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USING AUGMENTED REALITY IN DIFFERENT BIM WORKFLOWS

UPORABA RAZŠIRJENE RESNIČNOSTI V RAZLIČNIH DELOTOKIH BIM PROJEKTIRANJA

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Building Information Modelling

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Izvleček:

Digitalna platforma za modeliranje gradbenih informacij (BIM) podpira integracijo vseh faz gradbenega projekta. Model BIM tako lahko vključuje vse podatke in informacije, ki se pojavijo v življenjskem ciklu gradbenega projekta: od faze načrtovanja in gradnje, do faze obratovanja in vzdrževanja. Z zagotavljanjem uporabniku poglobljenega pogleda na okolje in omogočanjem integracije med navideznim in naravnim okoljem postaja razširjena resničnost nepogrešljiva tehnologija pri načrtovanju delovnih tokov in modeliranju podatkov v vseh fazah gradbenih projektov. V okviru magisterskega dela smo raziskali in ovrednotiti potencial in izzive uporabe razširjene resničnosti v kontekstu celotnega življenjskem cikla projekta BIM. V ta namen smo analizirali tri različne primere uporabniških scenarijev. Prva dva primera uporabniška scenarija se nanašata na infrastrukturna projekta z neenakomerno natančnostjo podatkovnega in informacijskega modeliranja, ki ga zagotavljajo tridimenzionalni modeli v BIM. Zadnji uporabniški scenarij pa se nanaša na poslovno stavba, ki je v celoti izvedena v 3D modelu BIM. Magistrsko delo ponuja pregled okvirov izbranih uporabniških scenarijev, poroča o koristih in izzivih uporabnosti programske opreme z ustreznimi orodji za interakcijo v realnem času med AR in BIM prek mobilne naprave ter analizo dobljenih rezultatov.

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Abstract:

As all phases of the project are incorporated into the Building Information Modeling platform (BIM), which provides a model containing all the data and information that occur during the life cycle of a structure: from the design and planning phase, through the construction phase, to the operation and maintenance phase. As the tools used on this platform advance technologically, the architecture, engineering and construction (AEC) industry is increasingly seeking the cost-effective benefits of investing in technology. By providing the user with an immersive view of the environment and enabling integration between the virtual and natural environments, augmented reality (AR) is becoming an indispensable technology in design and data modeling workflows. In this context, the research aims to report and evaluate the potential and challenges of using augmented reality in a broad approach within the life cycle of a project in BIM and through three case studies in different construction scenarios. Two case studies are an infrastructure projects with uneven depth in data and information modeling provided by three-dimensional models in BIM. The last case study is a office building fully executed in 3D model BIM. The master thesis provides a review the contexts of each case study projects, reporting on the benefits and challenges of the applicability of the software with appropriate tools for real time interaction between AR and BIM through a mobile device, and analyzing the results obtained.

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1 INTRODUCTION

With the rapid growth of the project design phases within the BIM digital platform, the information entered and registered in the 3D model must be well structured. The result of visualization in augmented reality should be viable and correct. The AR system combines the virtual and natural world with interaction and synchronization of geometric and non-geometric information based on the 3D BIM model (Wang, Wang, Shou, & Xu, 2014). Augmented Reality is currently considered by computer science and computer science scholars as a "New Age" of technological transmission mode information, with advantages resulting from its potential. (Meža, Turk, & Dolenc, 2015). In the construction industry sector, the correct use of AR provides improvements mainly in the construction phase, which significantly affects the efficiency of projects with the potential to improve quality and safety parameters and, consequently, the cost and duration of the project, which positively guarantees qualified construction management as suggested by (Kivrak, Arslan, Akgun, & Arslan, 2013). According to (Meža, Turk, & Dolenc, 2015) and (Zhang, Yu, Li, & Hu, 2014), suitable standards such as Industry Foundation Classes (IFC) have the potential to solve the interoperability problem software and information representation in design. The fundamental reading of this research, focusing on several scientific articles and book chapters written in the last two decades, brought to light the evident interest in the AR system in the context of the AEC Industry. This technology has been multiplying due to the constant evolution of software development and applications for mobile devices and the need for professionals involved in the life cycle of a project to take advantage of the real-time visualization that this system offers. The main uses of augmented reality are construction monitoring, dynamic website visualization, detection of construction inconsistencies (Bademosi & Issa, 2019). The construction industry also faces a growth process from integrating Industry 4.0 throughout the construction project life cycle phases. This growth, suggested by several researchers, is due to the introduction of the innovative behavior of Building Information Modeling (BIM) in the AEC Industry, bringing many advantages and changes in current construction practice, granting process adaptations, making them effective.

Currently, augmented reality (AR) and other new technologies play a crucial role in civil construction, especially in aiding decision-making. For example, in the 3D phase, using a specific AR application can save costs and materials in construction. In the 4D stage, it can offer facilities for the coordination of works, and in the 7D phase, it can bring advantages to maintenance professionals. The knowledge passed on through readings of scientific articles, conference proceedings, books and, other academic references regarding the advantages and challenges of using augmented reality (AR) combined with building information modeling (BIM), in addition to experiences practices in construction sites from the different case studies used in this research, contributed to a consistent and complete critical analysis, with results compared to each other, highlighting the contribution of AR to solve some gaps within the workflow in BIM.

2 LITERATURE REVIEW

2.1 Building Information Modeling: BIM

2.1.1 General overview

The roots of Building Information Modeling (BIM) began with the first ideas about how the concept of models of a given object through several different media used in architectural projects as cite (Björk & Penttilä, 1989) and, as reported by (Russell & Elger, 2008) on the introduction of BIM in the AEC market. Following this evolution and detailed investigations between software companies and research institutes, in 1995 started the Industry Alliance for Interoperability (IAI). From experiences, as described by (Russell & Elger, 2008), the (IAI) established criteria for defining buildings, allowing the exchange of information about them without losing their essential data. In 1997 the first published working format was called Industry Foundation Classes (IFC). IFCs have a basic definition of terms and relationships between building elements and can exchange lossless semantic data between software during the life cycle project.

In the book, Hardin & McCool (2015) define Building Information Modeling (BIM) as a modeling technology and a grouping of processes with a common purpose: designing, transmitting, and analyzing building models, reflecting and emphasizing issues from across the world. Process and not only the information of the construction model, and these models are objects characterized by: (1) construction components with their representations in digital format and that bring computable graphics and their respective assigned data that allow their identification in an application or software, in addition to parametric rules that objects can intelligently manipulate; (2) components with data referring to behavior descriptions as needed for analysis and work processes, for example, withdrawal of quantity, specification, and energy analysis; (3) consistent, non-redundant data represented in component views and each part of its assembly.

National Building Information Modeling Standard (NBIMS-US 2012) defines Building Information Modeling (BIM) as the digital interpretation of a facility's physical characteristics and properties. It is an instrument for sharing information from an installation, generating a database with data collected during the life of a project. This description complements the statement that a basic premise of BIM is a collaboration between collaborators, including the employees themselves. Of the tasks present in the different phases of the life cycle within a project or installation, it becomes possible to insert, extract or update information in BIM.

The use of exchange resources is constantly changing. This evolution seeks to optimize the technology according to the complexity of technical processes in civil construction, making the data contained in the models interoperable, that is, shared among the project participants making BIM represent the management of this information (NBIMS-US, 2012).

To better understand the evolution of BIM in the construction industry, it is necessary to understand the importance and value of BIM in the project management of a building throughout its lifecycle. Hardin & McCool (2015) write that parametric-object modeling technology constitutes the principal basis of BIM. Parametric Technologies Corporation developed it in the 1980s (cited by BIM Handbook, p. 29) and complemented by reporting that in the early 1990s, BIM was available in the civil construction market as a tool capable of processing 3D CAD models. From the catalytic milestone for adopting BIM that was the acquisition of Navisworks by Autodesk in 2007, some applications, services, and hardware were associated with BIM in 2010. The growth of this technology sector continues to develop and be improved according to the current needs of AEC, such as the increase in the number of plug-ins and add-ons related to BIM, providing more dynamics for workflows with interoperability and the free exchange of data and information between systems.

Hardin & McCool (2015) describe the most significant value of BIM for the construction industry as being the model's ability to obtain information and extend its use to various other software, giving it relevance and functionality for different workflows and processes such as financial estimation and chronological, logistics, safety, and quality. New collaboration methodologies and increased information sharing on proprietary web-based platforms make this process more accessible and effective in all project phases.

2.1.2 Interoperability

For Ren & Zhang (2021), *the BIM and IFC (Industry Foundation Classes) Model View Definitions (MVDs) Application* has a reference to the BIM theory written by Dr. Chuck Eastman 45 years ago (cited by Daniotti et al., 2020). Describe BIM within the AEC domain as a standard open platform, which allows for communication and collaboration between stakeholders without them possessing specific skills. *BIM Interoperability from Technical and Process Dimension Analysis* is an ongoing challenge, with constant research in (1) the technical dimension where interoperability is linked to a possible exchange of data between systems without significant changes; (2) and in-process measurement.

Among the interoperability that BIM makes possible in the AEC are visualization techniques such as augmented reality to recognize and manage defects to be corrected, manage the installations and visualize the environment before its construction. Energy modeling and energy simulation can apply AR during construction management. Combining the geographical information system (GIS) with other techniques, such as systems capable of identifying the object's location in real-time, improves the interoperability between different data types, such as those used for augmented reality. For the description of *BIM for architectural design and structural analysis within the context of the project* *delivery method*, Ren & Zhang (2021) comment that the combination and interoperability between information and data, processes and functions in the preparation of a project is a great challenge. In the construction industry, there are different types of project deliverables. For type-specific operations, the methods can be design-bid-build (DBB), design-build (DB), construction management at risk (CMR), construction management agency (CMA), multi-prime construction management (CMMP), and integrated project delivery (IPD).

One of the best known and most used formats for interoperability in the AEC is the IFC (Industry Foundation Classes), whose main characteristic is the standardized digital presentation of the built environment, as a standardized and open data scheme (ISO 16739-1: 2018), designed to be neutral between all parties involved, can be used in various hardware devices, software, and interfaces from different suppliers and with the ability to define the physical components of a built environment, such as manufactured products, MEP systems, structural analysis, cost breakdowns and, schedules, and is commonly used for information exchange. IFC data can be systematized in XML, JSON, and STEP formats, exported or, imported through web services such as files or databases (BuildingSMART, 2021).

For the interoperability of non-geometric information in an open format, a widely used international standardization is COBie (Construction Operation Building Information Exchange). Characterized by capturing and delivering information in spreadsheet models or other models according to COBie-enabled software and, in addition to the data presented in STEP (Physical File Format – SPF or IFC-SPF) format, can be shown in XML schema. Such information is from installation assets and equipment, grouped and organized during the construction project phases and which will serve as a basis to facilitate the maintenance and operations of the construction, assisting in the Computer-Managed Maintenance System (CMMS) and Computer-Aided Facility Management (CAFM), (BIMe, 2021).

2.1.3 Workflows in the life cycle of a building

According to BIMe (2021), a workflow means a path that cuts and identifies the main sequential activities to be performed and considers the significant decisions to achieve the delivery goal. When it comes to workflow in BIM, it should be considered for extensive processes to achieve strategic/operational objectives, which may include multiple schemas documented in a project, construction, or operation based on a BIM model. There are two types of BIM workflows so that a given task can adopt one of them according to the proposal to be followed.

- Internal BIM workflows are sequential activities and tasks to generate, modify, and exchange BIM models within an organization.
- Collaborative BIM workflows have as a basis on a model between several parts, with sequential activities that facilitate exchanging data and information from models and documents between project stakeholders.

The general definition above by BIMe (2021) serves as a basis for elucidating the different types of BIM workflow and knowing which best fits the project to be worked on. There are numerous work plans in the global AEC and manuals created by organizations to help choose the most suitable flow for a given lifecycle of a BIM project. It can be divided into design, construction, and operation phases in different stages (RIBA, 2020) and adapt to achieve the organization's ultimate goal (Figure 1).

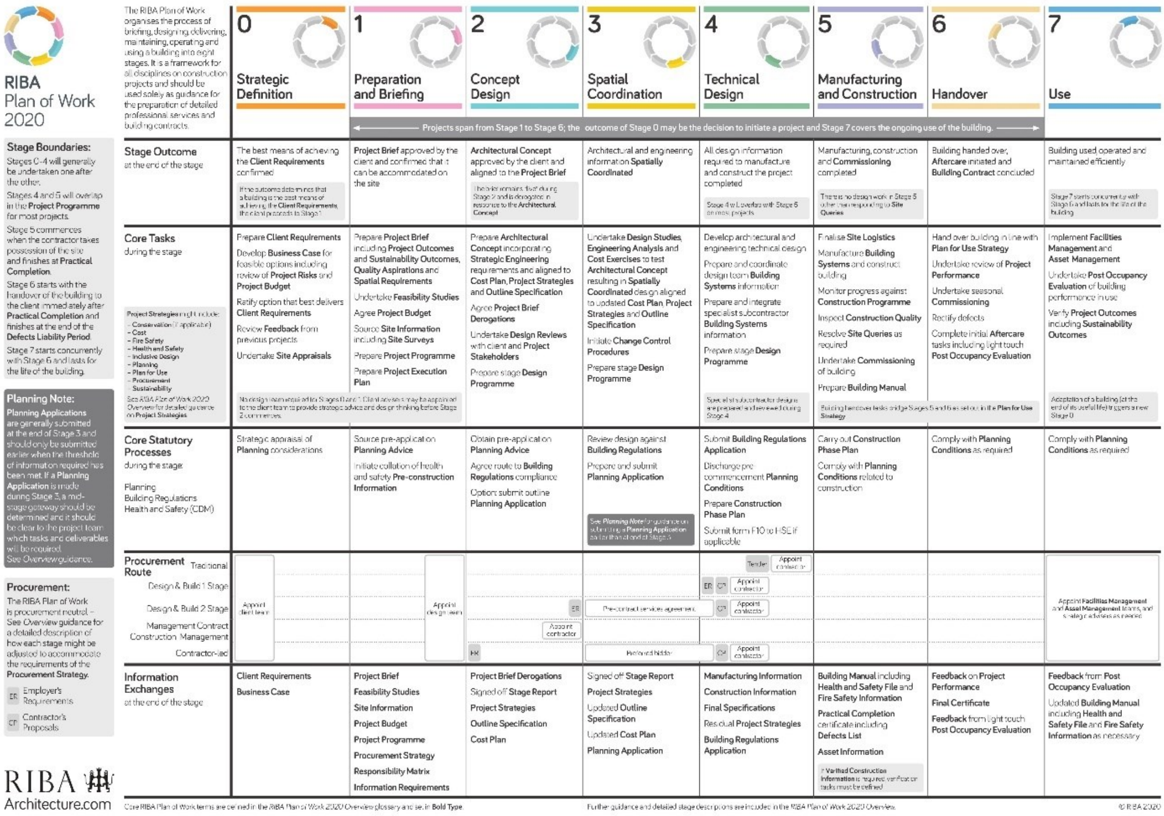

Figura 1: RIBA Plan of Work 2020 (RIBA, 2020)

Many organizations in the AEC industry prepare their own "BIM Manual," where design guidelines are inserted and used by engineering design professionals, with protocols and standards to be followed, examples of best practices, and consistent models. Standards vary and should follow contracts depending on the initial project strategy and considering the use of necessary information such as Asset Information Requirements (AIR) and Employer Information Requirements (EIR). They should support the contractor's activities in the different phases of construction, such as estimating, construction planning, and component manufacturing (Eastman, Teicholz, Sacks, & Liston, 2011). The correct use of the "BIM Manual" will assist the organization in meeting the project goals, where the elaborated standards are interconnected with the project workflow process and emphasize the need for sharing models, use of portable devices, platforms, and easily accessible tools. This model portability favors collaboration between project members, an essential requirement of the BIM approach (Autodesk, 2021).

With the evolution of technologies related to BIM, the inclusion of these innovations such as AR, VR, MR, and others should be considered in the project phases as stipulated in the BIM workflow manuals to assist in communication interpersonal and interdisciplinary in real-time.

In his research, Renzi (2018) says that the methodology used in Building Information Modeling started with 3D models. However, with the advent of alternative technologies, such as Virtual Reality and Augmented Reality, as visualization tools. The construction community seeks to innovate with BIM technology through specific workflow devices to apply to real-world problem solving, such as equipment installation, conflict checking by matching different design disciplines, and time and cost estimates.

The entire context covered by BIM must give importance in a workflow, considering that BIM models are more than geometric representations. Therefore, they appear into various dimensions, from 2D to 4D (drawing, programming), 5D (costing), 6D (lifecycle information), and 7D (facilities management), as listed by Saar, Klufallah, Kuppusamy, Yusof, & Shien (2019) and illustrated below (Figure 2). The data models used differ according to the schema used to organize the data and the schema language to transport the data. Some translators may use a different schema language than another, such as IFC to XML, according to Eastman, Teicholz, Sacks, & Liston (2011). The IFC data model is considered an open and platform-independent file format, facilitating interoperability in the civil construction and engineering sector, being used through specialized BIM programs and, therefore, with proprietary platforms such as Revit (Autodesk), ArchiCAD (Graphisoft), Navisworks Manage (Autodesk), Project Wise Navigator (Bentley), Solibri Model Checker (Solibri) and others.

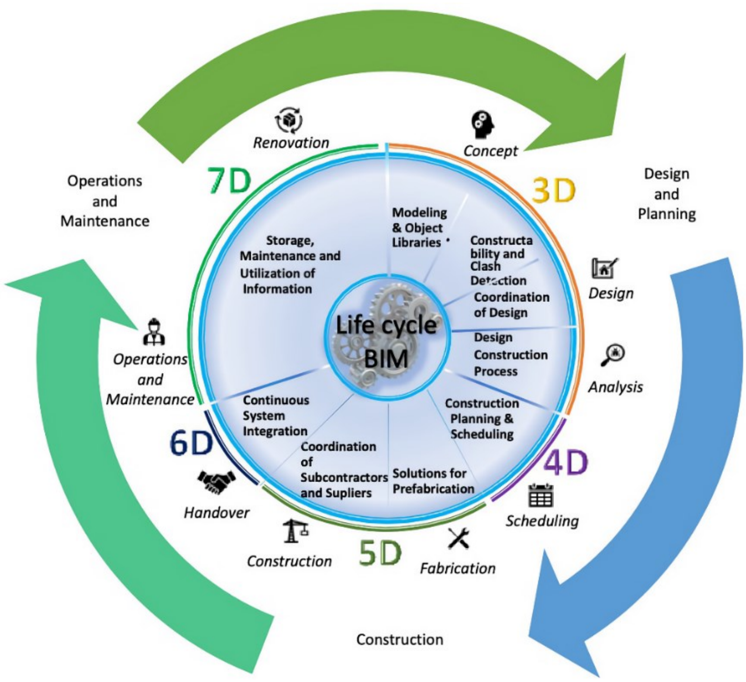

Figure 2: Lifecycle BIM (by author)

For specific purposes of this research, the BIM workflow will be according to the work cycle phases shown in Figure 2 with the four defined steps: (1) Pre-construction; (2) Construction; (3) Handover (Facility Management); (4) Operation & Maintenance (O&M), which will be detailed later. This panorama that relates the life cycle with the workflow steps is directly related to the three chosen case studies, one in step (4) Operation & Maintenance and the other two in step (2) Construction.

2.1.3.1 Pre-construction

In this phase, the benefits of BIM assist in aiding the feasibility of desired program requirements for quality construction, cost and time budgeting, and risk management. The union between a 3D model and a cost database is of great value for understanding the customer and the design and construction team regarding planning issues, a phase known as 4D. During the design phase, constructability conflicts are identified and corrected in the 3D model through analysis and simulation tools, increasing construction quality and productivity, and improving collaboration using Integrated Project Delivery (Eastman, Teicholz, Sacks, & Liston, 2011).

2.1.3.2 Construction

This construction phase is variable, as it depends on the stage of the project is. The application of the "BIM virtual construction model" facilitates understanding items to be built with the combination of all disciplines and their components and guides the visualization of their sequencing. This verification can happen through information management platforms linked to visualizing three-dimensional models with a database. One of the leading BIM activities at this stage is using the model-based layout in the field. Other attributions considered are using the model as a guideline for precast construction, monitoring the progress of the work, and using reality (Eastman, Teicholz, Sacks, & Liston, 2011).

2.1.3.3 Handover

The benefits of using BIM in this facility management phase are directly related to transferring facility information during the construction process. Designers, general, and MEP contractors collect information about installed materials and systems maintenance in the built environment. This database is linked to the "building model" object to be handed over to the owner and used in facility management (Eastman, Teicholz, Sacks, & Liston, 2011). COBie spreadsheets are the standard for integrating file formats from previous phases into Facility Management (FM) programs.

2.1.3.4 Operation & Maintenance (O&M)

The pre-build and build phases use geometric and non-geometric information (graphs and specs) stored in a standard data environment in the BIM workflow. The updated building model, after all, changes made during construction, can provide accurate information about as-built spaces and systems, which makes it essential for the maintenance and operation of a built environment.

In this phase, the database integrated with BIM supports the planning and execution of construction for maintenance, remote operation for facilities management. Real-time monitoring and precise location of control systems such as energy efficiency (Eastman, Teicholz, Sacks, & Liston, 2011).

2.2 Augmented Reality (AR)

2.2.1 General overview

The researchers (Chen, et al., 2019) define augmented reality (AR) as a technology that combines virtual information with real-world information, used through technical means such as multimedia, 3D modeling, real-time location tracking. They add that AR has as its principle the application of virtual information, such as text, images, 3D models to a real-world scenario, making them complementary to each other.

