5.1 Enabling technologies for Extended Reality

XR technology relies on set of three components: computers, software and hardware devices. Over the years, companies have been developing software and hardware prototype that is compatible with XR technology. Thus this section of the will highlight available developed components in the domain of this technology. Hence evaluating the arising questions and limitations of the technology in the AEC industry and the emerging risks. A great advantage of the AR technology is it can be implemented with a smartphone [67] as mobile operating platforms also have kits for AR apps development such as ARkit, and ARCore developed by apple and google respectively.

The number of HMD in the market is also increasing as companies are partnering together to create better hardware solutions for both VR and MR, hence this HMD each have an advantage and a disadvantage, likewise limitations varies from device to another. AR devices are standalone unlike VR, when device have to be connected to a computer or mobile phone and to perform heavy task the computer must be a powerful one with much computing power, prices of VR/AR device in Fig. 5.1 and Fig. 5.2.

A great tool used for developing the immersive reality content is the gaming engine [68], engines such as: Unity 3D, unreal engine, cry engine, amazon lumbery, xenko and open source, however, with challenges of different file format support [69], [70].

Product	Oculus Quest	Nintendo Labo VR Kit	Sony PlayStation VR	HTC Vive	Oculus Go	Oculus Rift S	HTC Vive Cosmos	Lenovo Mirage Solo With Daydream
								
	$399.00	$79.99	$276.80	Best Price	$199.00	$399.00	$699.99	$299.88

Fig. 5.1 prices of VR HMD source [71]

5.2 Difference between HTC vive pro and oculus Rift S

There is always a question of which is the best VR headset, according to the Telegraph UK, the HTC vive and the Oculus rift S stand as the first two best VR HMD of 2019 [72]. These two devices support most VR tools and plugins like IrisVR; IrisVR is an easy-to-use VR software for the architecture, engineering and construction industry. With IrisVR, architects, engineers, and preconstruction teams can instantly bring any 3D model into virtual reality for design review [73].

Fig. HTC VIVE PRO VS OCULUS Rift S. source[74]

Hence, the difference between HTV vive pro and Oculus rift S.

	HTC vive pro	**Oculus Rift S**
Display Resolution	2880 x 1600px	2560 x 1440px
Refresh Rate	90Hz	80Hz
Field of View	110 degree	110 degree
OLED	YES	YES
Electronic display	Yes	yes
Gesture control	YES	NO
Price(euros)	879	359
Degree of freedom	6DoF	6Dof

Table 5.1 highlight difference between HTC vive Pro and Oculus RIFT s. [74]

5.3 Computer Requirements

Looking for a computer that is compactible to VR, one need something that can handle heavy loads. When it comes to high-end desktops or laptops (and other advanced tasks like gaming or video editing), the CPU, the GPU, and memory are the most critical components. Without these high performing components working in sync, you could have a miserable experience; which increase the risk of motion sickness. A high-end processor assists in positional tracking and controls how real and immersive your virtual environment will be. A discrete graphics-processing unit (GPU) is recommended, the GPU is responsible for rendering the high-resolution immersive images needed [75]. A computer with minimum requirement having a starting price of 1000 USD.

