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Review paper: Investigation of Augmented Reality –BIM Benefits in Design Process in the AEC Industry

Sadeer Hel Al-Dhaimesh, Nooriati Taib*
Institute of housing, building and planning, Universiti Sains Malaysia, 11800 Penang, Malaysia E-mail:Sadeer9091@gmail.com, nooriati@usm.my
*Corresponding author

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The industry of Architecture Engineering and Construction has long been known as dynamic and complicated. Growing demands on building projects in areas such as safety, energy, time, and economic management have driven the sector toward new tools and processes, including more effective utilization of digital technology, in recent years. Building Information Modelling (BIM) is gradually establishing itself as a core technique among the several accessible digital solutions, with its practices and technologies being progressively used. The existing barriers to BIM adoption, on the other hand, allow the creation of supporting technologies. The current article examines Augmented Reality (AR) as a tool in this regard. A comprehensive study was carried out to investigate existing research in the domain of BIM-based AR, revealing insight into its integration in the AEC industry. PRISMA-P is the reviewing approach that was adopted. A total of 79 articles were chosen for the study from a sample of 120 articles. This assessment demonstrates that AR implementation is far from complete, with various constraints such as connectivity and localization issues, a lack of non-geometric information, and other difficulties in employing AR techniques on the building site. The motivation for *this paper comes from the lack of attention to augmented reality through BIM among previous studies adding that previous theorists included augmented reality adoption alone. This paper is distinguished by its content for AR application into BIM from the conceptual stage, architecture stage, construction stage, and maintenance stage.*

Povzetek: V preglednem članku je predstavljena uporaba obogatene resničnosti v arhitekturi in gradbeništvu.

1 Introduction

Architecture, Engineering, and Construction sector are known for their growing difficulty and competitive nature, which is due to tight time limits, complicated tasks, and limited cost, which has driven the exploration for automatically generated and technically sophisticated solutions and methods. The architecture design process is the sequential development and analysis of a building project [1]. This procedure is often divided into seven phases to offer control to the project by establishing review intervals, developing a systematic distribution of design information, and identifying the natural stages of design. This is why the design process is critical; it organizes project management and provides effective communication for design purposes. The stages of the design process provide for effective and transparent production planning, reducing risks that might lead to costly, time-consuming delays[2].

Automation and digitization have recently provided this industry with the capabilities to achieve improved performance and reliability, lowering costs and updating operations [3]. The attempts to spread and integrate Building Information Modelling (BIM) are a prime illustration of the company's radical transformation[4].
The adoption of the BIM approach has yielded evident benefits in terms of cooperation, budgeting, 3D designs, maintenance, quantities, and material categorization, among other aspects[5]. As a result, more integrating and adaptable techniques that can leverage of diverse characteristics and be established based on construction project participants, personnel, everyday activities, and understanding are needed[6].

BIM-based Augmented Reality (AR) innovations in the AEC industry have been documented, with a variety of applications. Recent researchers have defined AR as a subset of Virtual Reality (VR) that might also provide a real-world environment with the incorporation of virtual elements. Moreover, AR technology has progressed beyond marker-based implementations to tracking solution systems[7]. AR/VR market valuations are anticipated to be $18.8 billion through 2020 as well as $60.55 billion as of 2023, with an annual growth rate of 40.29 percent. AR has also been listed as one of the primary BIM-related study disciplines[8].

The design process is a systematic and iterative approach to create a solution that meets a set of requirements. It involves several stages, including conceptual design, predesign, design development, construction, and operation, Augmented Reality (AR) and Building Information Modelling (BIM) are two technologies that have revolutionized the design process and have become integral tools for many architects, engineers, and construction professionals.[9]

This research offers an outline of building information modelling as well as the current state of the art inside the application of augmented reality in different building information modelling user situations. It covers many issues that must be solved, in addition to a range of end-user applications and use cases for AR applications in design, engineering, including construction (AEC).

2 Related works

AR has been suggested by researchers as a promising tool for enhancing and improving representation techniques in Architecture, Engineering, and Construction (AEC) projects offer numerous benefits to job site operations.