In Craig's view (Craig, 2013), in his book “Understanding Augmented Reality: Concepts and Applications,” broadly and generically describes augmented reality as a means by which information is added to the physical world and cites (Azuma, 1997) where he declares the existence of three attributes of AR: combination between real-world and virtual world; interaction of this combination in real-time; possibility of recording the real and the virtual in 3D. Going deeper into the theme, (Craig, 2013) lists the main aspects of augmented reality as the physical world augmented through digital information superimposed on the actual physical world. The result of the information is as a record in the physical world; there is an interdependence between the location of the natural world and the user's physical perspective in the real world; interactive experience between the user and the virtual information, being possible to make changes to this information. It reports another fundamental aspect of AR: the physical world increased through digital information superimposed on a realistic view of the physical world. And such knowledge is unrestricted, and may be visual, auditory, or olfactory, taste or touch, and may also be static as digital photography or 3D graphic model with or without sound.

No less critical or even considered by Craig (2013) as an essential element for augmented reality is the aspect of the spatial record. The digital information inserted has a location (or physical space) in the real world. An example of registration (Figure 3) depicts an experience with a digital vessel in a site regardless of the viewer's location. In augmented reality, it is possible to interact with the virtual object. If the person moves away from the table, the vase remains registered in the real world.

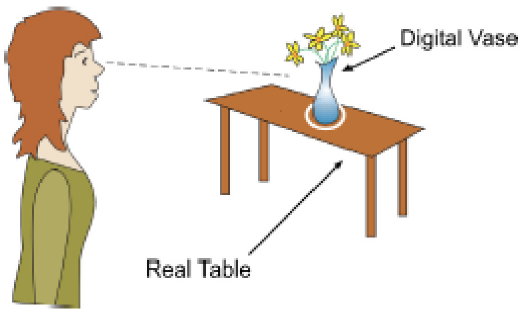

Figure 3: A digital vase sits on a real table and has a location in the world. It is in registration with the real world. (Craig, 2013)

With similar logic, for Chen et al. (2019), the critical elements of augmented reality are intelligent display, 3D recording, and intelligent interaction technologies that play essential roles in AR development.

There is a conceptual divergence between researchers and people working with technologies about whether augmented reality is a technology or not. For Craig (Craig, 2013), AR is a technical medium that uses other technologies. For example, he considers virtual reality a 'special case' of augmented reality or vice versa, as VR is a fully synthetic environment that only synthetic images (visual images, auditory or not). Furthermore, he points out that although virtual reality systems track the user's location and orientation to correctly create the screen's point of view, there is not necessarily a specific, grounded location. Another technology guided by Craig's article is telepresence, which allows the user to be present in a particularly remote place and to have the ability to perceive as if he were present in another area. This relationship with augmented reality occurs when the user is in one place accessing an AR application from another remote location. The technology is known as Global Positioning System (GPS) is used to track a specific physical position and can be used in AR as technological support with the same functions.

The process of augmented reality within an application takes place in practically two significant steps of time: first, the application needs to determine the current state of the physical world and the current state of the virtual world; and, in the next step, the virtual world must have its registration with the physical world so that the user of the application realizes that the elements of the virtual world are part of his real world. And, to support the steps described above, there are three main components in the augmented reality system which are: (1) Sensor(s) capable of identifying the state of the physical world at the application deployment site, providing real-world information In real-time; (2) Processor capable of interpreting the data captured by the sensor(s), affecting parameters of the laws of nature in the real world and rules of the virtual world, generating the indispensable signals to guide the screen; (3) Appropriate screen to sensitize the user to give the impression that the virtual world and the natural world are coherent and harmonious (Craig, 2013).

For Augmented Reality to work, several hardware components are indispensable, as briefly listed by Kipper & Rampolla (2013):

- A computer or mobile device;
- A monitor or surface for displaying the images;
- A camera;
- Sensor or location systems (such as GPS, compass, or accelerometer);
- Network infrastructure;
- A marker (a physical object or place that marks where the real and virtual worlds merge);

And, according to the authors, some types of software are needed:

- A program or application running locally;
- web services;
- A content server.

Based on recognition techniques and regardless of the types of devices used for interaction, Kipper & Rampolla (2013) divide the AR methods into four: pattern recognition, trace or contour tracking, location, and surface.

The essential steps to achieve augmented reality follow similar processes regardless of whether the method uses markers or location. The marker-based way is to insert a virtual 3D model into an actual physical object, and the plan based on site follows the same process. However, instead of using a marker, it assigns digital information to a set of coordinates.

The first method to be described by Kipper & Rampolla (2013) is pattern recognition. It performs a simple recognition in a basic shape or marker. When the pattern is recognized, the system replaces this area by adding static or mobile elements, such as a video scene or a 3D model (Figure 4).

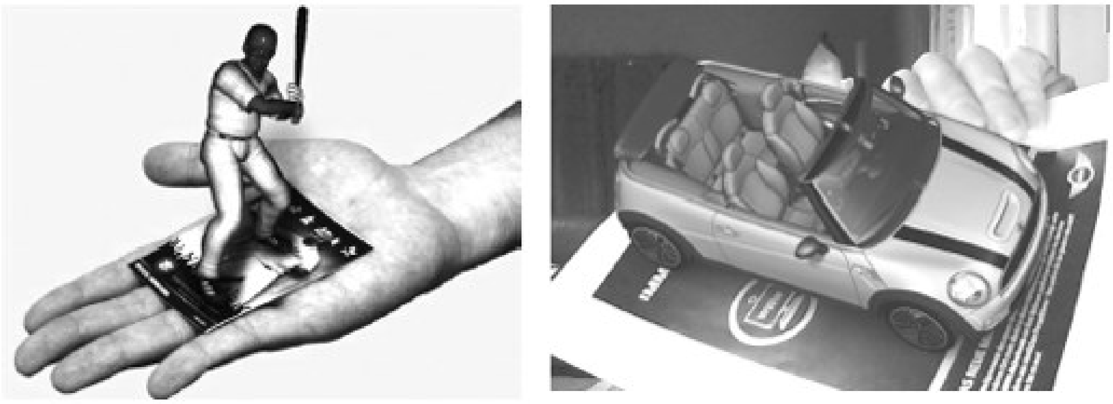

Figure 4: Marker-Based Augmented Reality (Kipper & Rampolla, 2013)

Tracking body features and facial recognition or contour is when a part of a person's body is identified and mixed with some digital element. The user can interact with 3D objects using natural movements, for example, taking a virtual object hand. Simultaneously the camera tracks the contour of the hand and adjusts the virtual object accordingly. The process is similar to facial recognition. The AR software can determine features such as eyes, nose, mouth and subsequently uses these reference points to overlay virtual objects (Figure 5).

Figure 5: Using Augmented Sunglasses (Kipper & Rampolla, 2013)

The location method originates from geolocation information such as Global Positioning System (GPS) or location triangulation information. Its use in an AR system in conjunction with camera position makes it feasible to insert icons or objects on buildings or people as the user moves through the real world. The use of location-based augmented reality is simple. It happens through a conventional mobile device, provided it has the necessary components such as a camera, viewfinder, GPS, accelerometer, and digital compass (Figure 6) (Kipper & Rampolla, 2013).

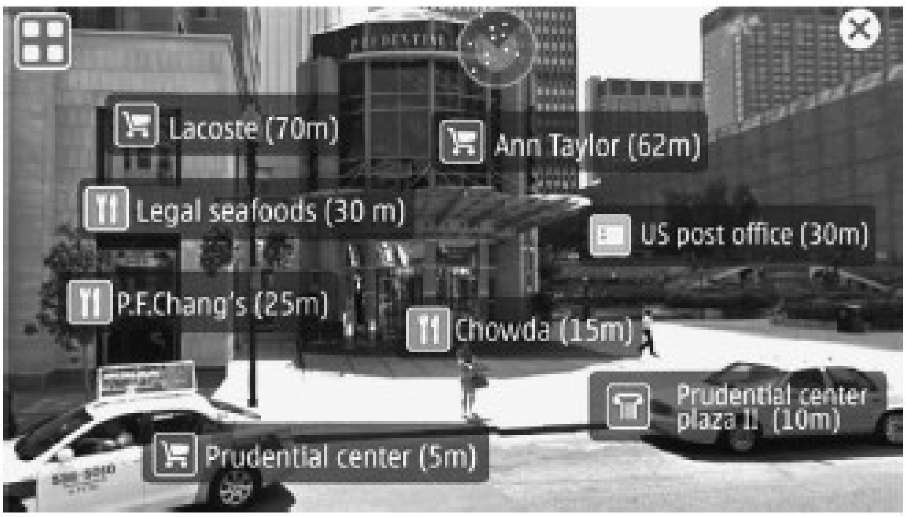

Figure 6: An AR Browser Showing Various Locations to the Viewer (Kipper & Rampolla, 2013)

Kipper & Rampolla (2013) explain the surface method as one that uses physical spaces such as walls or floors that react to the touch of people or objects and provide virtual information in real-time. For illustration purposes, the authors cite the augmented reality floor that uses a unique title, which can simulate pebbles, sand, snow, grass, and various other surfaces through precisely calibrated vibrations. Sensors in the floor detect the force of a person's foot and then calibrate a response on the plate, which vibrates at the right frequency provides the simulated sensitivity of different materials. Speakers inside the platform add the appropriate sounds, completing the illusion. In essence, the floor becomes a big touch screen. The purpose of the potential of this technology can be in games, training, and entertainment (Figure 7).

Figure 7: A User Interacts with Virtual Documents on a Physical Desk Using LightSpace (Kipper & Rampolla, 2013)

The researchers Kirner & Zorzal (2005) describe the four types of augmented reality system, classified according to the type of display used Azuma et al. (2001), involving optical vision or video vision:

- Direct visual vision system;
- Direct video vision system;
- Monitor-based video vision system;
- Projection optical vision system.

The Direct Optical Vision System uses glasses or helmets with lenses that enable the direct vision of the natural world while viewing virtual images aligned with the scene. When describing the Direct Video View System, the real scene is captured by a camera and integrated with virtual elements presented directly to the user's eyes through tiny monitors. The monitor-based video vision system, in turn, uses a camera to capture the natural scene and then integrates with the virtual objects and is viewed on a monitor. The user's point of view depends on the positioning of the camera. It is an easily accessible system, with a home computer and a fixed webcam. Its concept can be applied in AR on mobile devices, with the difference that the camera and display can be quickly oriented comment (Kirner & Zorzal, 2005).

And finally, they describe another type of AR system: the projection optical vision system that uses surfaces from the natural environment where images of virtual objects are projected and presented to the user without needing additional equipment that he should handle or wear. Even though it is interesting, this system is very restricted to accurate space conditions or projection, they conclude (Kirner & Zorzal, 2005).

According to Bajura & Neumann (1995), there are four causes of errors in the registration of the combination between real and virtual images, such as: (1) If the origin of the tracking system and origin of the world coordinate system are misaligned, virtual objects will appear out of their correct positions; (2) the virtual source-object transformation is not the same as the real source-object transformation of an object, resulting in the object out of position as an error; (3) If the position of the virtual camera is not the same as the position of the actual camera, the tracking system will show two errors. As a result, the pose causing incomplete registration, and the temporal one causing insufficient enrollment only when the user moves. This error can arise in Mobile Augmented Reality (MAR) systems that employ inertial sensors from movements, resulting in registration and deviation errors; (4) if the virtual camera to image mapping does not correctly model the actual camera, a record according to the position of the screen.

For these errors to be corrected, Bajura & Neumann (1995) presented through an experiment, dynamically measuring the incorrect registration in each virtual image combined with the accurate picture, taking advantage of this data for the proper correction of the system errors that caused the registry error. They found two alternatives to improve the system: transform each component to make them more accurate or change the open circuit to a closed circuit (Figure 8), which can detect its output and correct errors dynamically. In the AR system, the closed-circuit tolerate inconsistent transformations because it automatically applies 'corrections' to the conversions even when seeing registration error. For the final corrections to occur, two factors are fundamental: first, the method used to detect and measure the incorrect image registration and, as a second factor, the imprecision and image-space perception of the transformation parameters to be adjusted.

The image measurement method automatically pinpoints what corrections to make, recognizing points on each registered object, locating the coordinates of the natural and virtual images, and identifying if the registration is incorrect. Errors can be corrected through the orientation of the camera and sometimes the position of the camera. An inconvenience of this method is the inability to estimate the distance between object and camera or even the object's orientation. The application used for AR can determine the size of the corrected results and whether they are feasible as the final preview of the enlarged image.

When used to correct temporal errors in the video, the AR system loop delays the actual image stream to match the latent path time of the virtual image. It is time to measure the incorrect record and generate a corrected virtual image, making it possible to obtain the temporal and spatial image record at each recognized point of the image viewed in AR (Bajura & Neumann, 1995).

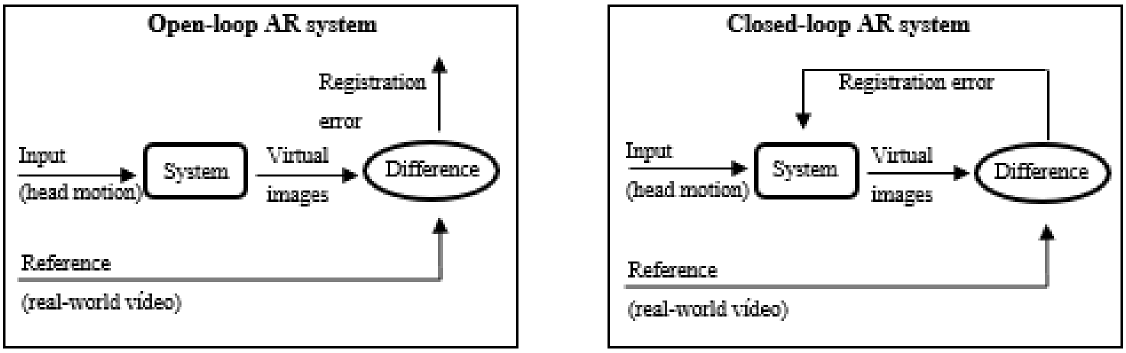

Figure 8: Open- and Closed-loop AR systems: Error is feedback for correction in a closed-loop system (Bajura & Neumann, 1995)

According to Wang, Wang, Shou, & Xu (2014), the AR platform in the BIM + AR + Architecture Visualization System (BAAVS) bases on an open-source AR SDK (Metaio SDK). Multiple techniques and development languages combine following the various possible applications of different “open sources” for these platforms to be compatible with each other with better tracking stability. JavaScript defines the interaction between 3D tracking point and 2D marker tracking and model content; OpenCV (Open Source Computer Vision Library), IN2AR (programming language), XML (extensible markup language), and AREL (Augmented Reality Experience Language) for a coordinate system, transformation, and rotation of the AR Model and Metaio SDK with 3D feature point tracking, frame by frame (Wang, Wang, Shou, & Xu, 2014). The AR system supports the .obj and .md2 formats, and their properties are imported into the AR system via the attached .xml format.

SDKs, which are software packages that use sensors built into mobile devices, allow 3D models to be structured and placed in environments without the need for markers. This technique makes it possible to identify features in the background and track their movements by combining this information with information added by the mobile device's sensors to determine its position and orientation as the user moves within the environment (Machado & Vilela, 2020).

2.2.2 The general evolution of AR

Machado & Vilela (2020), Kipper & Rampolla (2013) report that mobile devices and the accelerated advancement of technology fostered the progress and popularity of AR and mentioned the initial studies of AR by Sutherland in 1968. He proposes the head-mounted display (HMD), which works by triggering a device connected to a computer. Its uses are over the viewer's head, and its creation name is The Sword of Damocles (Kipper & Rampolla, 2013) (Figure 9). From this research, Sutherland takes over the AR development through the United States Air Force, the Massachusetts Institute of Technology (MIT), and the NASA Research Center. Following the evolution of this technology, scientists from Boeing Corporations Caudell and Mizell (1992) experimentally developed an AR tool to aid in assembly work. Loomis, Golledge, and Klatzky (1993) grouped AR and GPS, and audio to provide navigation assistance for people with visual impairments.

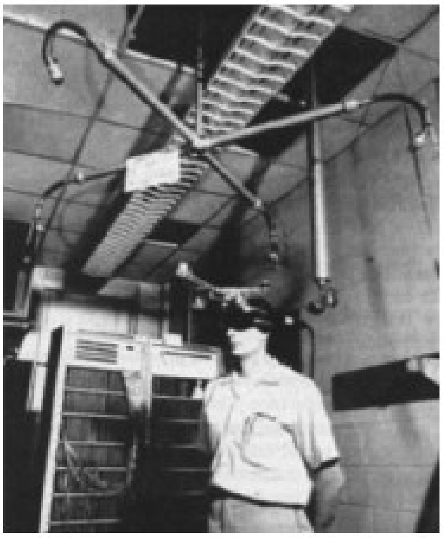

Figure 9: The Sword of Damocles Optical Head-Mounted Display (Kipper & Rampolla, 2013)

Continuing the chronology of AR evolution, Kipper & Rampolla (2013) describes that in 1996, Jun Rekimoto developed a prototype of augmented reality and called it NaviCam, introducing the 2D matrix marker (Figure 10), that can be a physical object or a punctual reference of a place where real and virtual environments are mixed. The tag is the reference point that the computer system identifies from the digital information, making it one of the first marker systems to enable tracking by a camera. This type of marker is still in use today.

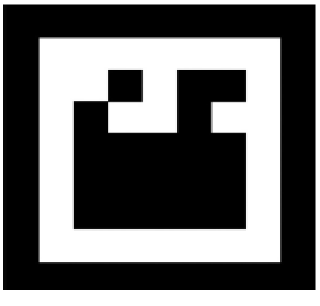

Figure 10: A Common 2D Augmented Reality Marker (Kipper & Rampolla, 2013)

Recent AR applications use different tracking settings, classified into "marker-based" and "markerless" types. Marker-based tracking has the property to track a marker that mobile cameras can reliably detect. Also, the design of tags can often ensure quick alignment to allow for efficient monitoring. On the other hand, markerless tracking settings can configure and track different targets without any markers. Markerless tracking settings will enable the use of a global positioning system (GPS), orientation, facial image detection, 3D maps, and so on, as explained by Zaher, Greenwood, & Marzouk (2018).

In 1997, one of the essential Augmented Reality researchers, Ronald Azuma, elucidated the definition for AR and identified it with three characteristics: (1) combination between real and virtual; (2) real-time interaction; (3) it has 3D registration (Kipper & Rampolla, 2013).

In the same research by Machado & Vilela (2020), the authors list generically the main new experiments of the researchers who developed prototypes in the mobile AR system and described the advances and limitations (cited in Feiner, Macintyre, Höllerer, and Webster, 1997; Azuma R. T., 1997 and Azuma et al., 2001); the development of AR technology to be used in plant inspection (cited in Klinker et al., 2001); the application of AR as a tool to help the solution electrical problems during car assembly in the Ford industry (cited in Friedrich and Wohlgemuth, 2002), the use of AR for training equipment operators in the heavy construction industry (cited in Wang and Dunston, 2007), the use of AR to control the development of a gas installation project (cited in Wang et al., 2013a).

In contrast, Kipper & Rampolla (2013) describe a temporal chronology of the leading innovative events for Augmented Reality. In 1999, the foundation of the company Total Immersion, the first AR solutions provider creating the D'Fusion product to operate on various platforms. In the same year, Hirokazu Kato unveiled the open source ARToolKit, allowing video captured in the real world to integrates with virtual objects, including 3D graphics. In 1999, Hollerer, Feiner, and Pavlik created an AR system garment allowing users to experience AR information combined with the external scene. The following year, Bruce Thomas et al. developed an AR version of the Quake game (Figure 11a) with GPS, compass, and vision-based marker tracking. In the same year 2000, Simon Julier et al. created the "BARS," an AR battleground (Figure 11b) composed of a computer, wireless network system, and a head-mounted display (HMD).

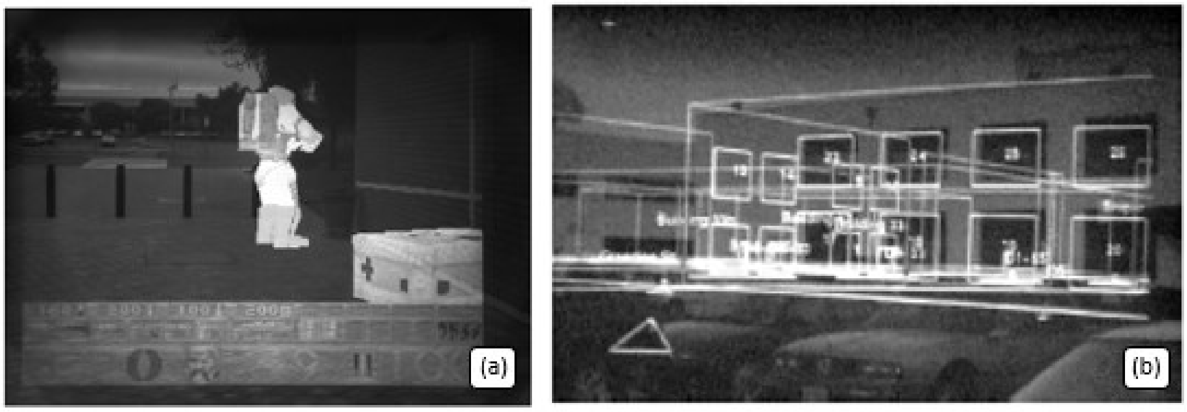

Figure 11: (a) AR Quake as Seen by a Player; (b) The Battlefield Augmented Reality System (Kipper & Rampolla, 2013)

In 2001, Reitmayr and Schmalstieg developed a mobile AR system for more than one user to simultaneously share the same augmented reality space (Figure 12a). And in the same year, the AR system for education and tourism, “Archoguide,” was developed by Vlahakis et al. (Figure 12b), with a navigation interface in scenarios on 3D models of temples and statues, and avatars in racing competitions. Kooper and MacIntyre created the Real-World Wide Web (RWWW) browser, recognized as the AR browser milestone, completing the primary AR creations in 2001.