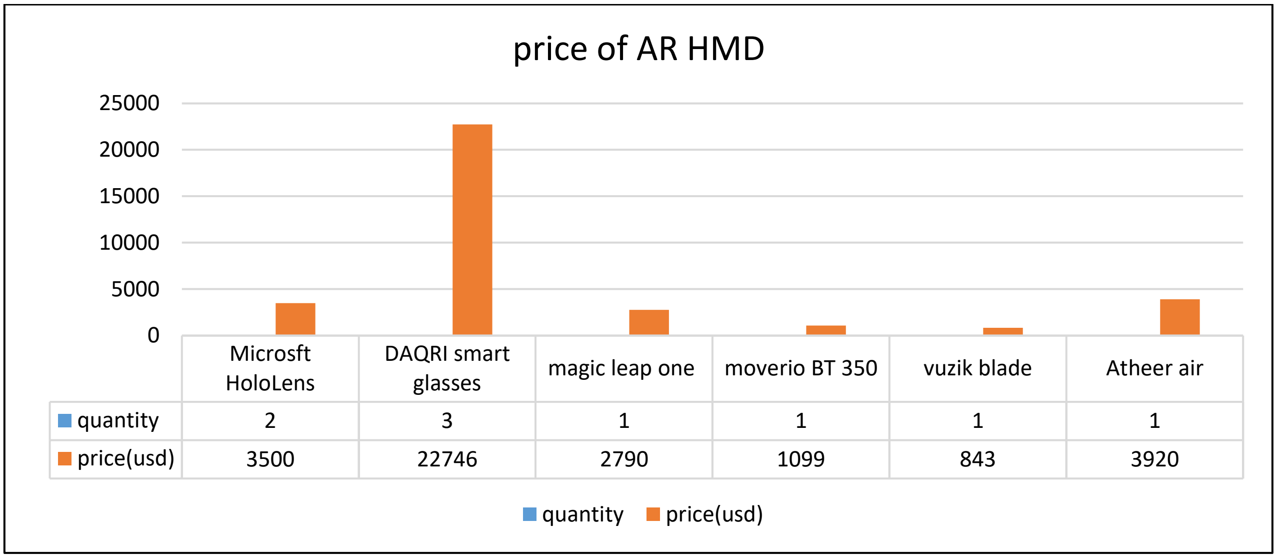


Fig. 5.2 prices of AR devices.

5.4 Enabling technologies for IoT, BIM

There are many technologies that enable IoT; crucial to the field is one that enable the connected devices to communicate to each other. Some of which are in table 5.1 [76]. Largely, the future of the Internet of things will not be possible without the support of IPv6; and consequently, the global adoption of IPv6 in the coming years will be critical for the successful development of the IoT in the future [77].

Short-range wireless	medium-range wireless	long-range wireless	wired
Bluetooth mesh networking Light-fidelity Near-field communication Radio frequency identification z-wave Wi-Fi ZigBee	LTE-Advanced	Low-power wide-area networking Very small aperture terminal	Ethernet Power-line communication

Table 5.1. Source: *[2]*

While many BIM users have been on transition to 3D platforms, 4D, 5D and 6D are already on their way. 4D solutions provide a visualization of the construction schedule. 5D, 6D and BIM add cost and materials to existing 3D BIM solutions. These new versions of BIM will add details such as aesthetics, thermal properties, and acoustics to maximize user's return on investment [78]. There are many solutions available for running the building information modelling; however, the paid versions of this software offer a more extensive functionality and requires user training to be able to use the software.

While BIM is a way of working and managing information (rather than simply the use of one tool or another), the adoption of a range of tools and resources facilitates BIM. Two of the tools that are key to adopting BIM are 3D modelling software and Common Data Environments (CDEs). Autodesk continues to be the most commonly used software vendor for the production of models and drawings, with 70% using their tools; Revit, is used by 46% of survey respondents, 14% using AutoCAD and 10% AutoCAD LT. with the next most popular tool also being one that enables the production of digital models: Graphisoft's ArchiCAD (15%). but responses to this question indicate that practitioners are focusing on using modelling software that supports their adoption of BIM, rather than tools to produce 2D drawings. While many practitioners use Autodesk tools, the survey found that Graphisoft use is comparatively high among small organizations, rising to 24% among this group. From our recent Construction Technology survey, we found that several CDEs are widely used, in particular: Viewpoint, Autodesk 360, Asite and Aconex. Viewpoint was the most popular, used by 41% of respondents. CDEs are becoming increasingly important. They enable the storage of data in one place, reducing the need for duplication, which helps to reduce error and conflicting information. Locating this data in the cloud promotes collaboration as it enables any of the project team to access it, from anywhere. This also improves transparency [79].

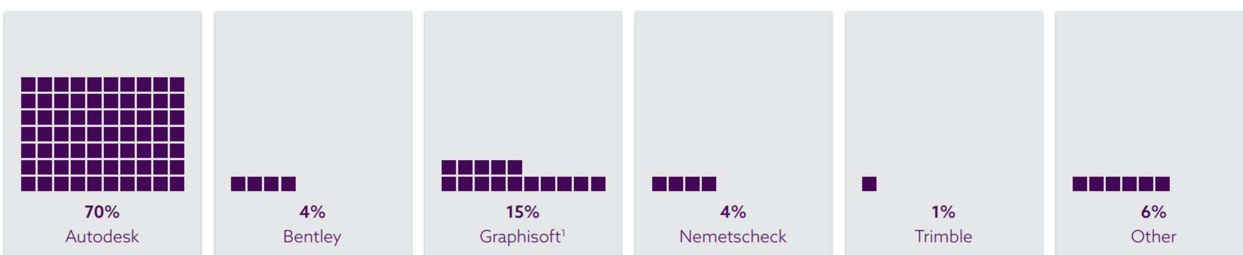


Fig. 5.3 BIM 3D modelling software [79].