In his research, M. Albahbah, created a detailed map, highlighting the potential areas of application for AR in industrial construction. Their findings suggest that AR has the potential to benefit eight work tasks, namely layout, excavation, positioning, inspection, coordination, supervision, commenting, and strategizing[10].

Rankohi and Waugh categorized the applications of AR in the AEC industry into seven groups, including visualization or simulation, collaboration and communication, modeling, evaluation, monitoring, education and training, and inspection or safety.[11]

Several theorists studied augmented reality-based BIM benefits, for example, Paes and Arantes tackle cases that include design options for clients and quick decision-making with fewer changes in order during design [12]. While Goulding and Nadim presented the potentials of testing and feasibility of architecture design[13].others Li and Yi proved that AR_BIM enables a better and more realistic environment as a result saves person-hour. Others have conducted a group of benefits as reducing cost and risk, allowing earlier detection of project workflow, engaging stakeholders and clients in the design, better marketing of projects designed by AR, and simulation of lighting, shading, and shadow and conducted benefits as human scale and translation of architectural drawings [14][15][16][17].

The findings show that currently there are limited previous studies that classify the benefits of augmented reality according to the design process in one study [18]. Most of the researchers focus on demonstrating the use of AR_BIM in a single phase of the design process. Adding that no study classifies AR_BIM benefits regarding form and function.

For this reason, this paper contains a review of AR_BIM applications in AEC projects. This will be done in two-fold, the first AR_BIM cases in form and function, and the second, AR_BIM cases in the design process including, conceptual design, design, pre-construction, construction, and operation.

3 Literature review

3.1 Augmented reality overview

Augmented Reality (AR) is a computer-generated multimedia overlay over the actual world that may interact with the environment in real-time. There is no occlusion between computer-generated information and real-world stuff in AR. In most situations, computer-generated information can only be seen on smartphones or tablets [10]. The immersive viewing environment provided by phone-based AR devices is quite restricted. Furthermore, limited wearable AR technologies and Google Glasses are meant to overlay information objects or digital items on top of real-world surroundings [19].

AR is classified into four types: 1. marker-based AR (for example, scanning a QR code); 2. Location-based AR (for example, integrated with GPS for location 3. Projection-based AR (projecting to the actual surfaces). And 4. Implementing innovative AR (for example, the Furniture app that positions the virtual object in a real environment) [20].

AR is a setting in which computer-generated data is supplied into the operator's view of a real scene. AR allows viewers to access, visualize, and communicate with complicated information in the sense of the environment [21]. In other phrases, computer-generated components have been got to add to the real-world situation, observed reality [22].

AR systems are often divided into three stages: data input, computing, and visualization. The data input phase focuses on the generation, processing, and structuring of data. As in the framework of BIM-related activities, this entails creating a BIM model that can be utilized to augment reality [23]. Integrating virtual information as 3D geometry, particular element data, and so on) and actual settings is an extremely complicated phase that can occur on a mobile device or on a distant server. Furthermore, the mixed visualizations may be displayed on portable mobile devices such as smartphones or tablet devices, as well as head mountable gadgets[24]. The advancement and development of AR applications allows developments for education, design, production, construction, and enjoyment become more feasible to help enhance educational outcomes[25].

3.2 Building information modeling

Building Information Modelling (BIM) may be traceable to the initial thoughts regarding ways to employ the notion of product models in architecture design employing multiple media, as stated by previous theorists discussing the emergence of BIM further into the AEC industry [26]. Along with this progression, the Industry Alliance for Interoperability (IAI) was founded in 1995, to develop a standard for characterizing buildings that would enable the sharing of information about structures without losing its semantic content. This functional style is known as Industry Foundation Classes (IFC), and it was initially released in 1997 [27].