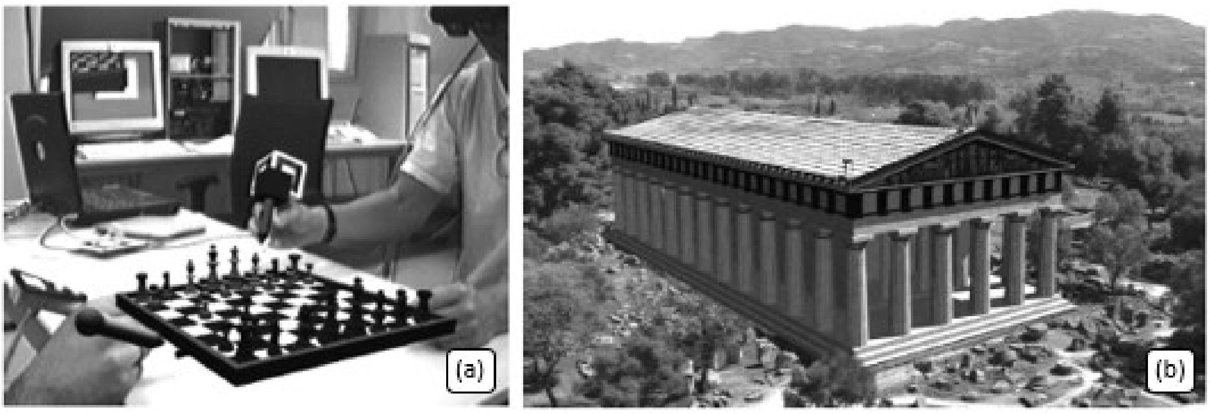

Figure 12: (a) A Multi-User AR System: (b)Archeoguide (Kipper & Rampolla, 2013)

In the chronological sequence, Kipper & Rampolla (2013) report that in 2004 Mathias Möhring developed the first 3D marker tracking system on mobile phones, with the detection and differentiation of multiple 3D markers enabling the interaction between 3D rendering and real-time video stream. In 2006, Nokia started the Mobile Augmented Reality Applications (MARA) research project, developing an AR application with multi-sensor functions in mobile phones. In 2008, the company Mobilizy launched Wikitude World Browser with an AR system. The application integrates GPS and compass data for overlays from Wikipedia in the real-time view by the smartphone camera. And, concluding the chronology in their book, Kipper & Rampolla (2013) mention that in 2009, SPRXmobile launched Layar, an AR navigator that uses GPS and compass data to record through an open client-server platform equivalent to traditional web pages on a browser PC.

With the growth and maturation of AR technologies, applications have become more variable and famous in various sectors such as education, design, manufacturing, construction, and entertainment sectors. Becoming the potential to help improve existing technologies and promote a better quality of life, especially for people with physical and mobility limitations.

2.2.3 Technological principles

Augmented Reality (AR) displays delimit a 'clear boundary' between the user and the environment. In this private and mobile window, there is an interconnection between real and virtual data with the superimposition of the virtual world on the real world. They adapt to luminosity through visual means to provide the user with the overlay of optical data (figurative or graphic) on spaces, built environments, objects, or people. There are three main types of monitors: head-mounted display, portable display, and spatial display.

a) Head-mounted display (HMD)

These types of HMD establish a visualization system placed in the head where it is possible to visualize the physical and digital information in the user's view of the world. They can be into two models:

- Optical-See Through (OST) devices directly view the natural environment where virtual content is printed (Figure 13). In this case, virtual and realistic data are optically combined through a semi-transparent mirror.
- The transparent videos provide an indirect view of the real environment, and its visualization is through two cameras placed on the headset. The virtual environment is digitally superimposed on the video signal before being viewed through the transparent video viewers. (Figure 14).

Figure 13: (a) Optical see-through HMD conceptual diagram; (b) Two optical see-through HMDs, made by Hughes Electronics (Azuma R. T., 1997)

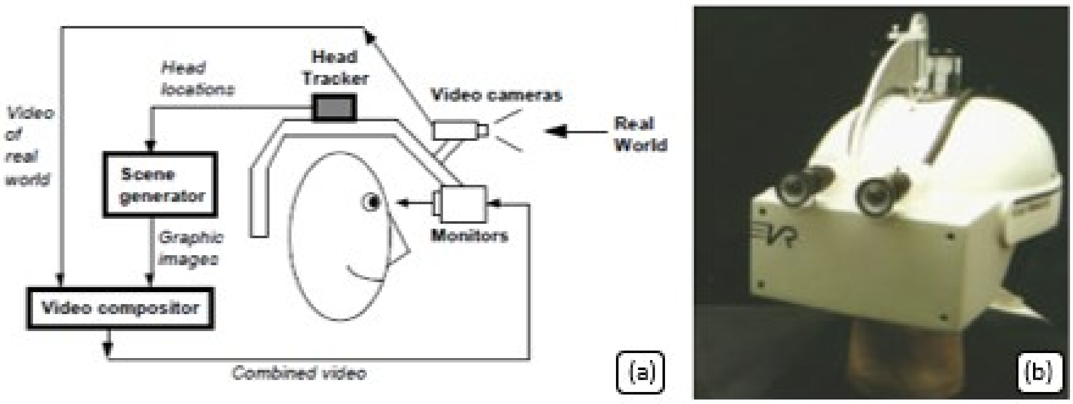

Figure 14: (a) Video see-through HMD conceptual diagram; (b) An actual video see-through HMD (Azuma R. T., 1997)

b) Handheld Display (HHD)

They are portable monitors that use processing devices and a kind of 'showcase.' This set can be easily held by the user (Figure 15). They operate through transparent video procedures overlaying illustrations on the object's original condition and use sensors such as advanced compasses and GPS units, markers (ARToolKit), and PC vision techniques (SLAM). Examples of portable monitors are Smartphones and tablets (Carmigniani et al., 2010)

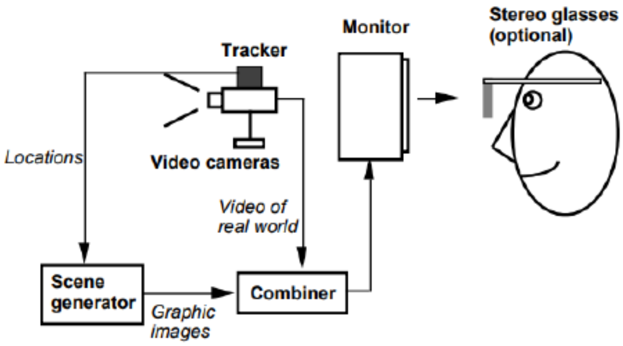

Figure 15: Handheld display device by (Azuma R. T., 1997)

c) Spatial Display

Spatial augmented reality (SAR) displays systems figures within the space in which the user finds himself. This system provides multiple display devices and allows multiple users to visualize the increase within a physical environment. This spatial display system can be: Video-see through displays use traditional monitors as screens; transparent optical displays that generate photos related to the natural environment (fine screens, planar or curved mirror beam splitters, or optical holograms are examples of SAR displays); projectors based on the concept of direct magnification of real-world objects, present digital information about the things that are magnified (Carmigniani et al., 2010).

Jin (2016) reports in her article based on the fundamentals of augmented reality that there are three types of AR displays – (1) head-based (HMD), handheld or portable (HHD), and space-based (SAR) displays that are combined and illustrated in (Figure 16). It also explains that the translucent planes inserted in the optical path, as shown below, represent transparent displays. Optical and transparent video technologies were applied in different positions. Following the same logic and shown in the figure, the placement of the projectors can be in any of the three places for spatial AR.

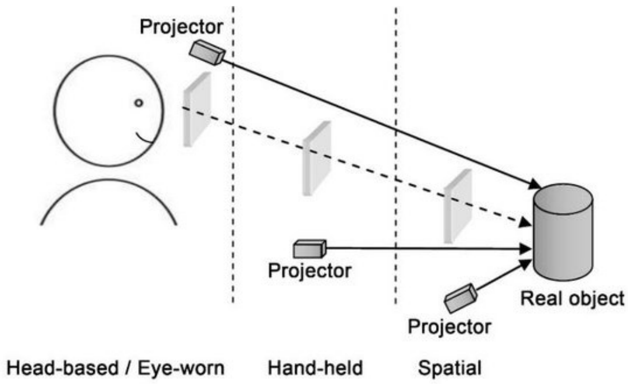

Figure 16: Conceptual illustration of video see-through display technology, by (Jin 2016)

In short, the three types of screens are different from each other. The head-mounted display and portable monitors provide an augmented reality display for each user separately. The spatial screen offers a collective view, with multiple users at the same time. However, they all have different qualities of augmented reality resolution, which can be seen in the table below (Table 1) based on the table by Carmigniani et al. (2010).

Types of displays techniques	HMD		HANDHELD			SPATIAL		
	Video-see-through	Optical-see-through	Video-see-through			Video-see-through	Optical-see-through	Direct Augmentation
			Types of displays	HMD	Hand-held			
ADVANTAGES	▪ Complete visualization control ▪ Possible synchronizati-on of the virtual and real environment	▪ Employs a half-silver mirror technology ▪ More natural perception of the real environment	▪ Potable wide-spread ▪ Powerful CPU ▪ Camera ▪ Accelerome -ter ▪ GPS ▪ Solid state compass	▪ Portable ▪ Powerful CPU ▪ Camera ▪ Accelero-meter ▪ GPS ▪ Solid state compass	▪ More powerful	▪ Cost efficient ▪ Can be adopted using off-the-shelf hardware components and standard PC equipment	▪ More natural perception of the real environ-ment	▪ Displays directly onto physical objects' surfaces
DISADVANTAGES	▪ Requires user to wear cameras on his/her head ▪ Requires processing of cameras video stream ▪ Unnatural perception of the real environment	▪ Time lag ▪ Jittering of the virtual image	▪ Small display	▪ Becoming less wide-spread ▪ Small display	▪ More expensive and heavy	▪ Do not support mobile system	▪ Do not support mobile system	▪ Not user dependent: Everybody sees the same thing (in some cases this disadvantage can also be considered to be an advantage)

Table 1: Comparing technologies of different types of displays, based on the table by (Carmigniani et al., 2010)

2.2.4 AEC Industry evolution of AR

According to the article by Machado & Vilela (2020) on the evolution of AR technology, the authors comment on the innovations that have emerged over the years, such as the use of overlaid photographic images of the environment with information on the content of construction site, helping to monitor the work (cited in Golparvar-Fard et al., 2009b); the application of GPS for automatic data capture on construction sites (mentioned in Behzadan, Timm and Kamat, 2008 and Hakkarainen, Woodward and Rainio, 2010); the production of a platform with the purpose of integrating BIM 4D and AR (cited in Golparvar-Fard, Peña-Mora and Savarese, 2011b); application of integrated data technology with GPS called iHelmet for use on construction sites with real-time transmission (cited in Yeh, Tsai and Kang, 2012); application development with integrated AR and BIM, based on modeling 3D building objects inserted in an online augmented reality environment (cited in Jiao, Zhang, Li, Wang and Yang, 2013); studies on the application of AR as an auxiliary tool in MEP installations in construction (cited in Irizarry et al., 2014); proposal for an AR-based 4D CAD system for transmitting real-time information through images extracted from web cameras installed on a construction site, providing practical simulation in 4D and 5D (cited in HS Kim, SK Kim, Bormann and Kang, 2017) ; application of virtual reality and augmented reality technologies to investigate the state of the art of the building, considering the safety of processes in the construction industry (cited in Li, Yi, Chi, Wang and Chan, 2018).

The significant expansion and increasing complexity and sophistication of construction projects and the rapid technological advances of Industry 4.0 reinforce the need for improvement in the construction industry. AR is described as a tool for aggregating information and a platform for publishing data that allows the user to view displayed information, interact with posted content, and collaborate with others in real-time from remote locations. The use of AR can help to avoid errors in the activities of the construction site, such as affecting the quality of projects, causing delays, increasing costs, and leading to disputes between the employer and the contractor, as reported by (Kivrak, Arslan, Akgun, & Arslan, 2013).

According to research by Nassereddine, Hanna, & Veeramani (2020) that describes insights into the future potential of adopting AR in the construction industry, architects, engineers, and design engineers have increasingly gained interest in using AR. There is a high expectation of AEC professionals for the more frequent use of this technology during the design, pre-construction planning, construction, and maintenance planning phases.

Recently, research carried out by Schranz, Urban, & Gerger (2021) reports on the integrated use of Construction 4.0 technologies and their potential to be harnessed by government agencies in Vienna (Austria) as construction authorities, both for the optimization between different departments and partners in the construction licensing process, such as the integration of BIM. Researchers report the possible use of AR during the licensing application process and the construction period, which should serve as an inspection of the construction of the building to verify that it is following the project submitted in the licensing application as well as in compliance with the building regulations for the construction site.

There is an ongoing research project in the same city, "BRISE-Vienna" (UIA, 2019), funded by the EU (Urban Innovative Actions) on the development of an open BIM process. This research refers to using IFC files to create semi-automatic verification through 4.0 construction technologies and Artificial Intelligence to create digital models for legal matters.

Another usefulness of combining BIM with Augmented Reality (AR) is for visualization of Building Energy Systems. According to Dudhee & Vukovic (2021), although BIM models present information on energy systems, this BIM/AR integration has a gap to be filled and explored so that it is possible to observe and investigate the performance and behavior of the building's energy system. To better understand the current limitations of using BIM/AR in a possible visualization of digital information from energy systems, the researchers Dudhee & Vukovic (2021) created a BIM model to be visualized in AR according to the method shown in Figure 17.

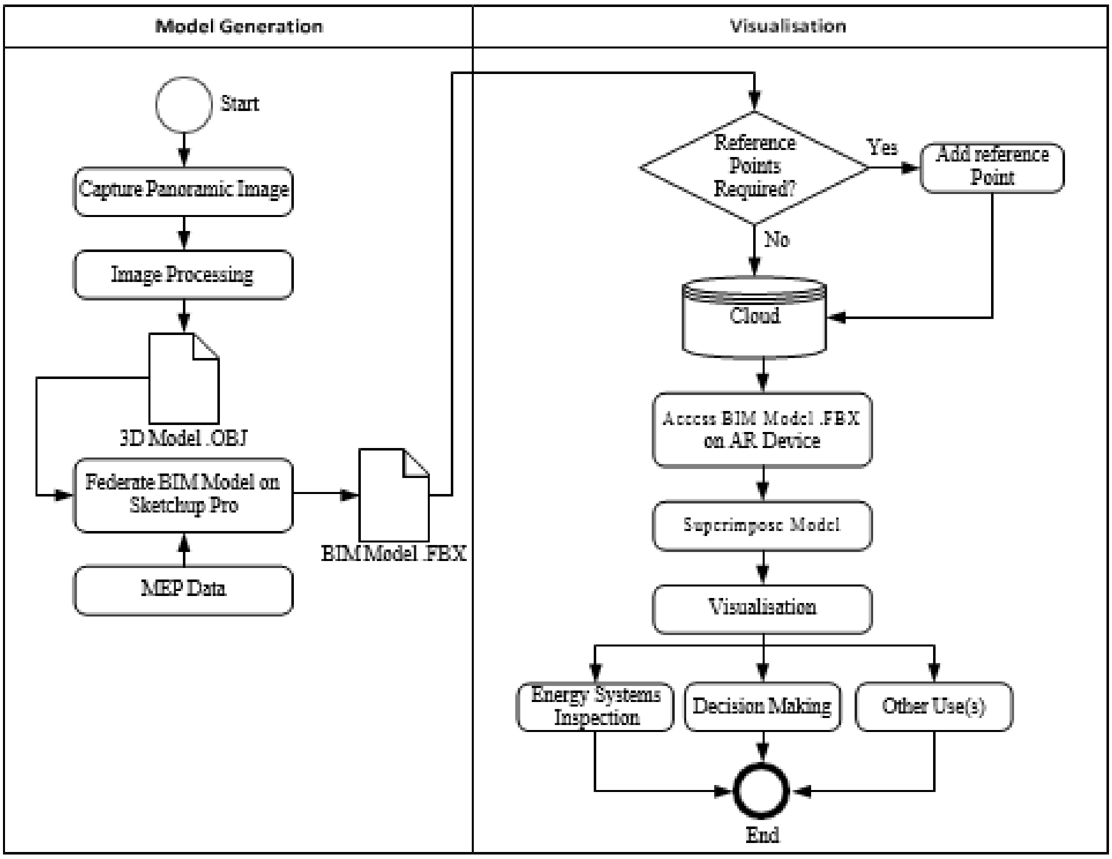

Figure 17: BIM modeling and visualization in AR schematic flowchart (Dudhee & Vukovic, 2021)

The experimental 3D BIM model is an oval-shaped room with mechanical, electrical, and hydraulic (MEP) data created using a 3D camera (Matterport Pro 2) integrating the Matterport SketchUp Pro application were added the data. MEP information, the 3D model in OBJ format, and scaled 1:1, thus avoiding dimensioning problems.

Red was used to represent electrical lighting components; gray color represents HVAC systems and green piping systems. The textual information of technical details is next to the related elements (Figure 18a).

The model was superimposed - by trial and error - on the physical building through the 3D Viewer Beta software and visualized in Augmented Reality by Microsoft HoloLens 1 – Developers Edition. The room pictured in AR at two different moments, the first with the MEP systems added to the model and the second without the apparent MEP systems, and, in both cases, the AR interactions with the models were successful. However, the researchers point out a clear difference in quality between the OBJ formats in the 3D model and the FBX format in the augmented reality model. However, the AR model had the natural geometry of the components of the represented systems (Figure 18b).

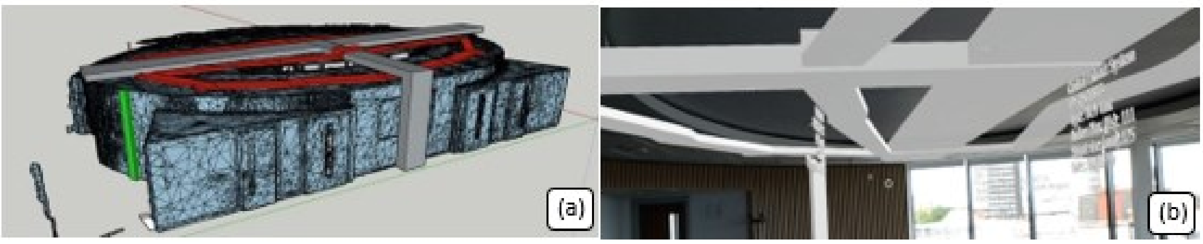

Figure 18: (a) Room mesh model with MEP components; (b) Model visualization in AR environment (Dudhee & Vukovic, 2021)

The result can vary depending on various factors such as software to create the model, equipment, and software to visualize in AR and the limited amount of information. Dudhee & Vukovic (2021) reinforce the need for the model to be superimposed on the physical building in horizontal and vertical alignment, using reference points and positioned on a flat horizontal surface so that the scale can facilitate the process overlapping. The user must remain static during image capture so that the result is not inaccurate in misinterpretation building information. The type of data restricted to the geometric design and predefined information of the energy systems, which can visualize in AR, is considered an additional limitation.

Another critical use of AR applications combined with BIM, with the overlay of digital information on the real world) Heritage Building Information Modeling (HBIM) is related to historic buildings, where data is captured digitally with images and laser scans. The complexity of various historical buildings, such as irregular geometry, heterogeneous materials, variable morphology, damage, and complications arising from a long chronology, makes creating a 3D model with details and information accuracy using HBIM challenging (Barazzetti & Banfi, 2017).

To illustrate the application of AR in HBIM, the researchers Barazzetti & Banfi (2017) used Castel Masegra in Sondrio (Lombardia, Italy) as a case study using Autodesk Revit software. Create a detailed HBIM model and precise, in .dwf format with 500 MB to preserve the object's information, which was generated through laser scanning and photogrammetry, creating a point cloud composed of 7.5 billion points. However, to make it possible to insert the model in mobile applications, the model is simplified for viewing by professional users and those interested in digital tourism. However, it is noteworthy that the file saved in .dwf format contains information stored as a level, type, and category that exports at the template creation to the version for mobile apps on smartphones and tablets.

A new option to understand, interpret and preserve the cultural heritage and model the historic building may be through mobile apps for visualization in AR, combining geometry and digital information. Augmented reality can be used for interactive activities between users such as tourists or experts in the sector and built heritage. The model of Castelo Masegra (Figure 19) created by the researchers Barazzetti & Banfi (2017) can be an example of an informative product for tourists. It used the AR-media application that consisting of several plug-ins for 3D modeling, as Autodesk 3ds Max, Sketch-Up, Cinema 4D, Vectorworks, Nemetschek Scia Engineer, and Autodesk Maya and, for the final visualization, the AR-media Player was used, which can be accessed by Windows or OS X (desktop) or by monitors as a Head-Mounted Display (HMD).

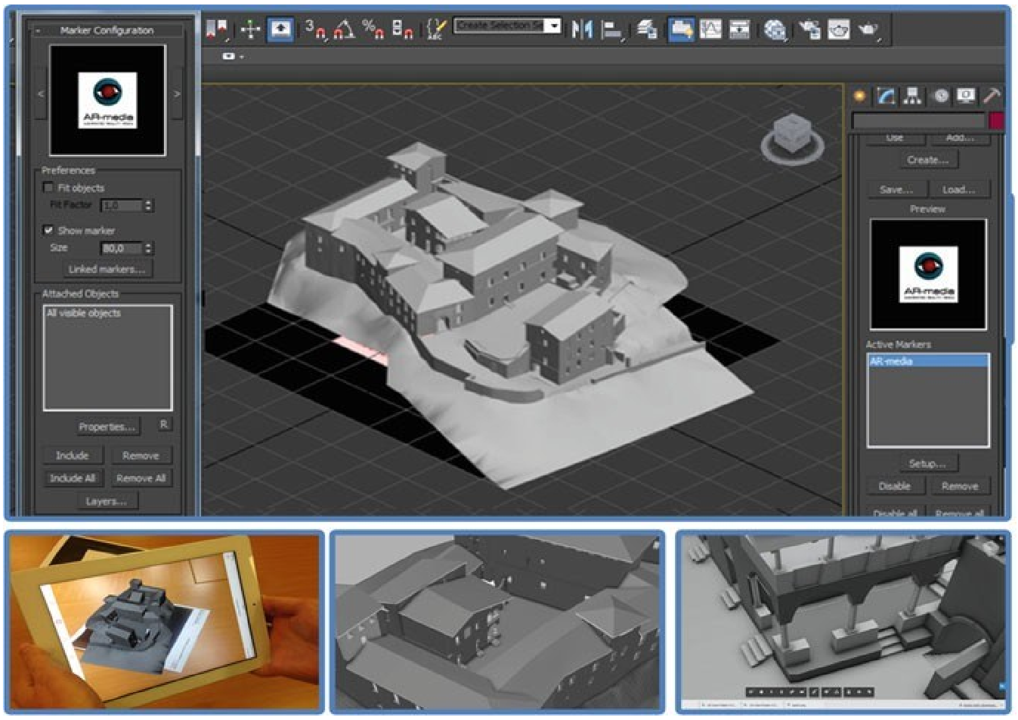

Figure 19: Model of Castle coupled with AR. The 3D model in AR-media was generated from the HBIM in Revit (Barazzetti & Banfi, 2017)

Barazzetti & Banfi (2017) report that from the original BIM model in Revit, the .dwf format was transformed into .fbx format to be imported by Autodesk 3ds Max software, which caused the loss of information about object properties. However, after such import, the model can be linked with specific markers and saved in .armedia format providing. As a result, a model of limited size and capable of being used in mobile applications. The final object can be displayed automatically at the time of capture of the marker by the camera.