The table below show the pricing plan of some BIM software that appeared in the above table, the plan contains full functionality of the software(all prices shown are in Euros) [80]–[83].

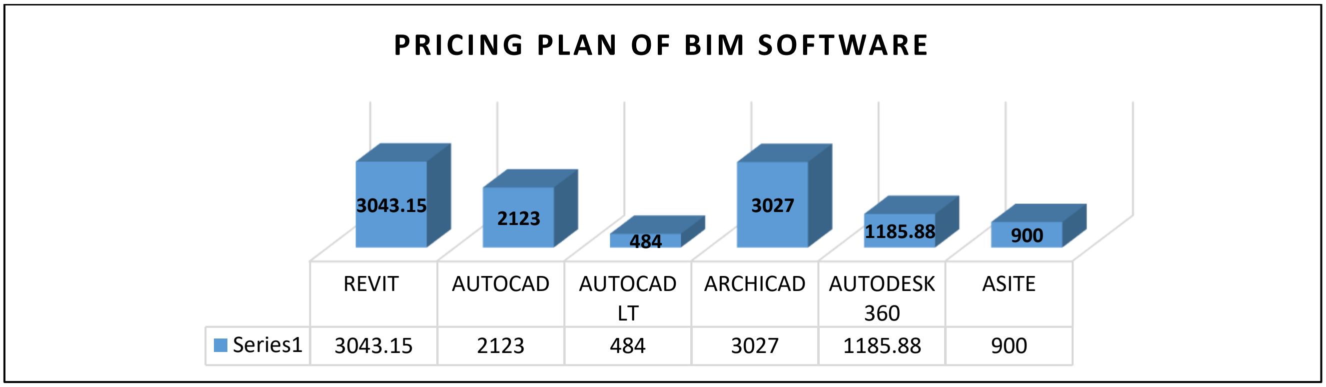


Fig. 5.4 pricing plan for BIM software

5.4 Concerns arising due to the use of XR technology

Health issues is one major concern to the adaption of the XR technology in the AEC industry, even though it is used to prevent accident in the work place it also pose other health and mental to the user who is serving as an analog interface. The use of VR glasses cuts the user entirely from the physical reality hence not aware of the surrounding; inadequate training might the pose the user at risk of workplace incident, additionally Simulator sickness with virtual reality applications have also been referred to as visually induced motion sickness or cybersickness [84].

Limitations of FOV: A limitation with AR/VR devices currently on the market is Perhaps field of view (FOV) which is one of the biggest. Today, these devices have a FOV of up to 90 degrees, compared to the 190 degrees horizontal and 120 degrees vertical for normal human vision. For these devices to create the immersive experiences they aim to, they must capture as much of the FOV as possible. AR/VR devices must show the projected image in a large FOV for the human eye to make the experience more immersive, which requires devices like headsets to be bulky. In their current status, the size makes prolonged usage of these devices unlikely and uncomfortable. As work continues in this arena, there are many specifications that need to be achieved to overcome AR/VR device limitations, including work on the weight, brightness, display quality, FOV, latency and finally the user experience, with the uprising trend the industry can overcome this within the right price point [85].

There is a lack of motivation for AR technology transfer. It is well known that construction sector are conservative and reluctant to change much especially in the aspect of moving toward new technology. Whether AR is truly a cost-effective solution in its proposed applications has yet to be determined. Much research can be done to prove to the design and construction practitioners about the feasibility and profitability of applying AR system [86].

Privacy concerns and standardization may lead to a very poor adaptation of this technology in the construction industry. Currently, there are no standards or regulations as to how this data is collected, used or shared. VR and AR data misuse could cause people to lose control of their identity and how they choose to present themselves to employers, insurers and others. There was special concern for the vulnerability of children who may be tracked using this technology from a young age and who are not capable of consenting to these risks [87].

Generally, the aim of data protection approaches is to allow services or third-party applications to learn something without leaking unnecessary and/or personally identifiable information. Usually, these protection approaches use privacy definitions such as k-anonymity, and differential privacy. K-anonymity (Sweeney 2002) ensures that records are unidentifiable from at least k-1 other records. It usually involves data perturbation or manipulation techniques to ensure privacy, but suffers from scaling problems, i.e. larger data dimensions, which can be expected from MR platforms and devices with a high number of sensors or input data sources, other security approaches include input protection, and output protection [88].