BIM digitized symbolizes the physical and functional characteristics of a building, allowing different stakeholders to collaborate across the project life to input, update, or adjust information inside the BIM process [28]. BIM is continually changing, trying to seek to optimize new tech in response to the sophistication of civil construction procedures, as well as the construction municipality has always been searching to keep innovating with BIM through all the workflow techniques including such AR / VR, that are currently being implemented straightforwardly to solve real-life issues such as configuration verifying and assessing [29]. Table 1 illustrates a comparison between VR, AR, and MR in real and virtual environments. The basis of building information modelling is the capacity to add meaningful information employing building information models that go beyond geometric representation; hence, they can also be examined in many levels, including 3D (design planning), 4D (schedule), 5D (expected to cost), 6D (product lifecycle information), to 7D (facility managing), the data structures used vary ranging from based on the format used both to organize the information and the model language to transfer the data [30]

VR-AR-MR	**Virtual environment**	**Real environment**	**Interaction**	**Type Mobile Standalone desktop**
Virtual reality	high	low	low	Desktop-standalone -mobile
Augmented reality	low	high	middle	Desktop-standalone
Mixed reality	middle	high	high	standalone

Table 1: VR, AR, MR comparison

3.3 Augmented reality-based BIM

Augmented reality can be defined as a system where a BIM is employed to augment the real world[31]. AR-increased BIM modeler, in which BIM model information is modified in an AR environment may also be anticipated. AR is nowadays being regarded as a "New Golden age" of information through all the sophisticated tech by scholars and professionals in the field of knowledge, due to the beneficial impacts of its developing technologies that its accurate use offers to the construction sector, particularly during the construction phase, supplying impacts the efficiency of projects, performance, safety, and health. And thus, project costs and duration, optimistically. However, integrating real-world and virtual objects can indeed be complicated[32]. Investigators identified four key issues that must be addressed: (1) the traceability system's origin also isn't associated with the world's coordinate system; (2) the shift from origin to the item is not precise; (3) the simulated camera's placement is not accurate - mainly due to gravity and kinetic sensor mistakes; and (4) virtual webcam mapping doesn't appropriately model the proper camera[33].

First, it is necessary to create geospatial characteristics for each BIM element so that the mobile AR system can use location data to determine the current location of the user and, as a result, be able to provide information about the regarded item [34]. Second, from the point that the data demonstrated in mobile AR relates to a user's position, a few points survey conducted inside of BIM also must be recognized. Third, for BIM to be workable in a smartphone AR environment [17].

3.4 Design process phases

The design process is the fundamental basis upon which any component is built; it investigates how we accomplish what we accomplish. It is a set of procedures that creative types use to create functional processes and products[35]. The design process is the sequential development and analysis of a construction project. This method is usually divided into seven five phases to provide sequence to the project by recognizing review periods, cycles developing a structured transfer of design documentation, and establishing the stages of construction. That is how the design process is critical; it organizes project work and provides effective communication on the design aim [36]. The stages of the architectural design process enable fast and straightforward production orders, minimizing the risk that might lead to costly, time-consuming disruptions. The architectural design process consists of main five phases; conceptual design, design, pre-construction, construction, operation, and maintenance. As for each stage, there is a set of checklists included in[37]. The figure below clarifies the design stages and the main checklist for each stage.

Conceptual phase: The conceptual design stage formalizes the preliminary concept. It helps to absorb engineering to give organizations a reliable assessment of common performance, potential looks, and a basic knowledge of the field of view of the ongoing development, such as marketability, labour, and anticipated costs [38]

Design phase: A process concerned with a lifecycle of the project, concepts, procedures, materials, and milestones Discover how project design can enhance the productivity of a team with thorough resources and graphic elements [39].

Pre-construction phase: Includes developing a project strategy, designing the project, obtaining permits or allowances, and assembling the labour and resources needed for construction. Pre-construction solutions may provide shareholders with a structured approach to working to evolve cost, scope, and timetable to complete the building on time and within budget. it is critical to the success of a project[40]. Throughout this process, the development team organizes, becomes associated with their perception,

And the basis of effective communication as well as the process is set. A building project could indeed rapidly become unorganized without a solid foundation, resulting in ineffective communication, gaps in the process, and prospective project delay [41].

Construction phase: the construction phase is a physical procedure of building, as well as all related processes including such landscaping, renovating, site preparation, and demolition[42].

Operation and maintenance phase: The Operations and Maintenance Phase's goal is to guarantee that the data system is fully operational and performing optimal way until the construction end of life[43].