2.3 Other technologies in AEC Industry

In addition to using Augmented Reality as an additional tool in the current models of project processes within the BIM platform, other technologies can also be instruments that facilitate different phases of the project life cycle. Virtual Reality (VR), Mixed Reality (MR), Extended Reality (XR), and Digital Twin (DT) are some examples, and so that there is no doubt the concepts and uses of such technologies will be below for reference only.

2.3.1 Virtual Reality (VR)

Virtual Reality (VR) is a computational technology capable of creating realistic images, sounds, and other sensations represented in a virtual environment and that simulates the user's presence in that environment (Alizadehsalehi, Hadavi, & Huang, 2020) (Wolfartsberger, 2018). The purpose is to allow the user to experience and manipulate the background as if they were inside the real world (Wolfartsberger, 2018), with its reproduction through devices such as HMDs, glasses, and configured monitors (Delgado, Oyedele, Demian, & Beach, 2020).

The fundamentals of current virtual reality (VR) technologies are ideas developed and described in experiments from the 1960s onwards, such as the iconic Ivan Sutherland, who in 1968 created the first head-mounted display (HMD) and who rendered wireframe models simple as the viewer positioning changes (Wolfartsberger, 2018). And through the foundations of this invention and with the new computational technologies and other evolutions of various devices and software with different targets that today exist Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR), Extended Reality (XR), and Digital Twins (DT).

The legal term VR was used in 1989 in Milgram's taxonomy through the “continuum” diagram (Figure 20) in which VR represents the conception of a virtual environment in which the user can enter this scenario with the feeling of being in the “real world,” with a limited level of “naturalism” such as visual and sound effects.

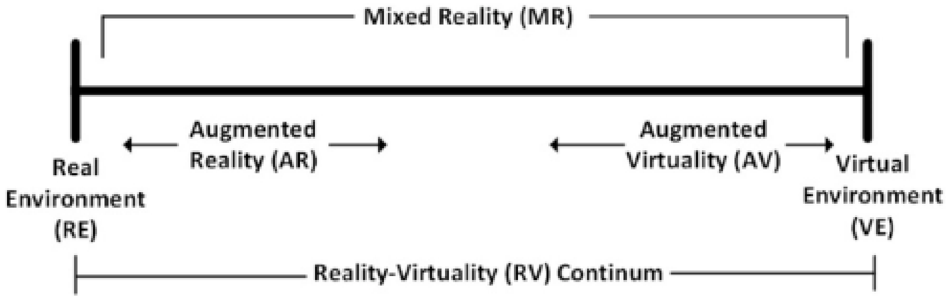

Figure 20: Reality-Virtuality continuum (Milgram and Colquhoun 1999), Definition of Mixed Reality, within the Context of the RV Continuum (Milgram & Colquhoun, 1999)

In the AEC industry and according to the evidence, VR technologies are effective in building safety training (Li, Yi, Chi, Wang, & Chan, 2018) in positive practices such as project schedule control (Fu & Liu, 2018), optimization of construction sites (Muhammad, Yitmen, Alizadehsalehi, & Celik, 2020). In addition to being able to favor a collaborative environment among all stakeholders, improving the understanding of complex projects, identifying design issues, and assisting in collective decision making (Figure 21).

Figure 21: Virtual Reality (Li, Yi, Chi, Wang, & Chan, 2018)

2.3.2 Mixed Reality (MR)

Mixed Reality (MR) is a "reality spectrum" that combines the best aspects of VR and AR (Alizadehsalehi, Hadavi, & Huang, 2020). and is interpreted through two different perspectives, one between "factual reality," which is seen by a user without computer-intervention, and the other “virtual reality,” where the computer creates an environment in which the user has no interaction with the physical world. The critical concept for Mixed Reality is “ flexibility,” as per Alizadehsalehi, Hadavi, & Huang (2020), as shown below (Figure 22).

Virtual Reality was formally used in 1989 in the VR continuum based on Milgram's taxonomy as a reference for Mixed Reality, which is the mixture between the natural world and the virtual world. VR refers to a virtual reality where the user can enter the scene with the perception of being in the limited real world, without sound and visual effects as shown in (Figure 22), with elucidating images based on Milgram's VR Continuum (Figure 20).

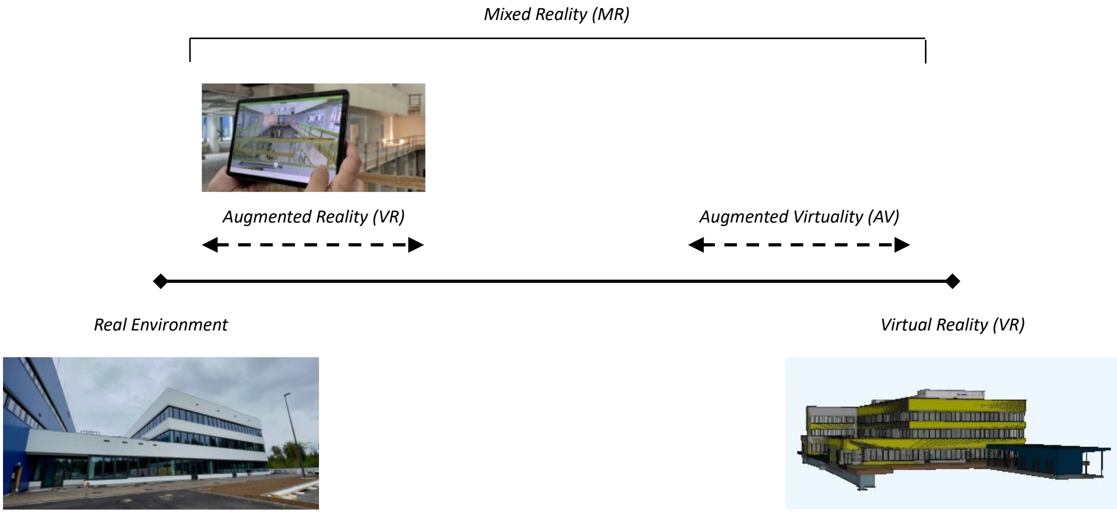

Figure 22: Reality-Virtuality continuum (based by Definition of Mixed Reality, within the Context of the RV Continuum Migram's VR Continuum) (Silva, Gaber, & Dolenc, 2021)

Woodward et al. (2010) describe how AR4BC (Augmented Reality for Building and Construction) software can perform mixed reality mobile interaction with 4D BIM models. With the combination of schedule information, geographic coordinates, accurate augmented reality with tracking, photorealistic rendering application representing real-world scenery and tools for interaction between a mobile user and remote computer.

2.3.3 Extended Reality (XR)

Extended Reality (XR) is considered a conglomerate of immersive technologies, including virtual reality (VR), augmented reality (AR), and mixed reality (MR), where the spectrum of experiences has boundaries between the real world and virtual environments. These technologies have diverse applications in the creative entertainment industry, such as games and videos, and have enormous potential to improve AEC's efficiency and productivity.

Through the BIM to Extended Reality (XR) workflow, it is possible to visualize the project proposal interacting with the human scale through an immersive experience. Users interact with the 3D model with the design overlay or read non-geometric data add-ons by scanning the QR code for facility management. In this mix of technology, one can resort to voice command and gesture recognition, allowing for more significant human-machine interaction. Alizadehsalehi, Hadavi, & Huang (2020) positively report integrating holographic technology such as Microsoft HoloLens with BIM in the project lifecycle phases. Devices used in extended Reality (XR) become very useful for complex models of existing buildings, such as HBIM that will extract information for the AEC industry, cultural heritage documentation, preservation, and tourism.

According to Alizadehsalehi, Hadavi, & Huang (2020), there are several data-sharing systems between BIM/XR, the most popular being those based on clouds, such as Autodesk BIM360 and Autodesk Viewer (cited in Banfi et al., 2019), as a combination of data according to categories, entered into a BIM model, such as scheduling, spreadsheets, text, etc. and different formats such as rvt, nwc, txt, dwg, etc.

In this same research, the authors Alizadehsalehi, Hadavi, & Huang (2020) cite as an example of XR-integrated software, Bentley Synchro, which has a plugin for Revit where it offers the user the option to review the construction steps through Microsoft HoloLens in the area of the location of Work.

2.3.4 Digital Twins

The beginning of digital twin development (DT) is recent, and its origin is related to the Product Life Cycle management model created by Michael W. Grieves in 2002. However, the applications used for digital twin on mobile devices have recently emerged with the evolution of the Internet of Things (IoT), wherein both technologies, a physical artifact, and its digital counterpart are connected, as reported by Jiang, Ma, Broyd, & Chen (2021).

With the expansion of applications in the AEC industry, there are some diverging ideas confusion among technology scholars regarding the concepts related to a digital twin, especially when it comes to Building Information Modeling (BIM) and Cyber-Physical Systems (CPS). It is because the components that structure a DT for civil engineering are not defined.

Some researchers declare in their articles that they are creators of a digital twin for an Organization & Maintenance (7D) phase of the project life cycle. Jiang, Ma, Broyd, & Chen (2021) established a new grouping of data and information for the creation of DT, assigning them as DT phases design and construction, as shown in (Figure 23).

Jiang, Ma, Broyd, & Chen (2021) review several scientific articles related to digital twin apply in the construction sector and others related to the definition of DT, BIM, and CPS. and their differences between them based on state of art about the physical part, in the model virtual, in the interconnections between the material and the virtual and in the combination of twins between the physical aspect and the virtual model, and concluded that in the AEC industry the three technologies have similarities and distinctions.

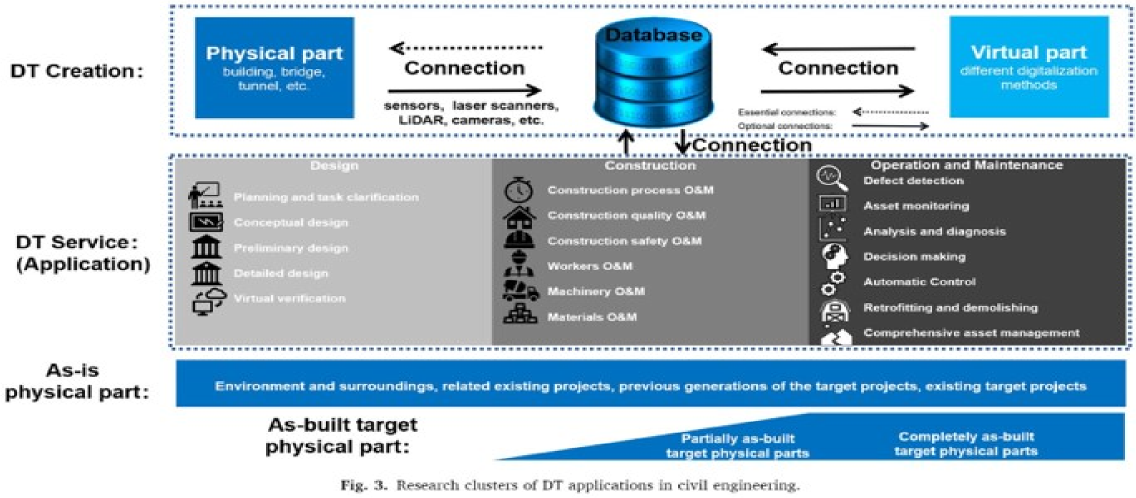

Figure 23: Research clusters of DT applications in civil engineering (Jiang, Ma, Broyd, & Chen, 2021)

Several researchers and experiences reported that DT could be useful in buildings, infrastructure, MEP, cultural heritage, and construction sites. For the generation of the virtual model, the current market offers numerous specific software for modeling, simulation, calculations, analytics, and algorithms used in digital twinning. Digital twin serves as a bridge between the physical part data and the virtual model data, obtaining different types of data such as point clouds, images, sensor data such as laser scans, digital image processing, geometric and non-geometric shapes.

As it is a relatively new technology in the civil engineering industry, Jiang, Ma, Broyd, & Chen (2021) suggest the development of algorithms and tools for DT; digital twins as a supplier of digital replica designs to assist the design process; digital twins as an additional tool in the development of intelligent constructions. In addition to detecting defects, monitoring data and information, and playing the connector between the physical and virtual parts. In short, a powerful instrument for the AEC industry.

2.4 Augmented Reality and AEC

2.4.1 BIM and AR: how it works

The definitions of augmented reality (AR) by several scholars always converge to the same focus. It is an overlay of computer-generated content in the real world that superficially interacts with the environment in real-time, as Li, Yi, Chi, Wang, & Chan (2018) reported. And, according to Meža, Turk, & Dolenc (2014), AR brings the virtual world of the computer to the user and relates it mainly geometrically and visually to the real world (Figure 24). In her article, Grazina (2013) describes augmented reality as a technology that superimposes computer-generated information and graphics on real-world images.

The integration between BIM and augmented reality (AR) can function as a reliable tool for coordination and communication. The visualization of the construction, associated with the projected model, can serve as a support tool to improve the identification, processing, and transmission of discrepancies in progress at the construction site, as Machado & Vilela (2020) argued.

Figure 24: Augmented reality (by author)

Nowadays, specific traditional software without interoperability tools to represent technical drawings is becoming obsolete, especially in large and usually highly complex projects. With the help of software capable of sharing information through the BIM platform, it becomes essential for managing a project during its development, construction, operation, and maintenance.

BIM is not a software, but it is a platform for combining different information (Saar, Klufallah, Kuppusamy, Yusof, & Shien, 2019). The geometric and non-geometric data are seen in real-time through the BIM model and AR integration, as Schranz, Urban, & Gerger (2021) comment in their article. Augmented reality is a tool that facilitates interoperability at all stages of a project, including the detection of conflicts between the disciplines involved. The BIM Platform covers from 3D to 4D (scheduling), 5D (costing), 6D (lifecycle information), and 7D (facilities management) as described by (Saar, Klufallah, Kuppusamy, Yusof, & Shien, 2019).

The economic advantages of integrating solutions between BIM and Mobile Augmented Reality (MAR) are in the facility management environment, where managers intuitively connect on the mobile device to efficiently access the geometric information and not geometric they need (Gheisari, Goodman, Schmidt, Williams, & Irizarry, 2014).

BIM is a kind of “central hub” of accessible data for new buildings of any type and size, in addition to existing projects and can integrate with data from various capture technologies such as Laser Scan, Global Positioning System (GPS), Response Fast (QR) coding among others to create different data/comprehensive information about a project (Alizadehsalehi, Hadavi, & Huang, 2020).

In AR applications for AEC, a transparent video approach is crucial to align with reality properly. According to Azuma R. T. (1997), one of the primary problems that usually limit AR applications is recording information. Williams et al. (2015) complement the argument by exposing that such issues can cause a misalignment of the enlarged images and, consequently, produce a complex workflow and data, bringing inefficiency to the product.

The researchers, Williams et al. (2015), to organize the stages of elaboration of the BIM data for the final visualization in AR, describe the BIM2MAR Workflow in three steps. First, new geospatial properties must be generated to visualize each object in MAR, which identifies the user's current position and produces information related to the thing. The second stage refers to the points represented within the BIM from placing the facts according to the user's physical location, allowing the user to perform MAR tasks with the BIM data. And, in the third step, for the tasks to be doable, the geometric and non-geometric data packages need to be distinctly separated into two exchange formats. For better clarification, the illustrating scheme is below. (Figure 25).

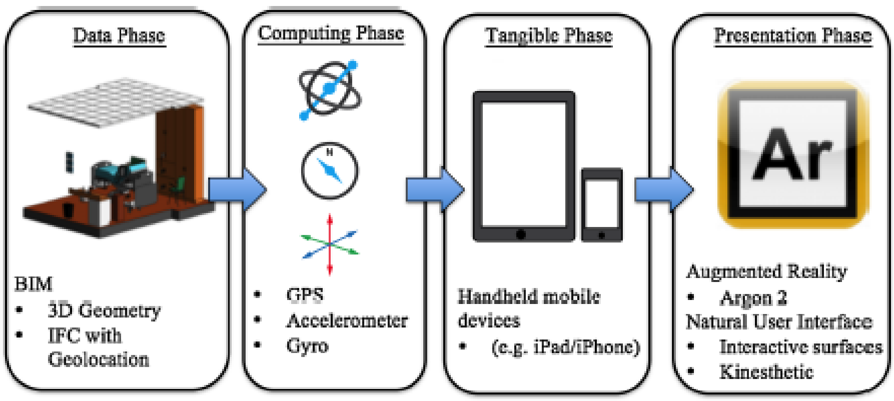

Figure 25: Workflow BIM2MAR architecture (Williams et al., 2015)

The geometric and non-geometric information (Wang, Wang, Shou, & Xu, 2014) created in the 3D BIM model is processed and translated through specific software to be transformed and visualized in AR.

In the research by Wang, Wang, Shou, & Xu (2014), the connection approach between BIM and AR (Figure 26) consists of three main elements: BIM model that supports the geometric and non-geometric information of the building and sends and receives BIM information to Data Transformation; Data Transformation is the element that immediately processes the information received to facilitate the intercommunication between BIM and AR; and the AR platform that is connected to Data Transformation and enables interaction between users with the BIM model in real-time for visualization and evaluation.

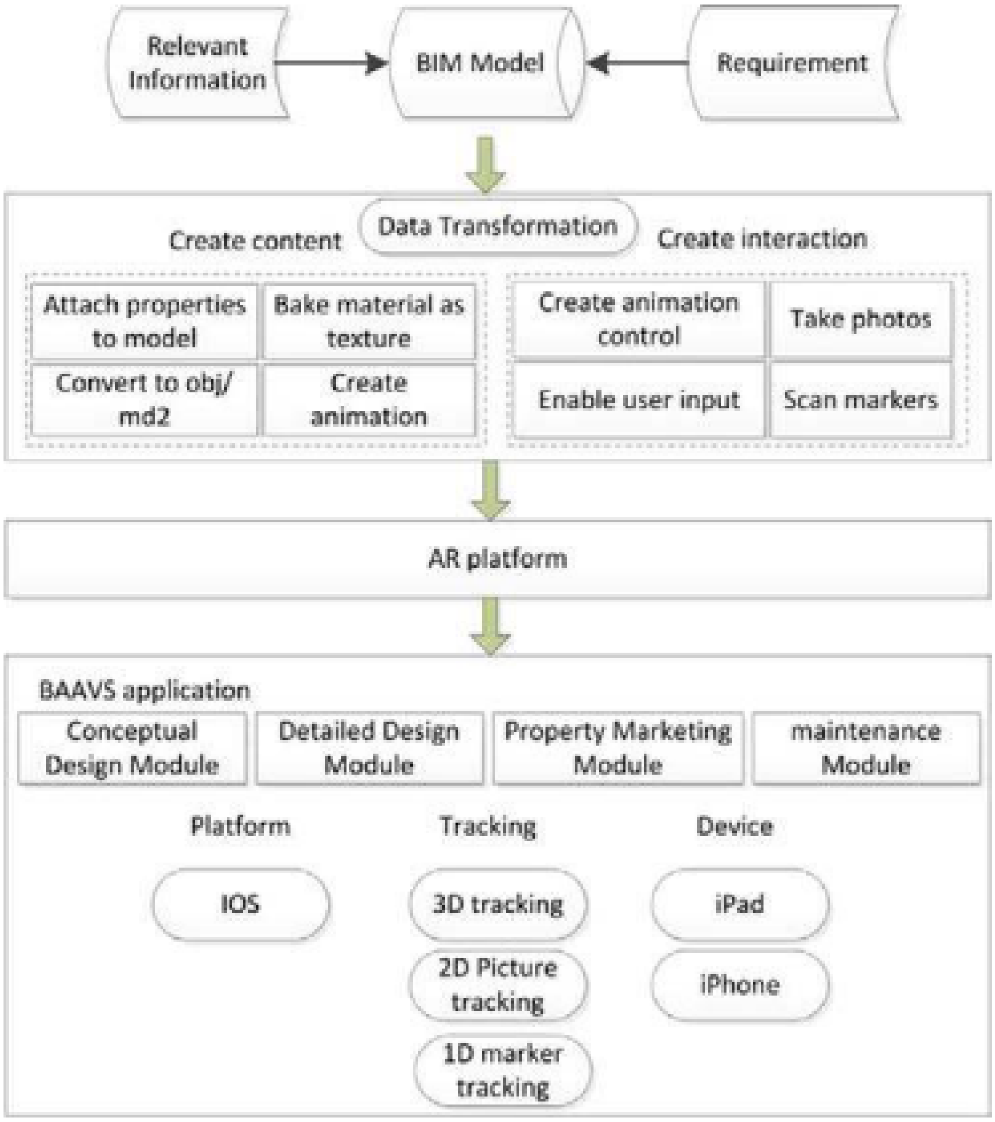

Figure 26: Approach to linking BIM with AR (Wang, Wang, Shou, & Xu, 2014)

In the article (Shin & Dunston, 2008), the authors repo that the use of AR in AEC also requires the validation of harmonization and the demonstration of feasibility. There are two fundamental issues to be discussed before AEC makes AR technology effective for decision-making. The first question is related to the limitations of technologies that support AR, such as the lack of precision in tracking the orientation and viewing position of the user, which are fundamental points for accurate registration of virtual objects in a world scenario real. The second issue is identifying specific areas in the construction project so that AR can be appropriately applied, giving examples for potential AR use, information for architectural maintenance, some field tasks in infrastructure, project details.