Countries where XR and BIM adoption is widespread has started to make efforts for BIM standardization policy or initiative. Table 5.1 summarizes BIM standardization and policy initiatives by each country together with the administration organization/regulatory body [89].

With the recent EU general data protection regulations (GDPR) policy, its impact is not only in the EU area but also across the world. Other countries also signed similar laws, countries such as (brazil, USA, south Korea, Japan, Australia, Thailand [90]).

Other limitations include insufficient trained workers to implement this technology I the AEC industry, technical limitations, and contents developed for the AEC industry as most companies developing XR solutions get few clients from the AEC industry.

Therefore, it is opportune to design, investigate, and implement security and privacy mechanisms that can be integrated with existing and upcoming MR systems, while their utilization and adoption are still not widespread [88].

Table 5.2 BIM standardization and/or policy initiatives by country

Country	Organization	Standardization and/or Policy Initiative
USA	U.S. General Administration (GSA)	• National 3D-4D BIM Program in 2003 • BIM required in all final concept approval for all major projects since 2007 • 3D, 4D, and BIM technology deployment encouraged in all GSA projects • GSA BIM Guide Series
	National Institute for Building Science (NIBS)	• National Building Information Modelling Standard (NBIMS) on Building Energy Performance(BEP)
UK	UK government	• Model-based BIM (level 2) mandated on all public sector projects by 2016. • Commitment to BIM in Government projects over a 5-year time frame
	BIM Task Group	• Support and assistance in transitioning to BIM and electronic delivery • Information sharing environment (Operations Building Exchange COBie)
	AEC (UK) committee	• Unified standard for the Architectural, Engineering and Construction industry CAD & BIM in the UK
	British Standards Institute (BSI)	• Information sharing standards created (PAS 1192:2)
Finland	Senate Properties	• Models meeting IFC standards in its projects mandated since 1 October 2007 • BIM Guide called Common BIM Requirement 2012, COBIM
Norway	Civil State Client Statbygg	• BIM mandated for the lifecycle of their buildings. • All Statbygg project using IFC/IFD based BIM by 2010 • Statsbygg Building Information Modelling Manual released in 2007
	Norwegian Homebuilders Association	• Norwegian Homebuilders Association BIM Manual
Singapore	Building and Construction Authority (BCA)	• BIM e-submission system mandated for regulatory submissions in 2015 • Singapore BIM Guide
Hong Kong	Hong Kong Housing Authority	• Full implementation of BIM on all its housing development projects by 2014 • BIM standards, user guide, library component design guide and references.
South Korea	Korean Ministry of Land Infrastructure and Transportation (MLIT)	• BIM mandated for all projects over S$50 million and for all public sector projects by 2016
Australia	BEIIC (the Built Environment Industry Innovation Council)	• National Building Information Modelling Working Party reporting to BEIIC • NATSPEC National BIM Guide developed in 2011

6. Conclusion

This study did not present a new research, however, it complements on existing literatures. It is shown from this studies that XR is applied in the AEC industry in a number of ways and is having a great impact in the industry. They application ranges from automated structural anomaly detection, efficient and less time-consuming communication between the AEC workers and professionals, time scheduling of project, training simulations, construction management and planning, some of the applications have been explained in detail.

However, the pattern of published materials in all fields discussed are significantly emerging. Indeed, XR and BIM will remain to be promising to the AEC industry. XR present itself as a global phenomenon. The body of research mainly comes from the western world, with a substantial contribution from the Far East and the main market in Asia.

Furthermore, integrating XR to other tools and resources will improve data integrity, intelligent documentation**,** distributed access and retrieval of building data and high quality project outcome, as well as multidisciplinary planning and coordination.

In addition, this study has identified some challenges that causes drawback to adaptation of XR technology in the AEC industry, the study of integrating AR, VR, MR with other technological tools such as BIM, IoT, big data and ML will continue to be the future research direction, and it is in no doubt that these barriers are manageable. Research and studies on BIM should be directed especially in field of studies relating to the AEC professionalism to improve training performance.

In order to stay competitive, firms need to be more agile than ever before; therefore, the need to invest in the implementation of new technologies and concepts is vital.

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