Following the choice of specific areas, the researchers' Shin & Dunston (2008) highlight the principles of the human factor as fundamental motivational points for choosing objective criteria for the requirements of visual information in specific work tasks, enabling the benefits of resources of AR. The main features described by Shin & Dunston (2008) are:

- AR makes it possible to follow the user's point of view through a tracking system.
- AR makes it possible to superimpose virtual objects on the real-world scene through the user's vision.
- AR makes it possible to render the image of virtual objects interconnected with the real-world scene and in real-time.
- AR makes it possible to locate virtual objects in a real-world setting within correct parameters such as location and orientation.

With the classification and description of the 17 work tasks by Shin & Dunston (2008), eight of them (layout, excavation, positioning, inspection, coordination, supervision, comments, and strategy) benefit from the use of AR. For the nine other tasks (penetration, transport, cutting, placing, connecting, spreading, finishing, spraying, and covering), the use of AR is unnecessary.

The life cycle of a construction project within the BIM concept has its structure as conceptual, design and planning, pre-construction (3D), construction, planning, and scheduling (4D), prefabrication, costing, construction, coordination of subcontractors and suppliers (5D), continuous information system integration (6D), operation and maintenance, facility management (7D), (Bademosi & Issa, 2019) (Azhar, 2011). There is a connection between BIM and AR phases and their benefits for each step of the design process.

In the 3D phase of the BIM lifecycle, communication between Project owners, essential stakeholders, and the project team has as its primary key the 3D BIM model for exchanging design ideas, detecting and solving conflicts between project disciplines. The combination of data from the BIM platform, such as the 3D model and GPS data system of the location and positioning of the terrain, at this stage, and using resources such as head-mounted displays (HMD) and mobile devices, brings the concept of three-dimensional visualization of the components inserted in the project and their respective locations on the ground. Such visualization can be through a walkthrough of virtual buildings or with augmented mobile reality (MAR), where the scale of the 3D model can be transmitted in the proposed final location and with the interaction between stakeholders and project owners (Bademosi & Issa, 2019). This type of information can support decisions and save costs in manufacturing component materials in construction.

In the next phase, AR and Construction (4D) can offer great utility within the coordination of works interacting with the support of the project team. With construction sites increasingly dynamic (Bademosi & Issa, 2019), the technology provides information to users anywhere, allowing mobile devices, including AR applications. Augmented reality offers a visual aid to oversee the construction process and inspect the final product in this construction phase. It facilitates construction discussion through a multiscreen environment, producing construction simulations, conflict detection, reading, and interpreting specifications of prefabricated materials and components through visual representation of current project conditions. Other critical AR applications during this phase include geo-location of BIM data at the construction site, verification of tasks in the construction process, reading and writing of field reports in real-time, retrieval and elaboration of information using augmented reality (Yeh, Tsai, & Kang, 2012), construction safety (Li, Yi, Chi, Wang, & Chan, 2018), site documentation monitoring (Zollmann, Hoppe, Kluckner, Bischof, & Reitmayr, 2014).

During the Operation and Maintenance phase, AR (7D) can locate and repair elements in the building for proper maintenance. Maintenance professionals need to know and understand a significant amount of information to find the maintenance point as soon as possible. It is precisely for this need that AR brings benefits that, through BIM, carries all the information from component manufacturers, constructive systems, details of installations, among others available for maintenance purposes.

The use of AR during the Lifecycle of Construction Projects is a current issue and reality in the AEC industry and academia, as the continuous and growing advancement of Information and Communication Technologies (ICT) and their applications in the construction industry. There are three central systems to superimpose the virtual on the real in augmented reality happens as desired Bademosi & Issa (2019). They are:

- Use of GPS and integrated compass to determine the accurate position of the user, aligning the virtual objects according to the project and its 3D BIM model, making it possible to verify them in the applications through smartphones and portable devices.
- The markers act as a fixed point of reference for a given position or scale of the virtual object you want to see in augmented reality through reliable tracking methods.
- A markerless system that needs the physical characteristics of the natural environment to track objects in the absence of reliable markers acting as a fixed point.

And, for augmented reality applications and their functions to run correctly, hardware components such as Bademosi & Issa (2019) are needed:

- Processing devices (computers).
- Displays of various models such as head-mounted displays (HMD), hand-held displays (HHD) such as tablets and smartphones, and spatial displays (SD) are instruments to project virtual information onto the natural objects to be augmented.
- Tracking and calibration systems built into augmented reality apps.

Augmented Reality can contribute to resolving the gaps between planning and execution and the interaction between project actors, becoming a vital ally for the development of the construction industry (Machado & Vilela, 2020).

2.4.1.1 Vantages and disadvantages of using AR/BIM in AEC

Augmented reality (AR) is a resource for helpful visualization combining data from the actual scene and the data generated on the computer. And, in addition, it uses a relationship of focus and context between real and virtual objects where it provides essential information of virtual content for the actual object, facilitating the user's guide on a virtual object inserted in a natural context (Kalkofen, Mendez, & Schmalstieg, 2009).

The benefits of implementing AR technology combined with the BIM platform improve the construction industry, both qualitative and quantitative, giving successful results such as completing the work within the estimated time and reducing estimated costs (Bademosi & Issa, 2019). These benefits over the lifecycle of construction projects are measured by categorizing the potential benefits of AR into quantitative units, such as scheduling and cost savings. (Oesterreich & Teuteberg, 2017).

The challenges of implementing AR technology in the construction industry are considered disadvantages, such as difficulties in portability and suitability for external use, inefficiency in tracking and automatic calibration in an environment devoid of technologies such as the internet, lack of perception accurate depth information overload. In addition to these challenges listed in the construction sites, there are other difficulties concerning personal resources, such as a low rate of professionals trained to use the tools applied to AR integrated with BIM.

The advantages and disadvantages of the AR implementation found during this research are listed in the table below, partially based on the data shown by Bademosi & Issa (2019), in a summarized form for better understanding (Table 2).

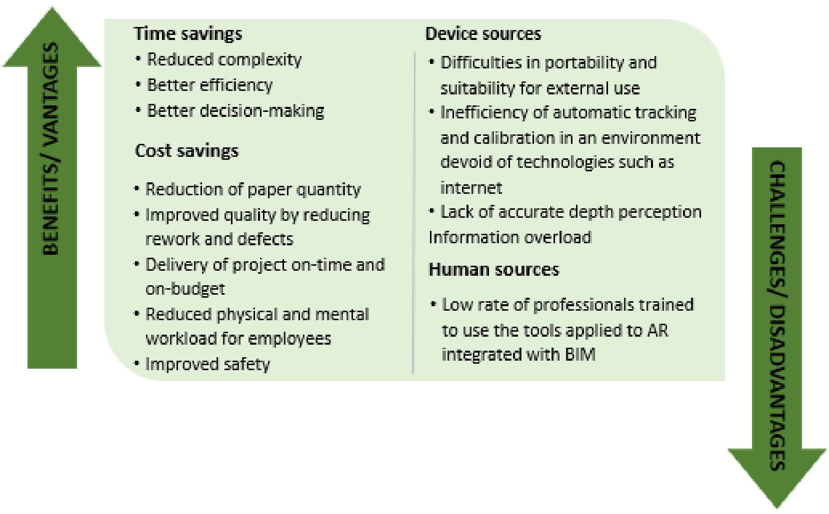

Table 2: Benefits/Vantages and Challenges/Disadvantages of AR implementation during the lifecycle of construction projects (by author)

One of the benefits of augmented reality is that the user gets cyber information at the construction site during the construction phase (3D to 6D) and in the maintenance phase (7D). One of the main points is the Global Positioning Systems (GPS), Wired Local Area Networks (WLAN), or Internal GPS (Bae, Golparvar-Fard, & White, 2013), where the user's positioning with the AR software must be accurate to achieve a precise and reliable result.

And, according to Bae, Golparvar-Fard, & White (2013), the main disadvantage for the use of this location tracking technology, based on radio frequency (RF), is the infrastructure to be installed on construction sites or in nearby locations for that the use of such technology is viable. Depending on the location of the work, such application becomes difficult.

Through several research and experiments, it is in joint agreement among researchers to use the set of generated and superimposed images to extract precise 3D geometry from stationary objects, such as buildings under construction (Bae, Golparvar-Fard, & White, 2013).

2.4.2 BIM and AR: Software

The current augmented reality market at AEC Industria offers various software with different interaction possibilities with the BIM platform. An example is Dalux software, which will be detailed in the **2.4.2.1 subitem** as it is the device used by the company responsible for the works of the three objects of the case studies of this dissertation.

The essence of BIM is the ability to add valuable information, quotes Renzi (2018), and adhere to a 3D model. Practice the entire process cycle impacts BIM on basic functionalities such as estimating, programming, logistics, and security. This technology has progressively attracted professionals in architecture, engineering, construction, and facilities management (AEC / FM) worldwide due to throwing evidence that BIM increases efficiency and productivity (Zaher, Greenwood, & Marzouk, 2018). One of the primary uses of BIM construction planning and management tools is conflict detection, spatial modeling and coordination, and programming. Several examples of BIM tools that are available for these purposes are in (Table 3).

BIM TOOLS FOR CONSTRUCTION MANAGEMENT			
Product name	Developer	BIM use	Developer weblink
Navisworks Manage	Autodesk	Clash detection, scheduling, coordination	www.autodesk.com
Project Wise Navigator	Bentley	Clash detection, scheduling, coordination	www.bently.com
DP Manager	Digital Project	Scheduling, model review, collaboration, quantity take-off	www.digitalproject3d.com
Visual 4D Simulation	Innovaya	Scheduling, coordination	www.innovaya.com
Vico Office	Vico Software	Scheduling, coordination, cost estimation, quantity take-off	www.vicosoftware.com
Solibri model checker	Solibri	Clash detection, coordination, quantity take-off, design review	www.solibri.com
BIMcollabZoom	Kubus	Clash detection, model review, collaboration, coordination	www.bimcollab.com
Dalux	Dalux	Clash detection, scheduling, model review, collaboration, coordination, Augmented Reality	www.dalux.com

Table 3: Examples of BIM tools for construction management, based on (Zaher, Greenwood, & Marzouk, 2018)

2.4.2.1 Dalux: how it works

Through a 3D viewer and the BIM platform, it is possible to combine 2D visualization with3D models, making work easier and saving time, creating links between objects in the model and documents in the Dalux Box, with mobile and online access, and can sync project files directly to the cloud. When a public mark made on the drawing is published and shared, its visualization becomes immediate for project participants.

Through hyperlinks, you can link PDFs of a plan, elevation, or section drawings and view the 3D model in the integrated Dalux Viewer via mobile device, compare if there have been changes, and get an overview of the updated drawings. BIM coordinators can upload to Dalux Box and Field 3D BIM models and drawings directly from Revit or Archicad using Dalux plugins. It is also possible to sync files to the Dalux cloud from the desktop and vice versa. In addition, Dalux Box and Field have an integrated 3D viewer that can combine all BIM files from different disciplines into a single 3D model and supports open BIM such as IFC files or directly import rvt files through the Revit plug-in. Drawings can be in PDF, DWG, DWFX, PNG, or JPG formats, and you can view 2D drawings and 3D models in the combined view. The purpose of Dalux Field is to work with quality control and task management. And, it utilizes the workflow of participants with project access to manage the entire project and help resolve problems in real-time. Interaction with the model in Dalux BIM viewer serves to make sections, take measurements and view BIM properties. Dalux supports BIM models in .dwg, .pdf, and other files on mobile devices (Android and IoS), in addition to providing access to up-to-date documentation. Dalux FM is a BIM-based Facility Management system. This technology allows access to all the information a works manager needs through a cell phone to improve the operation and maintenance phase. Such as the latest updates of the BIM model, 2D/3D drawings, FM documentation, photos, product details, assets, manuals, work orders, and repair requests. Dalux FM also supports QR-codes that allow more precise reporting and better track of assets history. The summarized scheme of the above technologies is illustrated below in (Figure 27).

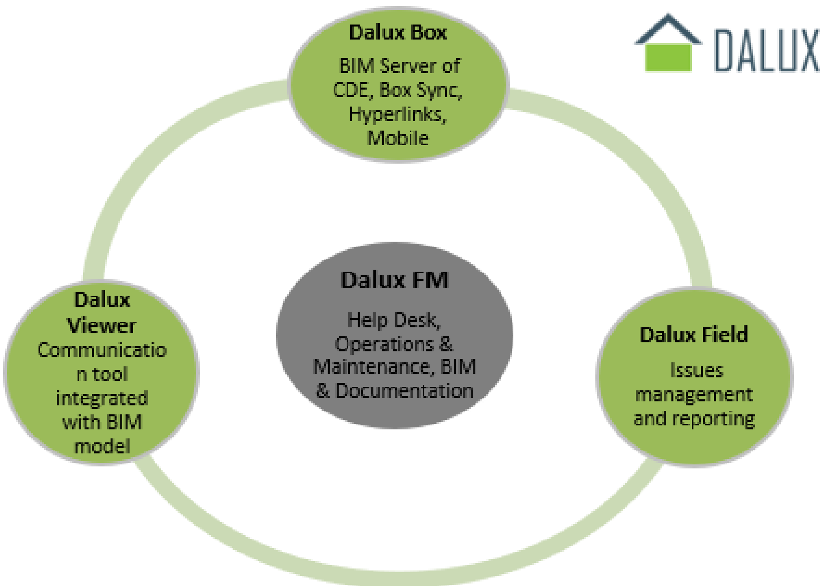

Figure 27: Diagram of the integration between Dalux technologies (by author)

2.4.3 BIM and AR: Mobile utility devices – Mobile Augmented Reality (MAR)

The user's perception in the real world and his interaction with objects is favored and enhanced by using the augmented reality system that provides information that the user does not personally identify. Visualizing these results through special devices such as glasses is possible by superimposing digital data generated by a computer over a natural world image. However, one should be aware of the use of this technology, as the inaccuracy of the alignment of the computer-generated data with the data from the real world is considered the main problem of the AR system; warn Izkara, Pérez, Basogain, & Borro (2007).

Currently, the integration between the 3D BIM model (virtual) and the construction site (accurate) through Augmented Reality (AR) allows the interoperability of the information necessary for the identification of divergences between the project and the execution. Recent studies such as mobile phones, tablets, head-mounted displays (HMD), and glasses enable a quick correction through some mobile devices.

According to Machado & Vilela (2020), the influence of using AR interconnected to the BIM platform encompasses the knowledge and acceptance of the evolution of technologies around automatic data capture in a virtual environment. This feature provides user interaction and experiences in immersive virtual environments across desktops, mobile devices, head-mounted display (HMD) devices.

Every day, technologies to use BIM and augmented reality are evolving through researchers and scholars. For example, according to the demands of the construction industry, numerous environments for AR applications demand mobility of the user's location and the need to access information in real-time. The use of mobile devices is critical to meeting these requirements.

When it comes to mobile augmented reality architecture, the most common and subtle practice in a mobile device for this technology is to have an input and output element for both visualization and interaction with the user. The entire processing and composition structure of the altered and finalized image takes place on a server (Kipper & Rampolla, 2013). However, this transfer of information transformed into an enlarged image between client and server can generate a severe processing time problem, both on the server and the mobile device, due to its hardware limitations. And, to overcome this deficiency, in some cases, it is possible to perform an actual scene magnification with each 'frame' of the captured image.

(Figure 28) broadly represents the main tasks in an augmented reality app. In the first task, image (a) illustrates the image capture. The camera captures information about the scenery of the natural world, and your visualization will be the background for the augmented image. The use of the captured scene for this task will be through the image processing technique. The next step is tracking the user's geolocation. The data processing from the previous steps occurs; the augmented reality scene is rendered, and the augmented set is previewed on the output device.

In addition to purely augmented reality tasks, other processing tasks may be required to build the corresponding augmented reality scene. Rendering the augmented reality scene is the fourth task. The last is the preview of the output device. Different client-server architectures can support this process, and the following figure shows the two extremes, any alternative in between will be valid.

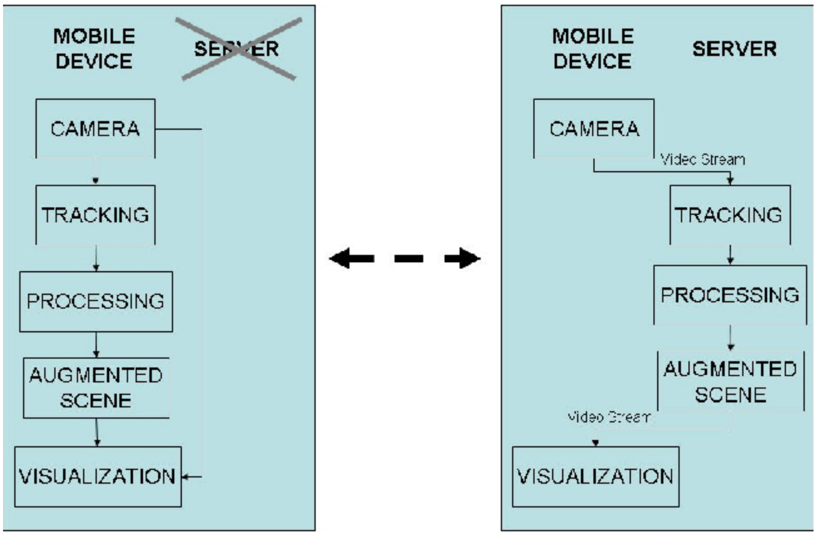

Figure 28: Client-server architecture for augmented reality (Kipper & Rampolla, 2013)

For Izkara, Pérez, Basogain, & Borro (2007) to research the state of the art of mobile augmented reality, it is essential to include an analysis of applications developed by recognized researchers in the areas of AR technology in mobile devices. And a particular dedication to the prototypes and applications they developed. Scholars to provide a better global perspective of mobile augmented reality. It also reports that the MARS (Mobile Augmented Reality System) project, which had its development between 1996 and 1999, is considered the first and most important event in the evolution of mobile AR, with a system structured as follows: a properly portable PC equipped with a graphics accelerator card with capacity for 3D visualization installed on the user's back, a GPS, a pair of glasses for visualization, a tracking system and a wireless connection for communication between the components of the PC., where data processing takes place, as shown in (Figure 29).

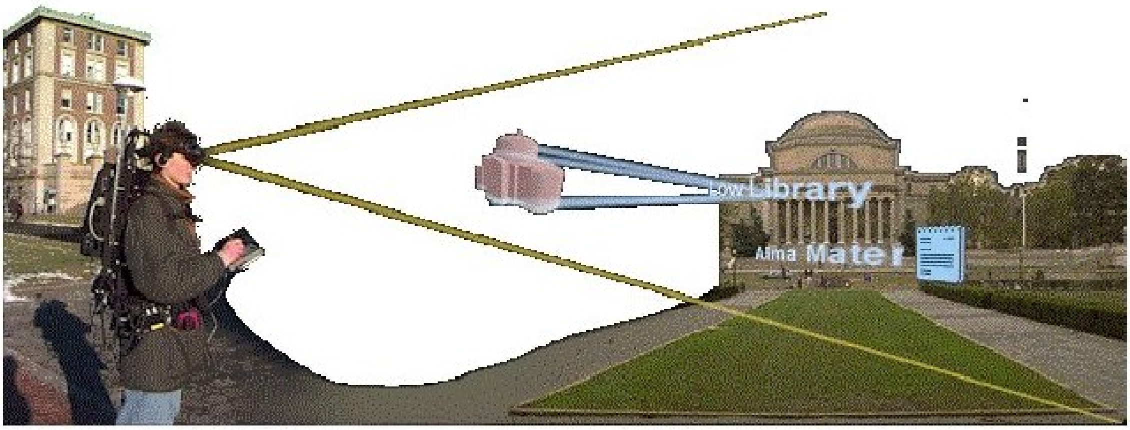

Figure 29: MARS Mobile Augmented Reality System (Izkara, Pérez, Basogain, & Borro, 2007)

When talking about the benefits provided by mobile computing and augmented reality technologies used in work safety in civil construction, Izkara, Pérez, Basogain, & Borro (2007) mention:

- Mobility and functionality. The use of mobile devices becomes helpful in transporting the technology in places inaccessible by a PC.
- Productivity increase. Ease of access to real-time information at the construction site.
- Accessible information with sharing is available according to the project phase.
- Allows access to the context of an uncontrolled environment, making better monitoring of the workplace possible.
- Ease of user-device interaction, allowing the user to focus on the work environment.

In a security scenario on construction sites, mobile computing, with mobile augmented reality included, provides better efficiency for both field workers and the safety officer (SR), whose job is to verify that prevention requirements and safety are following current workplace regulations.

To illustrate this scenario, the researchers Izkara, Pérez, Basogain, & Borro (2007) cohesively describe the procedures performed by the responsibility for security and demonstrate the technique in (Figure 30).

Information about the project's current phase is loaded into the SR using a Personal Digital Assistant (PDA) from a workplace server. The following components are essential for the visualization of information: a Radio Frequency Identification (RFID) reader; headphones to record current results and check the status of the previous inspection; a positioning system; a camera capable of detecting precise positioning and elements by image processing; a specific wristband for interaction between the user and the PDA through gesture recognition; and finally, it uses a head-mounted display (HMD) that will be useful for visual information records. The first inspection phase involves the inspection of the identity and training of workers through the RFID reader. It is also possible to verify that workers are correctly using their appropriate individual safety equipment through visual control interacted with the system through a wristband or voice command. In the second phase, the inspection refers to safety elements in the workplace and, during the SR's walk around the site, the system automatically detects safety elements to be checked. If there is doubt about the positioning of such elements, it can be assisted through HMD, requesting a map with the correct position of the component. In case of absence details, the system will automatically order these, and the inspection results will be registered electronically, either as documents or audio.

Figure 30: Safety at works in the construction sector (Izkara, Pérez, Basogain, & Borro, 2007)

The use of glasses in AR came about with the Google Glass project in 2013 in a head-mounted display (HMD) display device, allowing interaction between the user and the real world. A few years later, in 2016, Autodesk and DAQRI companies developed an HMD focused on virtual reality, enabling major transformations in production processes in the construction industry. In 2017, Microsoft launched Hololens (with an updated version in 2019 with the name de Hololens 2), an AR glasses also aimed at the construction industry, with an integrated system and robust sensors (Machado & Vilela, 2020). According to Saar, Klufallah, Kuppusamy, Yusof, & Shien (2019), Table-top AR-BIM is the simplest way to integrate the two technologies. It uses motion-tracking technology to capture the BIM model that changes as the user moves around the visual reference plane, providing a better model view. Another frequent device on the market is the SmartReality mobile app. It provides the user with the possibility of superimposing a 3D BIM model on top of construction plans, using any mobile device such as tablets and smartphones, manipulating the model with zoom, changing layers as a coating wall, etc. According to Saar, Klufallah, Kuppusamy, Yusof, & Shien (2019), SmartReality is very simple to use as users only need to upload their 2D drawings and 3D models to the SmartReality web portal, and it will perform the pairing work for users (Figure 31).

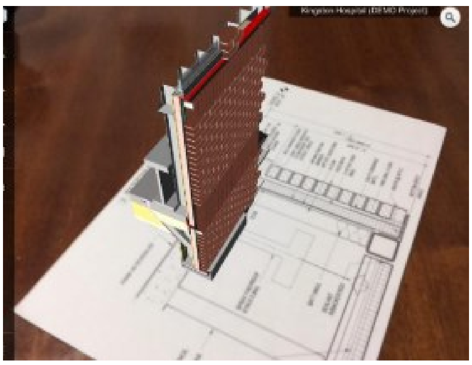

Figure 31: SmartReality Product by Hoar Construction (Saar, Klufallah, Kuppusamy, Yusof, & Shien, 2019)

The Portable AR-BIM is somewhat like the desktop AR-BIM system (Saar, Klufallah, Kuppusamy, Yusof, & Shien, 2019). However, it can track features in the captured scene. Instead of showing the entire BIM model, it is possible to enlarge the corresponding area of the part of the verification model.

According to Saar, Klufallah, Kuppusamy, Yusof, & Shien (2019), the idea of the portable AR-BIM system was implemented by Daqri Smart Helmet in 2016 and used in civil construction at the end of the same year. This System provides information on the overlay of the BIM model on the construction site. It provides users with a view of the finished work and is an effective tool for monitoring the construction site (Figure 32).

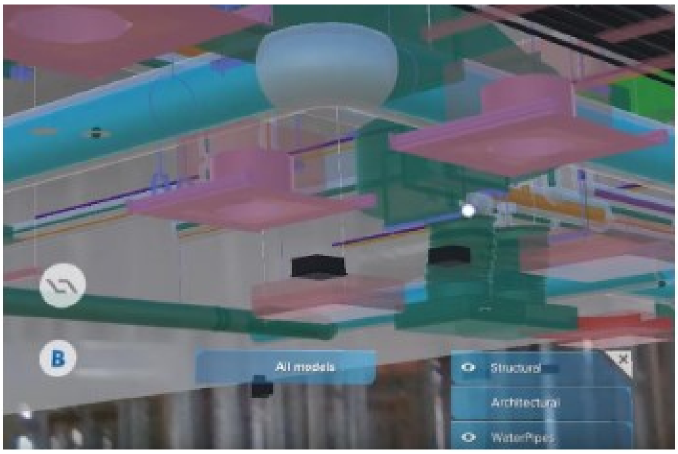

Figure 32: Daqri Smart Helmet by Mortenson (Saar, Klufallah, Kuppusamy, Yusof, & Shien, 2019)

AR-BIM remote monitoring allowed users to monitor the location just by staying in the office (Saar, Klufallah, Kuppusamy, Yusof, & Shien, 2019). Drones produce videos and send them to the office only at the end of image capture (Figure 33).

Figure 33: Augmentation of Drone Videos for Site Monitoring (Saar, Klufallah, Kuppusamy, Yusof, & Shien, 2019)

Zollmann, Hoppe, Kluckner, Bischof, & Reitmayr (2014) suggest that AR combined with a 3D aerial reconstruction can assist in on-site monitoring of a building, capturing data, and providing necessary information of the direct relationship between the physical space and the building construction in real-time. This strategy is made possible through air vehicles such as current drones with attached mobile devices, such as a cell phone configured to record the physical environment allowing inspection (Figure 34).

PROCEEDINGS OF THE IEEE SPECIAL ISSUE ON APPLICATIONS OF AUGMENTED REALITY ENVIRONMENTS.

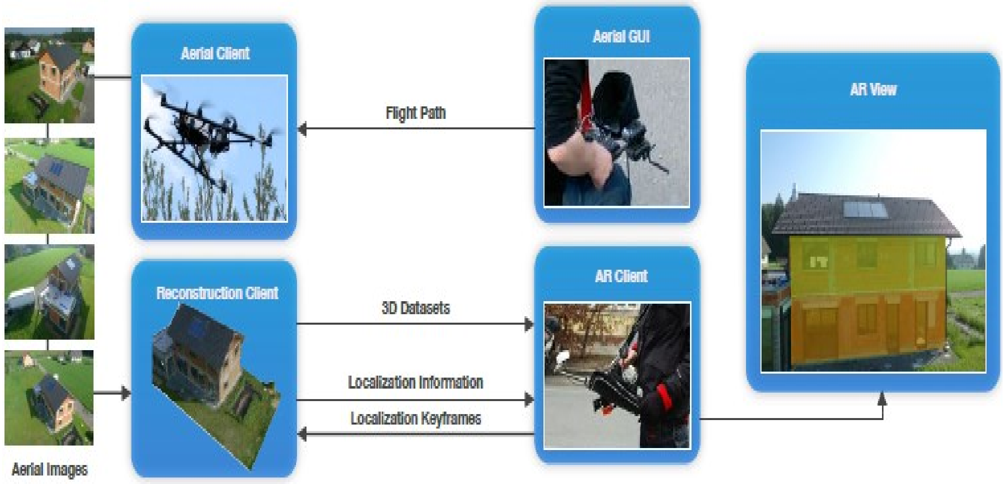

Figure 34: Mobile AR system inspection and documentation. Left) Aerial Client capturing Aerial Images of interest. It published and the 3D representation of the reconstruction site. Right) After that, the Reconstruction Client publishes the 3D data over the network as well. An AR Client spatially registered using an external sensor, or remote localization accesses the 3D data and renders it in the AR view.

3 METHODOLOGY

3.1 Research Process: A case study

The research aims to report and assess the potentials (Silva, Giesta, & Câmara, 2020) and challenges of using augmented reality in a broad approach to workflows in the lifecycle of a BIM project. For a more consistent assessment based on practical experience, the application of the case study method is the most coherent, with three case studies in different constructive scenarios. Two of them are infrastructure (a tunnel and a bridge) with unequal levels of depth in modeling data and information contained in three-dimensional models in BIM. The third case is an architectural building with complete modeling in a 3D BIM model. Special attention to the locations of the environments, comments on the benefits and challenges of the applicability of specific software with appropriate tools for the interaction between AR and BIM in real-time through a mobile device, and, finally, final data analysis, conclusion, and recommendations for future studies.

For the research strategy to provide subsidies in accordance the objective through case studies, the collection of accurate and authentic information data must be interconnected to serve as answers to the questions of the hypothesis: **Why use AR in BIM workflows as an essential tool for improving the life cycle of a project?**

As a qualitative descriptive methodology, case studies bring the possibility of using augmented reality (AR) integrated with BIM technologies to complement real-time information retrieval, improving the productivity of all construction workers (Chu, Matthews, & Love, 2018). Serve as examples of the importance of AR as an additional tool to aid information in BIM and which tends to be further explored by software scholars so that their current challenges are solved.

There are two main segments of the critical steps of the method: Preliminary Study/Literary Criticism and Hypothesis/events. The preliminary study has two phases. The first is entitled the research outline, where the first contacts with the dissertation theme occur, and the second phase is the moment to define the method to be applied. As a result of progress and familiarity with the subject, the stage called Hypothesis has into three events of its own: the first is the preparation of data collection, with the first contacts with the company Kolektor, responsible for the construction sites, scheduling for visits to the places that are part of this study, and first contacts with the Dalux software, which uses AR integrated with BIM technology and which will be used in the cases. Continuous research development and data collection were carried out at the construction sites using the AR visualization application installed on a mobile device (tablet), capturing photographic images of the experiences in the places and obtaining information data of the projects on the PC by the Dalux software. In the last part of the events, there is the analysis of the data obtained and conclusion, with the comparative analysis of the information obtained on-site and the design, identification, and reflection of the results obtained for a consistent finding and, finally, identification and presentation recommendations for future investigations.

The flowchart in (Table 4) below illustrates and guides the methodology strategy to be followed.

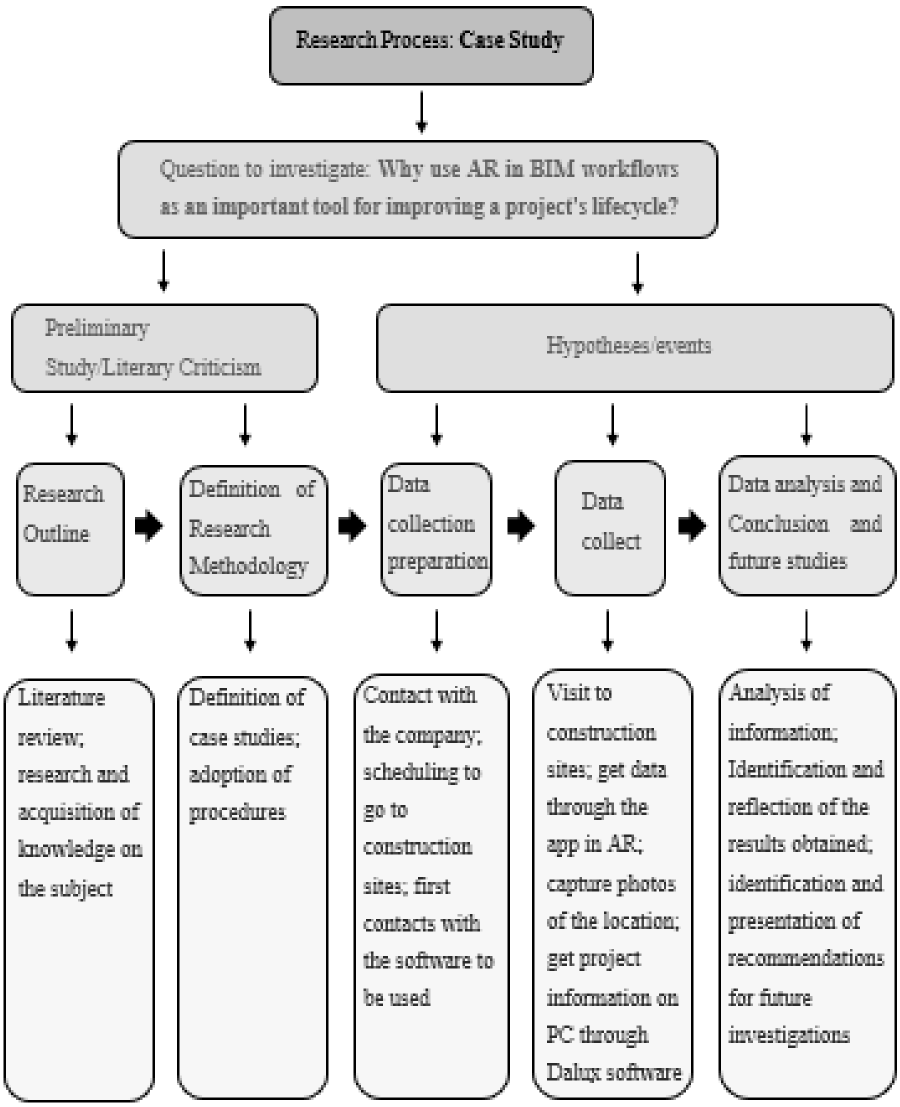

Table 4: Research steps

3.2 The importance of a construction site for a real case study

The Kolektor company, with operational excellence, quality, and efficiency in its works in the country and abroad and, the company offered the critical elements as requirements for the preparation of actual case studies as data of the construction process on the BIM platform, such as 2D design and its specifications, 3D BIM model and finished or in-progress construction sites. It offers diversity related to the type of construction (infrastructure and building), enabling the study of Augmented Reality in different workflows, the central point of the thesis theme. Opportunity to visit construction sites and acquire information from the work team, photographic images, use of appropriate equipment for capturing technological images, so that the practice of augmented reality is possible. Information that will be extremely important for developing the proposed theme and the elaboration of the results achieved.

- Possibility of visualizing the physical environment of the project under construction.
- Feasibility of photographing with greater focus and details of specific spaces to be studied.
- Augmented Reality allows construction workers, equipment operators, engineers, and managers to follow in real-time each stage of the construction site activities for which they are responsible. Thus, all phases of the construction site activities are carried out more efficiently.
- Opportunity to talk to professionals and workers about the normal development of the construction site, the routine, and its difficulties.
- Identify different workflows between different types of construction such as infrastructure (roads, viaducts, bridges, tunnels) and buildings (residential, commercial, industrial).
- Obtain information from project and construction site data and compare them to verify their alignments and possible errors, enabling their adjustments efficiently.

4 CASE STUDIES

Among all phases of a BIM project lifecycle, the use of augmented reality in workflows is commonly associated with three basic scenarios, as shown in (Shin & Dunston, 2008): The first is the design phase, where the use of AR can be an aid tool in the review of the proposed solution; the second scenario is part of the construction phase (Fu & Liu, 2018), with the AR contribution focus being on monitoring the progress of construction; and, finally, the scenario of the operation phase for which the use of augmented reality serves to help to build maintenance professionals (Duston & Shin, 2009). And, in the (Woodward et al., 2010) article, the researchers identified many other use case scenarios that could benefit from augmented reality, such as layout optimization, excavation, positioning, inspection, coordination, supervision, exchange of textual information, etc.

The three cases chosen for this research have different uses, two of them within the context of infrastructure projects (railway/tunnel, bridge) and the third, a building for commercial use and services. For all cases presented, a specific mobile application of BIM was used, the Dalux software DALUX, through which the BIM models were accessed and used as an integrated AR solution. The criteria used to select the application were: (1) possibility of scaling the augmented model in a non-isolated standardized system; (2) readily adapted for visualizing an object in an information model and building data and enabling information extraction; (3) able to link to a database that contains primary data of an object in a building information model to aid worker mobility (Chu, Matthews, & Love, 2018). Generally speaking, mobile applications operate in a BIM shared data environment, providing a central hub for communication between users, data sharing, etc.

4.1 Brief of Kolektor Company

The dissertation aims to explore augmented reality in different workflows within BIM technology through actual case studies. As well as to demonstrate some gaps and problems identified so that such studies were viable, a point of motivation for choosing the Slovenian company Kolektor is that it has the three different types of construction sites for the research to be carried out. Below is a summary of the areas of activity and technologies used by the company. All the following information about the Kolektor company can be visualized on the company's website https://www.kolektor.com/en and https://www.kolektorcivilworks.com/.

Kolektor is a global supplier with over 55 years of experience operating in three strategic business units: **Mobility Components and Systems**, **Energy Engineering**, **Engineering Systems, and Technology**, and is currently forming the fourth unit, **Digital**.

The **Mobility Components and Systems** strategic unit have tradition and experience in development, production, and support services in the mobile industry with integrated solutions for the automotive sector, responding proactively to the megatrends of electrification of vehicle drives and autonomous driving, and interconnection in the car. It uses clean technologies suitable for manufacturing products with the least possible impact on the environment.

The production companies at Kolektor have Quality Management under the international standard ISO 9001, and companies focused on the automotive market were updated by the technical specification IATF 16949.

Among its main environmental protection goals is the reduction of energy consumption, drinking water consumption, the amount of industrial waste and the amount of municipal waste; increased proportion of reused materials; development of products and services with the least possible impact on the environment during and after use; promoting environmental awareness among all those who work for and in the company and raising awareness among employees about environmental protection.

The **Energy Engineering** unit offers comprehensive solutions for engineering the production of crucial components for hydroelectric plants up to 20 megawatts per unit, produces energy transformers, and carries out engineering in management, protection, and control of electrical power systems. It also offers complete solutions for small hydroelectric plants, from conception, strategic engineering development, and even the implementation of technological assemblies in power generation facilities, all with sustainable resources for energy from renewable sources for distribution and industrial transformation stations; power plants and subsystems (turbine and generator) of hydroelectric power plants; automation, management, and protection.

The main point of the **Engineering Systems and Technology** strategic unit is the efficient use of energy, with innovative solutions in the construction of smart homes, cities, and communities. It offers an approach that encompasses preparing and implementing investments in built environments, such as industry, commerce, residence, road and railway infrastructure, and urban planning.

This strategic unit has into four sectors: **Civil Works**, Water Treatment, Automation, and Electrical Engineering and, as the last sector, Insulation Solutions.

The **Civil Works** is committed to constructing industrial, commercial, public, cultural, sports, and residential buildings and the infrastructure, dedicated to building road and rail infrastructure, bridges and tunnels, pipelines, and buildings for public service infrastructure. It is one of the leading service providers in construction in Slovenia, with two companies as strands: Kolektor Koling and Kolektor CPG. Investing in the future, the company is constantly looking for the best solutions in construction, engineering, and architecture, electrical, mechanical, and energy installations. It invests in the qualification and training of its employees simultaneously. And it is within this Kolektor Koling, the construction sites for the following case studies are located.

The strategic unit in formation, **Digital,** develops innovative solutions for the transformation and adaptation of small and medium-sized companies into the intelligent factories of the future. With the use of recent technologies in artificial intelligence such as intelligent industrial robotics and advanced visualization and simulation technologies, the Digital Strategic Unit offers safe, modular, scalable, and investment-optimized products and solutions necessary for the transformation into intelligent factories of the future.

4.2 Case study 1: Drugi Tir

Construction of access roads for the second rail track of the Divača-Koper section

The construction section used for the case study, an interspace of the second rail track of the Divaća-Koper, starts in Lokev and ends in Dekani with the construction of more than 17.4 km of roads with various structures serving as service routes for the construction of tunnels, support walls and the road of access to the valley of the river Glinščica and a bridge of approximately 35 m. On the access road on an old railway line Trst – Kozina, the former viaduct above Nasirec, around 90 m long, will be renovated. The conclusion of the works took place in early 2020.

Figure 35: Picture of the Divaća-Koper section (by author)

4.2.1 The proposed process and workflow

According to the specific concepts about BIM workflows detailed in item **2.1.3, Workflows in the life cycle of a building**, this case is the post-construction phase of the Organization and Maintenance (O&M) phase. Using a BIM virtual construction model in the previous stages provides essential information that facilitates understanding maintenance operations in this phase (Eastman, Teicholz, Sacks, & Liston, 2011) and the visualization of the work sequencing through the use of augmented reality.

The proposal for using this specific area bases on some main points, such as a large infrastructure construction site with long-distance tunnels, roads, and small one-story constructions that serve as equipment for future maintenance.

In this case, a mobile device (tablet computer) with an augmented reality application **(Dalux View)**, where it was possible, through a GPS connection, to visualize the facilities as concrete underground passages of the MEP tunnels and ducts and some accesses and the construction of a building.

Note: Some images suffered reflection interference because it is an outdoor area and a time of relatively intense sunlight.

For a better Augmented Reality visualization experience and the use of Dalux software, this construction site has two different locations: both georeferenced as shown and named as Standpoint 1 and Standpoint 2 (Figure 36).

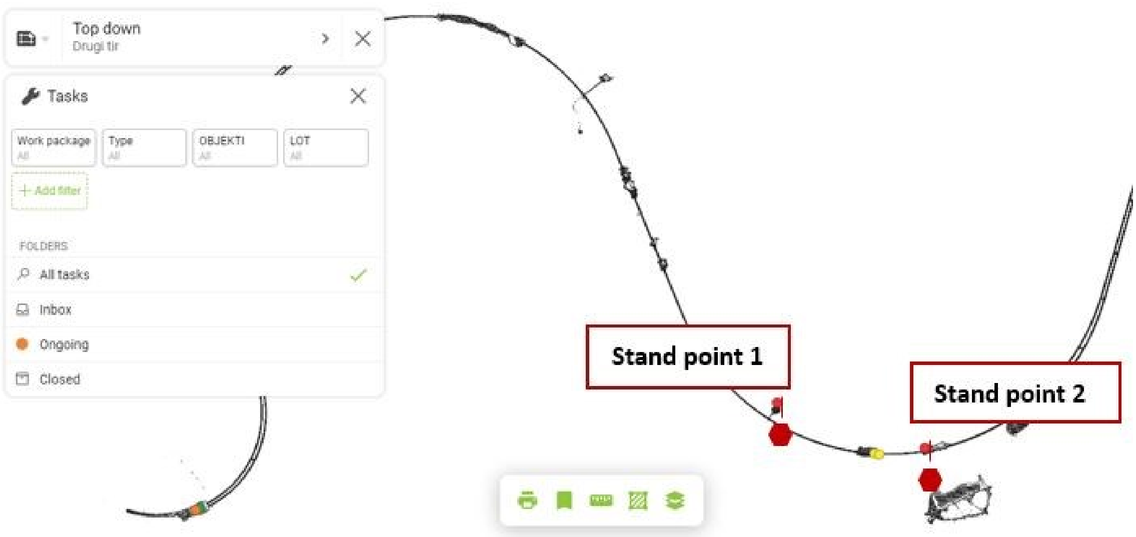

Figure 36: The linked location of Standpoint 1 and Standpoint 2 (by author)

With the coordinates active on the tablet at Standpoint 1 via internet and GPS, it is possible to create a georeferencing report (a) with the exact location coordinates linked and verified on the PC through the Dalux Box (b). In a more extended mode, you can check the 3D model viewed from Viewpoint 1 and compare the exact coordinates on both PC in Dalux Box (c) and on a tablet in Dalux Viewer (d), as shown in (Figure 37) below.

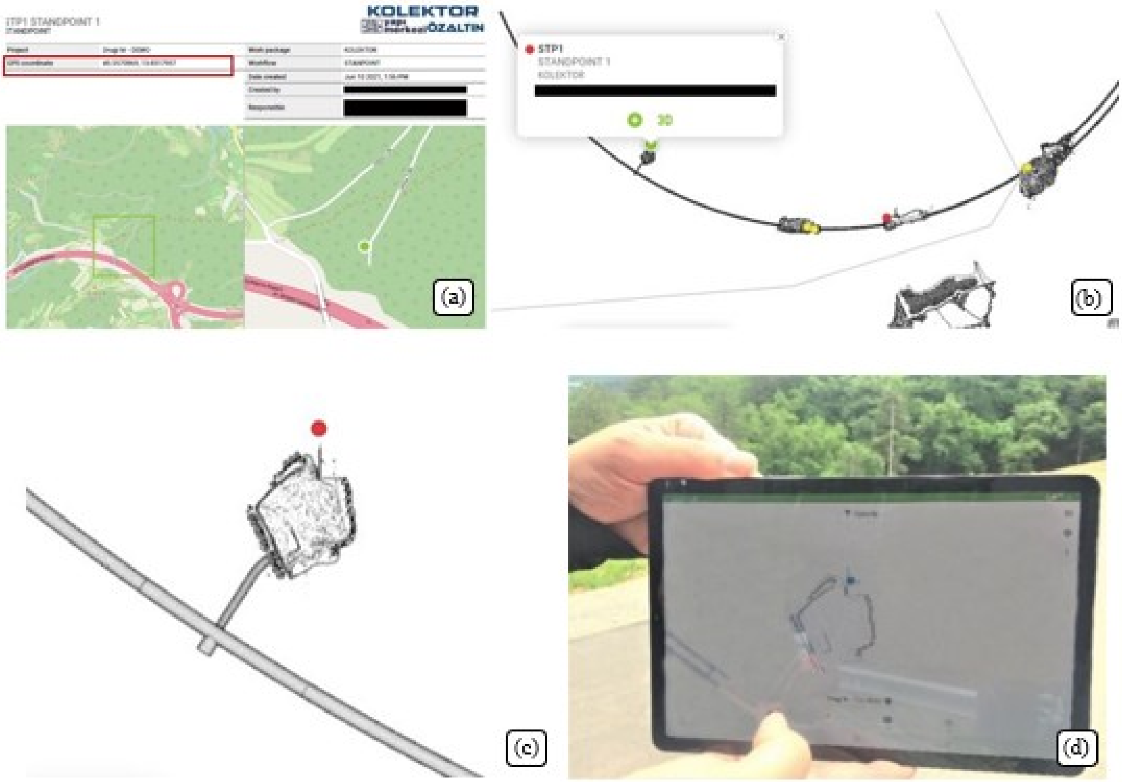

Figure 37: The accurate position report from Standpoint 1 (a), the actual location from Standpoint 1 in BIM model (b), the standpoint 1 exact position in Dalux Box (a), and Dalux View (b) in the locus (by author)

It is a BIM-based construction management platform. The software and its application for use and visualization in the field allow the user to update and manage the works through documents and view 3D models (Figure 34) in IFC format. Its integration is also possible through AR technology to visualize interactive 3D models on site (Figure 38).

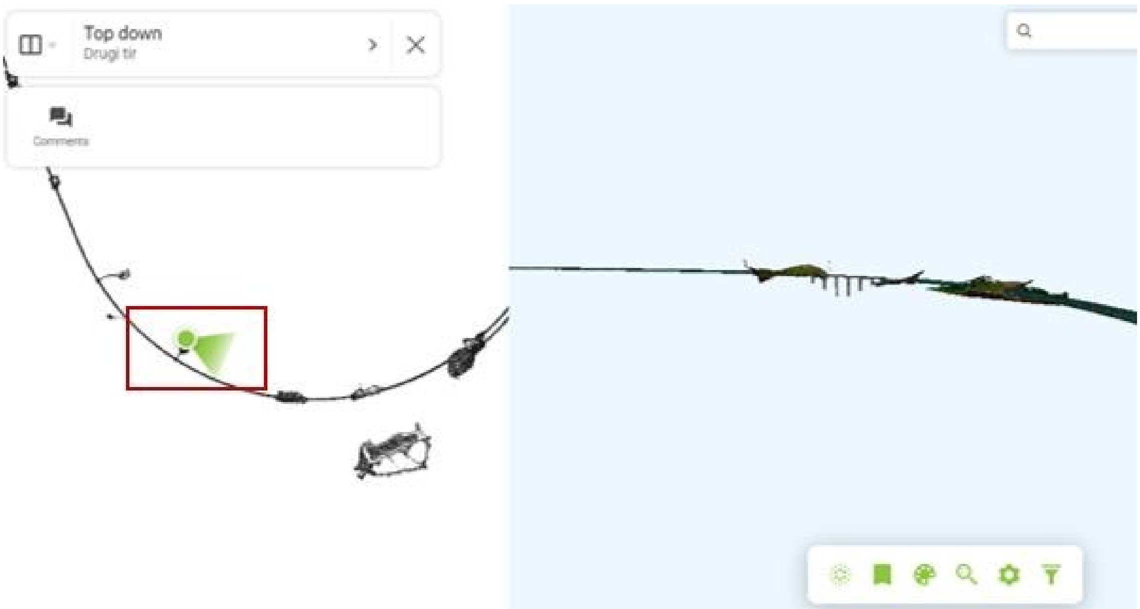

Figure 38: The IFC 3D model from standpoint 1

According to Ratajczak, Riedl, & Matt (2019), the focus is to provide interactive 3D models and documents to aid inspection and report issues. In this type of technology, the user's view on the device's screen is an image augmented and rendered with digital information from the 3D BIM model integrated with the actual image of the physical surroundings. This image overlay provides essential information for a site-specific task regarding objects of interest (Zollmann, Hoppe, Kluckner, Bischof, & Reitmayr, 2014).

Using augmented reality (AR) technology, it is possible to check the tunnel ducts and MEP installations, even with significant distances between the user and the object and a thick layer of the earth because it is a slope and natural green area around it. of the road. (Figure 39)

Figure 39: Dalux application used on the construction site standpoint 1 through Augmented Reality (by author)

As in Standpoint 1, it is possible to check the 3D model visualized from Standpoint 2 and compare the exact coordinates on the PC georeferencing report (a). Also, the 3D model envisioned on Dalux Box (b) and, in an enlarged way, on PC (c) and on the mobile device itself on Dalux Viewer, in this case, the tablet (d), as shown in (Figure 40).

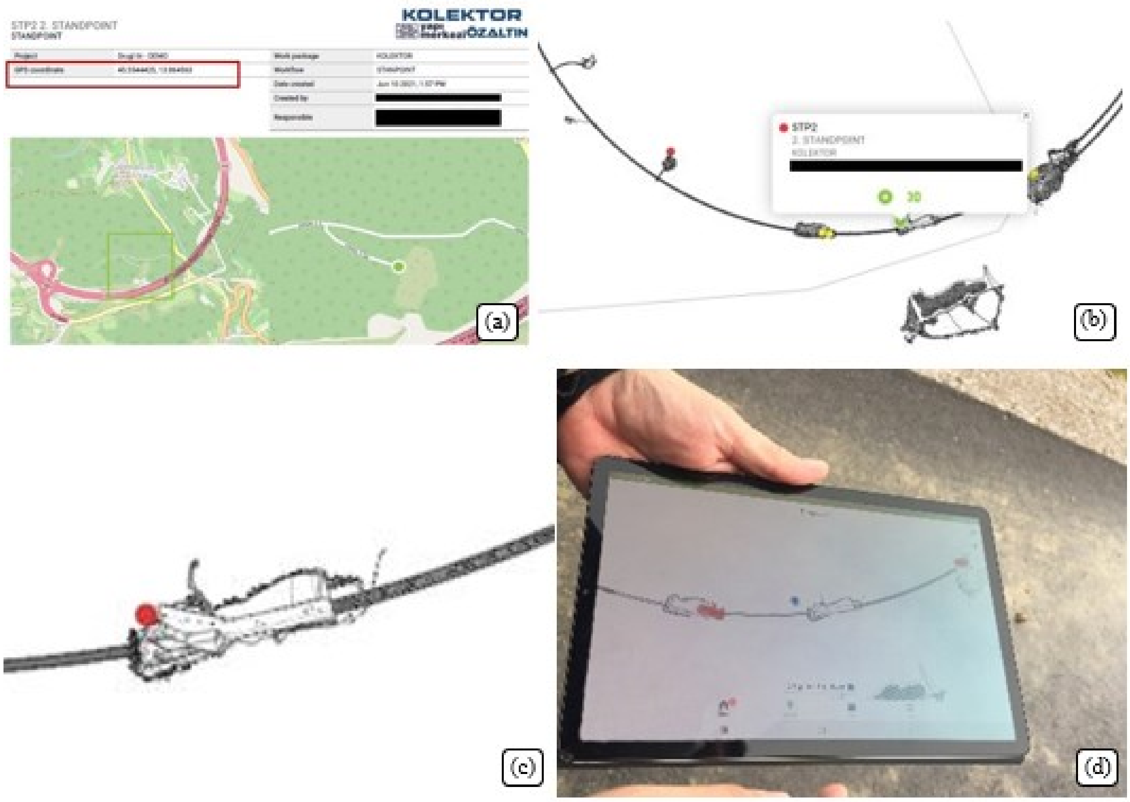

Figure 40: The standpoint 2 georeferencing report (a), 3D model location in Dalux Box (b), zoom in the actual position of the 3D model in Dalux Box (c), 3D model location in Dalux View (d) in the locus (by author)

The BIM platform used in the Dalux software allows the integration and real-time visualization of the user's location in 2D through GPS coordinates and the possibility of viewing the 3D model in IFC format according to the positioning of the camera rotation, as illustrated and shown in (Figure 41).

Figure 41: The IFC 3D model from standpoint 2 (by author)

In (Figure 42) below, using augmented reality (AR) technology, the possibility of verifying the path of the tunnel pipes (a) and MEP installations (b) is evident, even at significant distances and with a thick layer of earth per se. Treat a slope and natural green area around the road.

Figure 42: Dalux application used on the construction site standpoint 2 through Augmented Reality (by author)

4.2.2 Challenges and benefits

Challenges:

- Difficulty finding the correct orientation in the field for the GPS to capture the exact location and scale of the 3D model to provide the precise information to be visualized by the AR system, which can take a few minutes and provide incomplete information;
- Determine the location of a challenge, probably due to the geographic characteristics of the built area region;
- As it is an outdoor and daytime area for capturing and viewing images in AR, luminosity has become a challenging factor to use the app on the mobile device, in this case, or tablet.
- It is not possible to move or rotate the 3D model in AR. It is visualized as a static object, as it is georeferenced in a fixed position, positioned in front of the natural scene;

Benefits:

- Using the app can facilitate a broad understanding of the future construction site.
- Assist in maintenance control and possible reforms in the operation and maintenance (O & M) phase.

4.2.3 Results

After the experience of using the application for augmented reality, the main deductions are as follows:

- The correct georeferencing of all BIM models is essential for reading in the AR system.

- Environments with high brightness, especially in open areas under sunlight, can be challenging to use tablets and mobile phones.
- It is complex to find an ideal positioning in the field for the correct reading in scale and location of the BIM model.
- Determining the geographic location of the actual physical object for reading in the AR system can be a challenge. It depends on the geographic characteristics of the region of the built environment.

4.3 Case study 2: Marija Gradec

A new out-of-level passage was built in Marija Gradec, named underground passage, replacing the previous one with inadequate measures. The level crossing and connecting roads, two-level crossings were eliminated, and two bridges were built. Also included in this completed part is a new underpass for pedestrians and cyclists on the Laško – Celje section as part of the upgrade in Debar near Laško.

During the construction of the new bridge over the river Savinja in Marija Gradec, near Laško, the 160m long and up to 12m high anchored containment structure was built (subject of the case study) to widen the curve of the road in front of the bridge. With construction beginning in mid-July 2019 and open to traffic in February 2021, the bridge is 123 meters long (Figure 39). It crosses the Savinja river with two asymmetric spans, one of 75 and the other 48 meters. A gravel deposit formed a support river located outside the primary watercourse because of the river's current flow. The bridge connects the main road Laško – Šmarjeta on the right bank of the river Savinja with the road Laško – Šentjur on the left. The bridge project has a design that has little impact on the river flow and preserves the cultural heritage of the landscape surrounding Marija Gradec's church.

Note: information consulted on the website of the Republic of Slovenia https://www.gov.si/novice/2020-02-21-zakljucena-nadgradnja-zelezniskih-odsekov-rimske-toplicelasko-in-laskocelje/

Figure 43: The Marija Gradec bridge (by author)

4.3.1 The proposed process and workflow

This case follows the concept of the post-construction phase known as the operation and maintenance phase, detailed in **item 2.1.3 Workflows in the life cycle of a building**. The use of a BIM model in previous phases to provide vital information for the O&M phase is essential for the planning and execution of maintenance works, remote operation for real-time management and monitoring (Eastman, Teicholz, Sacks, & Liston, 2011), and visualization of operations sequencing through augmented reality.

It is a large infrastructure construction site (actually already completed) of a bridge. It has a 3D BIM model in the database and its GPS coordinates, making this study possible to obtain architectural visual interaction and real-time communication, reconciling the model and the built environment (Chalhoub, Ayer, & McCord, 2021).

Another critical issue for choosing this location as a case study is precisely the counterpoint of not having another accessible database besides the 3D BIM model in IFC format as basic information, which brings significant limitations for its use and visualization in augmented reality.

The BIM platform combines the software and app capable of reading augmented reality and, in this case, the tablet was used as a mobile device for the integration and real-time visualization of the user's location in 2D through GPS coordinates and the possibility of visualization of the 3D model in IFC format. Broadly, you can check the coordinates on Google Maps (a) and compare the location on the 3D BIM model (b), as shown in (Figure 44).

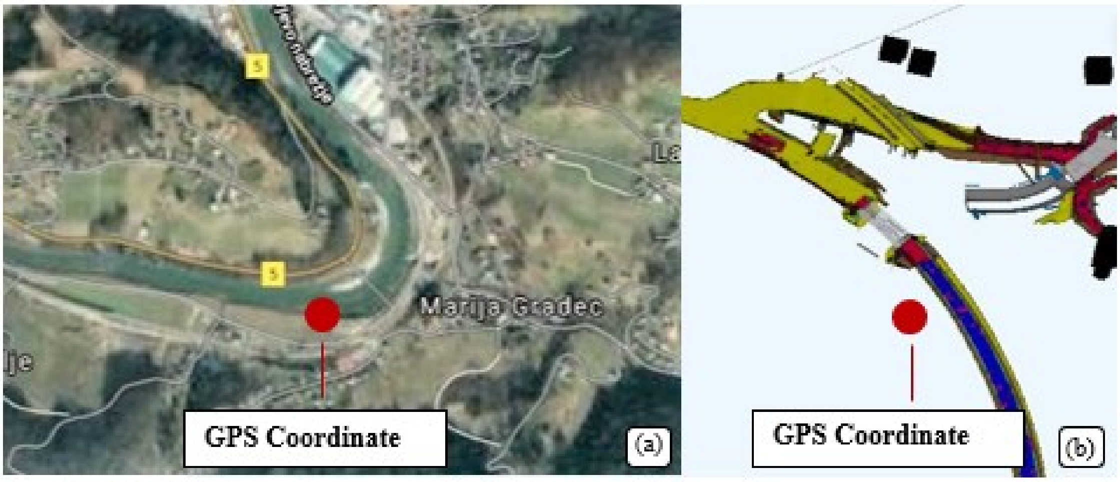

Figure 44: The geolocated of the bridge in Google Maps (a) and BIM model (b). (by author)

The importance of using augmented reality (AR) in a finished work is the possibility of following the Operation and Maintenance phase (7D) within the project life cycle. As it is a BIM Platform, it enables the monitoring and evaluation of the project stages, as shown in (Figure 45).

Figure 45: The view of the bridge (a) and visualizing (b) of the bridge in the AR system (by author)

Augmented reality realizes a significant role in automation in defect and quality management in the construction industry. Studies demonstrate that as AR technology advances in quality and defect management, there is a significant improvement in work performance proactively using BIM and AR technologies. Augmented reality is being recognized as an additional way to transport exceptional value in the post-construction phase (7D), where managers realize central control time points and measures so that both works and operations and maintenance are proactively verified to prevent defects in the so-called Quality Assurance (QA) and identifying and correcting defects through Quality Control (QC) (Ahmed, 2019). However, due to the lack of basic information within the 3D model, BIM in AR visualization has become unfeasible.

4.3.2 Challenges and benefits

Challenges:

- Due to information discrepancy, AR image capture has become ineffective;
- As it is an outdoor area and during the daytime for capturing and viewing images in AR, luminosity has become a challenging factor to use the app on the mobile device, in this case, the tablet.

Benefits:

In this case, as it was not possible to use AR to contribute data and information captured by images, there is no way to obtain concrete answers. However, through several researched articles, the unanimous conclusion reached is that AR has a relevant importance in the Operation and Maintenance phase (7D) such as:

- Maintain a building's performance over its lifetime, allowing for continuous adjustment, optimization, and modification' of building systems to meet specific requirements.

- Identify assets and call relevant information about an in-situ component through computer vision and object recognition systems.

4.3.3 Results

Below are the conclusions of this learning:

- It is critical that the BIM model add non-geometric data to the 3D geometric information.
- Visualization of the positioning and sizing of the BIM model in the application with AR system is possible due to available reference points.
- The use of tablets and smartphones is problematic in places with a high incidence of sunlight.

4.4 Case study 3: Iskra Mehanizmi

Located in Brnik, close to Ljubljana airport, the industrial complex (Figure 46) "IM Brnik Industrial and Commercial Building" has a structure composed of main blocks. One block is intended for the commercial sector, which develops from a monolithic reinforced concrete structure. The other block is designed for production and storage units, consisting of prefabricated concrete reinforcement.

Figure 46: Iskra Mehanizmi Brnik industrial complex. (by author)

This case study was prepared and carried out in the commercial area of the Building Complex as located in the situation/implementation plan (a). The georeferenced point is located on the first floor (b), as shown in (Figure 47). Conducting coherent field research for the use of augmented reality in significant architectural construction made it possible to verify that the design of the buildings and their entire context in the Common Data Environment (CDE) was worked on the BIM platform, including 3D BIM models. These principles make it possible to obtain the expected approach of architectural visual interaction and real-time communication through AR and GPS software.

Figure 47: The situation/ implementation (a) and GPS point on the first floor (b). (by author)

4.4.1 The proposed process and workflow

It is an object of study under construction following the specific concepts about BIM workflows detailed in item **2.1.3 Workflows in the life cycle of a building**. The use of a virtual BIM construction model facilitates the understanding of disciplines and their components by checking information management platforms linked to 3D models with the respective database (Eastman, Teicholz, Sacks, & Liston, 2011) and visualization of the sequencing of the work through the use of augmented reality.

For mobile devices with augmented reality applications in field research to be consistent, it is necessary to ensure that the construction project and its entire context in the CDE are made in BIM technology, including models 3D. Based on these premises, it is possible that, through AR and GPS software integrated with BIM, it is possible to obtain the expected architectural visual interaction and real-time communication approach.

The approximation between the BIM model and the AR occurs practically through three main components: the BIM model itself, the entire data transformation process mentioned in sub-item 2.4.2.1, and a mobile device with the AR Dalux platform application used in this research.

The app uses 3D tracking and an intuitive, virtual step-by-step guide to improve work productivity and reduce information search time. This process has the following steps: (1) Find the object of investigation; (2) Open the Dalux app on the mobile device and open the tablet or cell phone camera and point at the specific object; (3) View extended installation information; (4) Follow the augmented information to resolve issues such as repair, readjustment, or request to complete the installation.

(Figure 48) shows the geometric and non-geometric constructive information of the BIM model (Wang, Wang, Shou, & Xu, 2014), such as location by georeferencing (3D) and technical specifications (4D) of the manufacturers of doors and windows and maintenance information (5D) (a). The approximation between the BIM model and the AR takes place through its positioning, orientation, and scale of the BIM model (b).

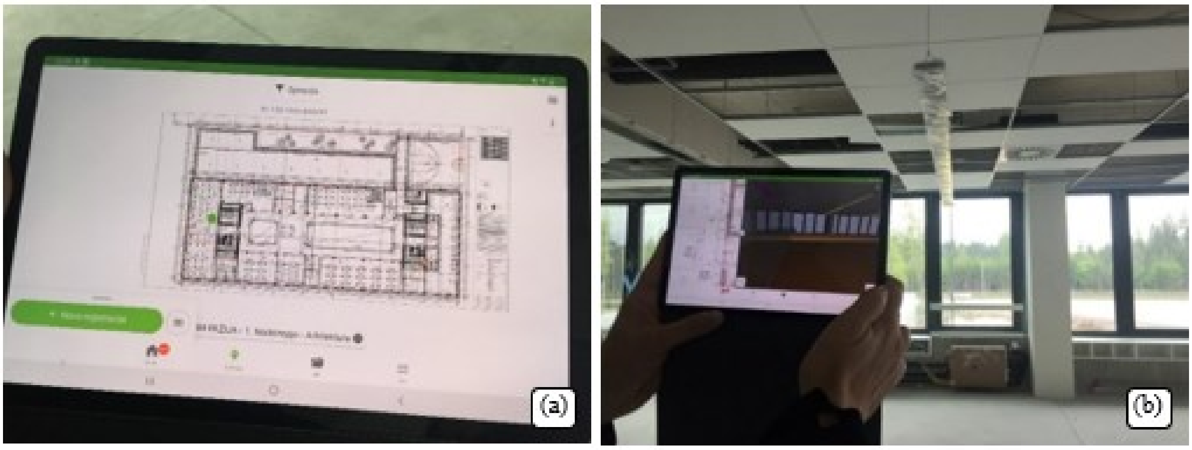

Figure 48: Location used for geospatial reference (a), positioning, orientation, and scale the BIM model (b). (by author)

To allow viewing on the AR platform, the 3D BIM Model sends and receives BIM information, such as installation adjustment requirements and verification of the work schedule, allowing the user positioned at the current location to interact with the 3D BIM model and other members of the team in a real-time project (c). According to customer requirements, BIM models are created from a 2D design drawing and information integrated into design specifications. In this case, there is a marking (orange rectangle) referring to the requested information (d)— (Figure 49).

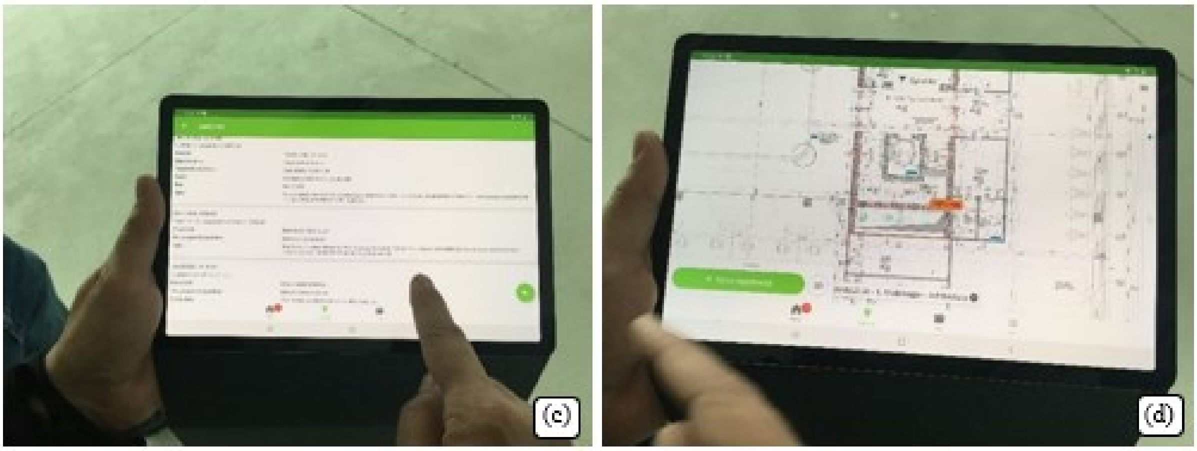

Figure 49: Exchanging information data in real-time (c), information data request (d). (by author)

After clicking on the orange rectangle position, a new window opens immediately with the details of the information in a 2D drawing with annotations about the location, the types of installations performed, and what is necessary to complete the orders (e). The levels of constructive detail included in the same information can be structural, architectural, MEP installations, or others necessary for the project's execution (f). Both situations are in (Figure 50).

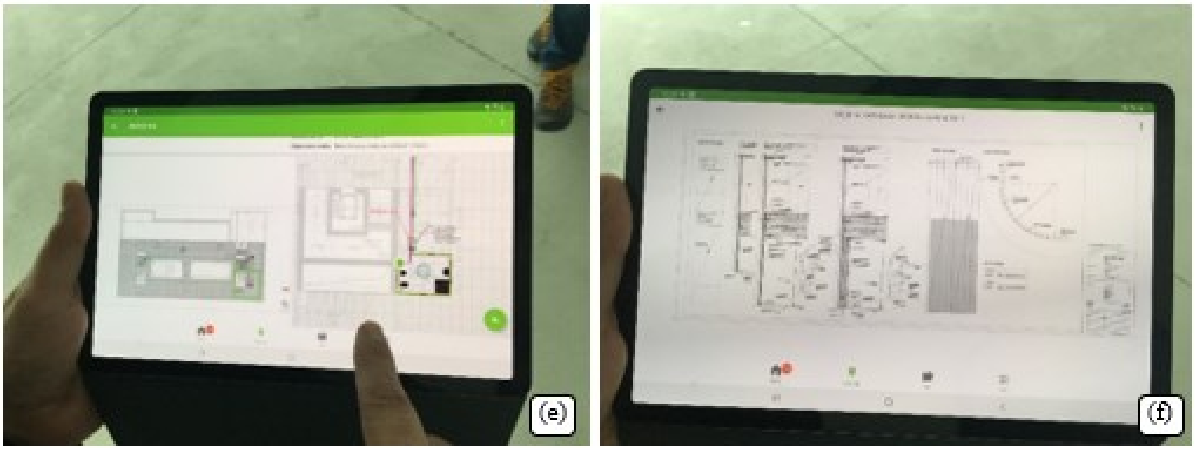

Figure 50: Checking specific information (e), accessing construction details (f). (by author)

4.4.2 Challenges and benefits

Challenges:

- It is impossible to move and rotate the 3D AR model; it is static and positioned before the actual scene.
- It is necessary to be in the correct position and stand still for the GPS to capture the exact location of the 3D model to provide the AR visualization, which may take a few minutes.
- Due to the technical limitation of the mobile device, the large-scale rendering effects of the AR models were occasionally not satisfactory.

Benefits:

- It is possible to scale on application and consult real-time CDE information, request revisions, and evaluate the MEP installation. For example, the installation date, if it is in the correct position, and whether the description of the materials in the project matches those appropriately used.
- Simultaneous real-time interaction between everyone involved in the process, from the customer, suppliers, project technical team, on-site execution team.

4.4.3 Results

This case study differs from the others seen above because it is a large project. Its geographic location is close to urban centers and the airport, allowing for a good internet network, which facilitates the search for the user's position by GPS inside the building. However, as it has many architectural, infrastructure, and MEP installation details, the search for the exact location of an object becomes a challenge. As the GPS location coordinate points change quickly, the user must remain static so that the visualization of the desired object has a satisfactory result. The primary reflections resulting from this case study are:

- Difficulty in determining the geolocation of objects within a building for the feasibility of reading in the AR system.
- The AR app can solve geolocation with different approaches.
- A BIM model's exact positioning and dimensioning in the AR application is possible through available reference points.
- BIM models usually have more complete data and information in buildings than infrastructure environments as bridges and tunnels. Consequently, the AR system can make better use of this available information.

5 DISCUSSION

5.1 Critical analysis

In the case studies, the focus was on understanding how the building models are visualized, filled with data acquired from the information provided by the BIM models quickly and accurately, facilitating real-time communication and user experience.

The benefits of using Augmented Reality through the application used, in general, in both case studies:

- Improve the ability to understand the stage of work;
- Visual understanding of the connection and interrelationship between the disciplines involved;
- Improve the architectural visualization level;
- Improve labor productivity and reduce costs.

The challenges in general for the company:

- As this is a new system, extra training time is needed for all the people involved, so that they can deeply understand this new technology and how it works;
- If the 3D BIM model does not have a high level of detail (ISO 19650-1: 2018), likely, AR models will occasionally not be as satisfactory as desired, limiting the view information, causing an inefficient communication result.

The biggest obstacles encountered during this experience are directly related to the fact that augmented reality technology uses georeferencing, making it impossible to manipulate and rotate the 3D AR model on the mobile device, in this case, the tablet, when another object is positioned behind the object in the foreground. The user wants to access their data, as the elements are fixed and placed in the actual scene. Another essential issue is related to the user's position, which must be exact and static. The GPS coordinate system captures the correct location of the 3D model to obtain an adequate visualization in the AR system, which sometimes can take some minutes. And, because it is a technical limitation of the mobile device used, large-scale rendering effects, that is, with many elements in the same scenario, were occasionally unsatisfactory in the AR model. The lack of non-geometric information or its scarcity when added to the 3D geometric model also generates problems in transforming the data to be visualized, which can distort or create flaws in the results in AR.
The case studies are different, with the first two characteristic infrastructure construction environments, tunnel and bridge. Both are part of the operation and maintenance (O&M) phase, and in theory, they should have the same BIIM – O&M workflow. However, as shown above, they do not have the same level of insight into aggregated information in the BIM model. The internal structure of the BIM workflows of these infrastructure cases is likely to be different. The third object of study is an

architectural project of a building to trade and service under construction. In this case, the BIM – Construction workflow is considered.

According to the definitions described in the reference articles for this research, BIM is a valuable technology to solve interoperability gaps between disciplines in the life cycle of a project. One of the main characteristics of BIM is the ability to link different elements of the same built environment, different functions within the same project, and different phases in the building's life cycle (Benedetti et al., 2014) (Figure 51).

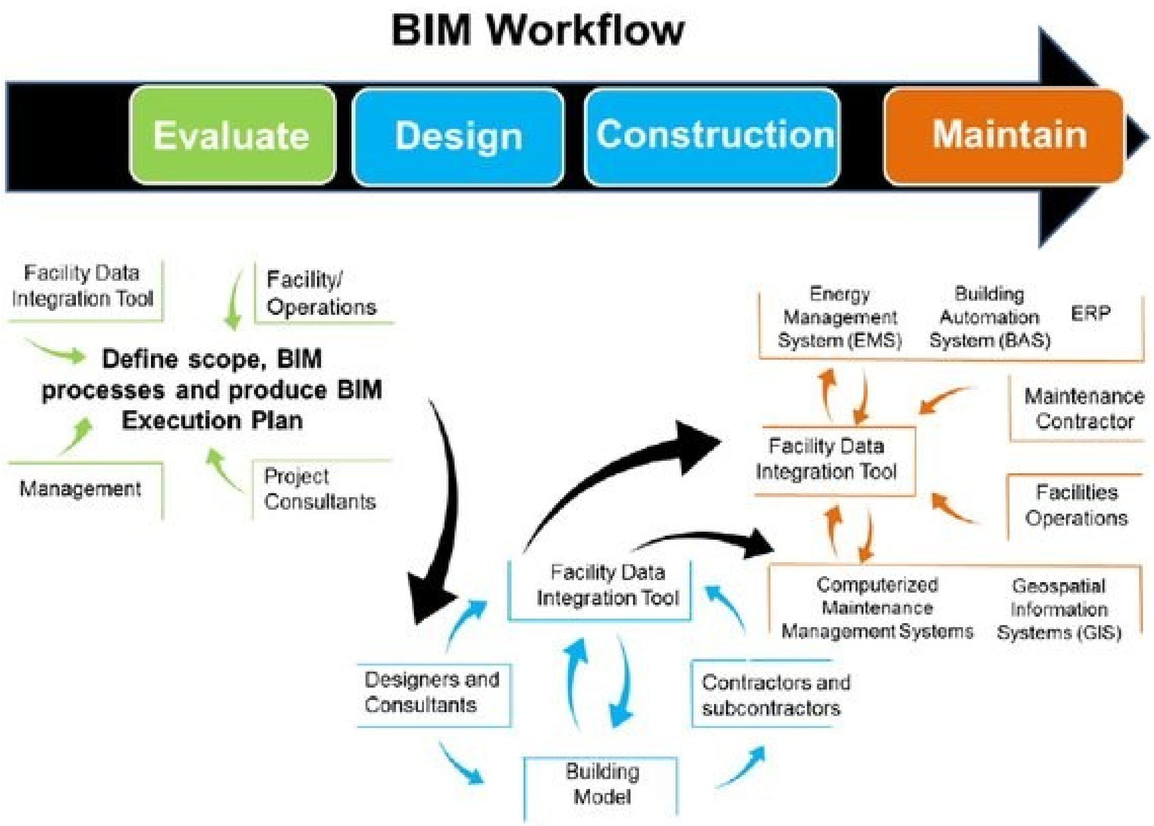

Figure 51: A benefits realization management BIM framework for asset owners (Benedetti et al., 2014)

To elucidate the usual behavior of augmented reality following BIM technology, the SWOT table below (Table 5) describes the Advantages (Strengths), the Disadvantages (Weaknesses), the Opportunities (Opportunities), and the Negative External Aspects (Threats) that are strategic analysis tools and deal with the objects of study of this research.

Even dealing with different workflows studied in this research, the SWOT descriptions suggest that they are general in scope, covering the three objects of study. It serves as strategic support in the Workflow phases in the building lifecycle, with a clear view of the advantages and challenges of using AR, its benefits, and the negative aspects of evolving technology such as augmented reality.

BIM and AR	
Strengths ▪ View and evaluate the object; ▪ Transport of information; ▪ Scale the object in the application; ▪ Consult real-time information from the Common Data Environment (CDE) and request revisions; ▪ Simultaneous real-time interaction	**W**eaknesses ▪ Difficult to position the objects in the real scene; ▪ Technical limitation of the mobile device causes unsatisfactory results; ▪ Large data transfers; ▪ Close integration with BIM software solutions
Opportunities ▪ Use for design and planning (3D); ▪ Use for scheduling (4D); ▪ Use for construction (5); ▪ Use for Continuous System Integration (6D); ▪ Use for Operation & Maintenance (7D); ▪ Easier knowledge acquisition and transfer; ▪ Next generation of augmented reality based BIM modelers; ▪ Education; ▪ Live remote interaction	**T**hreats ▪ Relying on augmented reality for specific BIM object information; ▪ 3D BIM model not available; ▪ Information not available; ▪ Information is not in the proper file; ▪ Incorrect information

Table 5: Augmented reality in SWOT analysis (by author)

5.2 Results and aims

According to (Bajura & Neumann, 1995), the four possible causes of errors in registering the conjunction between real and virtual images and their respective consequences are described in (Table 6).

	INACCURACY IN THE REGISTRATION OF THE COMBINATION BETWEEN REAL AND VIRTUAL IMAGES	
	CAUSES	CONSEQUENCES
1	Origin of the tracking system and bases of misaligned world coordinate system	the virtual object will be displayed displaced from its correct position
2	The virtual source-object transformation different from the real source-object transformation	the object will appear out of position
3	The unequal virtual camera position from the actual camera position will result in two errors	in the pose, causing incomplete registration. The temporal causing insufficient enrollment only when the user moves.
4	Virtual camera to image mapping does not correctly model the real camera	registration errors according to the position of the screen.

Table 6: Causes and consequences (by author)

In addition to the premises of the previous table, the studies cases result using a mobile device with the Dalux app are shown below:

Drugi Tir

- Results: Difficulty in the geolocation of the actual physical object; difficulty in viewing in AR caused by the incidence of sunlight; impossibility to move or rotate the 3D model in RA; it is visualized as a static object.

Marija Gradec

- Results: Difficulty locating the georeferenced bridge; difficulty in viewing in AR caused by the incidence of sunlight. It was impossible to find other information about the object of study due to the lack of information in the 3D model, despite good access to the internet signal. It is critical that the BIM model add non-geometric data to the 3D geometric data. Visualization of the positioning and sizing of the BIM model in the AR system application is possible due to the available reference points.

Iskra Mehanizmi

- Results: Difficulty in determining the geolocation of objects within a building for the feasibility of reading in the AR system; The AR app can solve geolocation with different approaches; Exact positioning and sizing of a BIM model in the AR application is possible through the available reference points; BIM models generally have more complete data and information in buildings than infrastructure environments such as bridges and tunnels. Consequently, the AR system can make better use of this available information.

After experimenting with the Dalux augmented reality app in the case locations and exposing the results of the challenges, it is expected that this MAR will overcome obstacles with the advancement of technology to facilitate the work of software developers to:

- Improve the tracking system to satisfy the complex demands of construction uses and achieve high accuracy.
- Brightness adjustment on future monitors to meet safety requirements and external conditions of construction applications.
- Possibly moving the object captured in AR on the screen to have an alternative view of the object or scene in the background.
- Advancement in quality and internet coverage in areas of difficult access.

The relationship between the results obtained from the three cases and the AR app improvement objectives is below (Table 7).

Entering data when using the AR app	CASE 1 Drugi Tir		CASE 2 Maria Gradec		CASE 3 Iskra Mehanizmi		Improvement aims
	YES	NO	YES	NO	YES	NO	
3D BIM model							Affordable costs for effective adherence to BIM technology
4D, 5D information							
Georeferencing (GPS, GIS)							Improve the tracking system for complex demands
Access to real physical object geolocation							
Sun light							Brightness adjustment on future monitors
Easy sign access of internet							Advancement in internet quality and coverage in areas of difficult access

Table 7: Challenges as a result of the case studies and the respective objectives of improvements to the app in AR (by author)

6 CONCLUSIONS AND FUTURE DEVELOPMENTS

This study summarizes information about the use of AR technology in the BIM project life cycle in the AEC industry. It covers all phases where augmented reality technology can be used to increase project efficiency and improve productivity, improve coordination and collaboration among all stakeholders, improve quality of work, and increase worker safety.

In the context of BIM technology, the use of Augmented Reality in the AEC industry allows designers to place the virtual construction project in a real environment; it ensures an engaging and interactive experience for builders and the ability for subcontractors to communicate efficiently with both clients and the technical team. Through AR, it is possible to obtain a special function, namely "instant visualization", which facilitates communication and decision making among project stakeholders and according to to (Wang, Wang, Shou, & Xu, 2014), AR, inherently involves human sensations with real and virtual information sources.

The case studies are different from each other. The first is a road infrastructure project, more specifically a tunnel (already completed). The second is an architectural project for a commercial/service building (under construction) with 3D models of BIM, which could be viewed at AR. They are used to illustrate how augmented reality is integrated into BIM and the benefits and challenges encountered in the research.

It is important to emphasize that AR can help bridge the gaps between design and execution and the interaction between project stakeholders, becoming an important ally for the development of the construction industry. The question is not whether AR is useful to improve construction-related tasks, but the challenge is to understand how to implement this technology and realize its full potential and competence.

AR needs to be studied in terms of its performance to improve understanding between the processes of information transfer to direct it to each phase of the BIM project, improve the development of software for integration between BIM and AR, and understand the data contained in BIM that is effective and essential for visualization in AR to achieve successful results. Such future research can improve the quality and speed of execution, reduce losses and increase work productivity within the life cycle. Moreover, with the rapid development of technology in Industry 4.0, a 3D model BIM integrated in AR can be developed to legitimize the promise of being used as an integral part of the construction industry.

Another aspect to be explored is an alternative information flow in building models capable of generating or updating data and information in real 3D space, on mobile devices and not just on PC screens. It is envisaged that developers and vendors of building data modeling software will improve their products in this way based on research and scientific articles.

Leaders in the computing field believe that augmented reality will significantly change the way BIM AEC applications work. However, augmented reality applications (AR) need to overcome technological challenges such as improving occlusion, the process of creating 3D content, and the quality and connectivity of components, and increase the computing power of devices (MAR). AR on smartphones is the beginning of overcoming some challenges, and smart glasses with AR could completely change the user experience. With these glasses, users can access speakerphone and content displayed in front of their eyes (like a 'space screen') to get a fully magnified view of the natural world (Silva, Gaber, & Dolenc, 2021).

There is still a long way to go, and the technology depends mostly on companies and project participants. However, with perseverance, persistence and time, mobile augmented reality (MAR) will be an essential and accessible part of architectural practice, making the boundaries between virtual and real worlds more fluid (Abboud, 2013).

7 ACRONYMS AND APPLICATION

2D	Bidimensional
3D	Tridimensional: 3D modelling
4D	Time-related info ǀ construction sequencing by means of Gantt charts and timelines
5D	Cost Analysis ǀ cost management, construction cost estimating, etc.
6D	Sustainability ǀ environmental, economic, and social sustainability impact studies
7D	Life cycle and maintenance ǀ Facility Management: planning and management of maintenance operations throughout the building's lifecycle
AEC	Architectural, Engineering, and Construction
AIR	Asset Information Requirements
AR	Augmented Reality
AREL	Augmented Reality Experience Language
AR4BC	Augmented Reality for Building and Construction
BAAVS	BIM + AR + Architecture Visualization System
BEP	Building Execution Plan
BIM	Building Information Modeling
CAD	Computer-aided design
CAFM	Computer-Aided Facility Management
CDE	Common Data Environment
CMA	construction management agency
CMR	construction management at risk
CMMP	multi-prime construction management
CMMS	Computer-Managed Maintenance System
COBie	Construction Operation Building information exchange
CPS	Cyber-physical system
DB	design-build
DBB	design-bid-build

DT	Digital Twin
EIR	Employer Information Requirements
FBX format	used to exchange 3D geometry and animation data
FM	Facilities Management
GIS	Geographical information system
GPS	Global Positioning System
HBIM	Historic Building Information Modeling
HCI	Human-computer interaction
HHD	Hand-held displays
HMD	Head-mounted display
HVAC	Heating, Ventilation, and Air Conditioning
IAI	Industry Alliance for Interoperability
ICT	Information and Communication Technologies
IFC	Industry Foundation Classes
IN2AR	Programming language
IoT	Internet of Things
IPD	integrated project delivery
ISO	International Organization for Standardization
MAR	Mobile Augmented Reality
MARA	Mobile Augmented Reality Applications
MEP	Mechanical, Electrical, and Plumbing engineering
MIT	Massachusetts Institute of Technology
MR	Mixed Reality
MVD	Model View Definition
NBIMS-US	National Building Information Modeling Standard
OBJ format	Object computer science
OpenCV	Open Source Computer Vision Library
OST	Optical-See Through
PC	Personal Computer

PDA	Personal Digital Assistant
PL	Programming Language
QR code	Quick Response code
Revit	BIM Software by Autodesk
RF	Radio Frequency
RFDI	Radio Frequency Identification
RWWW	Real-World Wide Web
SAR	Spatial augmented reality
SLAM	Simultaneous localization and mapping
SD	Spatial displays
SDK	Software Development Kit
SWOT	Strengths, Weaknesses, Opportunities, and Threats
STD1	Standpoint 1
STD2	Standpoint 2
STEP	Physical File Format – SPF or IFC-SPF)
VR	Virtual Reality
WLAN	Wired Local Area Networks
XML	extensible markup language
XR	Extended Reality

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