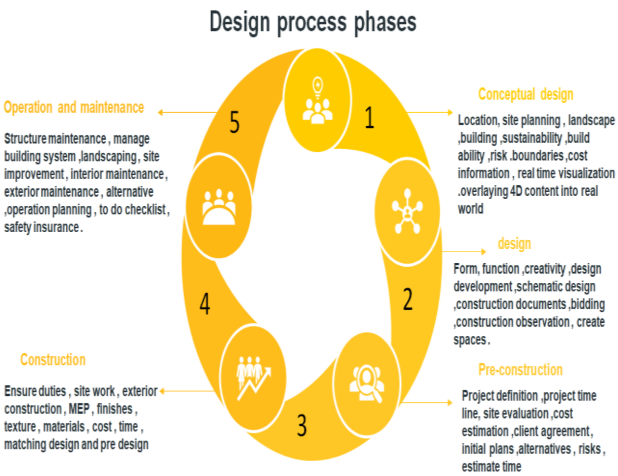


Figure.1: Design process phases duties from previous studies by authors.

The previous theorists conducted augmented reality applications separately without considering the transition towards BIM., as for that this paper distinguished by including case studies of AR through design stages as multi aspects; architecture design and other (pre-design, interior design, construction, maintenance). [44][45][15]. The objectives of this paper a to investigate the potential of AR_BIM in the AEC industry and compare the adoption percentage of AR_BIM in AEC in the design phase.

4 Methodology

PRISMA-P approach has been used to conduct this systematic review. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), it is a minimal collection of evidence-based elements for reporting in systematic reviews and meta-analyses [46]. This method was developed in 2009 and, owing to its repeatability, it is employed in an expanding variety of scientific and technology research domains due to its capacity to facilitate the creation of increased syntheses[47]. All relevant research processes were detailed, including information source materials, search method, inclusion, and exclusion criteria, as well as the primary instruments for assessing bias in eligible research[48].

The purpose of this study is to establish a framework for and classification of AR applications in architectural design. Researchers adopted a systematic literature review by investigating augmented reality-BIM in AEC. The major two academic sources, Scopus and Web of Science were employed for the study. As shown in Table 2. The procedure was AUGMENTED REALITY, BUILDING INFORMATION MODELLING, BIM BASED –AR, AEC, PRACTICE. The rules for research were based on :(augmented reality), (BIM Bases AR), and (AR adoption in AEC). All articles with the above keywords in the title/abstract/keywords were selected for this study. 79 articles were selected from a total of 120 after inclusion criteria for further analysis.

Inclusion Criteria	Exclusion Criteria
Related to AR	Related concepts such as VR and MR
Related to BIM	Non-BIM concept
Published from 2010-2022	Published before 2010
English language	Publication as non-English
Peer reviewed	Non-peer-reviewed
Published article	Unpublished article

Table 2: Inclusion and exclusion criteria

As for inclusion criteria, the bolometric method was adopted as following steps:

1. Identify keywords; BIM, Augmented reality, construction, and design process.
2. Include articles from the period 2010 to 2022
3. Include articles that are published
4. Articles from the Web of Science, the Science Direct, and Scopus
5. Include articles in the English language

However, the adopted PRISMA method is shown in Figure 2 the articles were extracted from multiple databases in about 120 articles, after the inclusion criteria it was about 79 articles for the study.

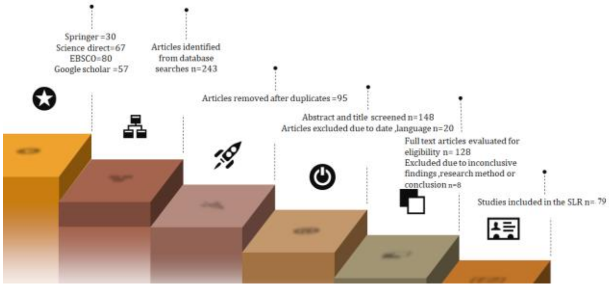


Figure 2: Bolometric analysis of the selected keywords and Prisma method [49].

After adopting the PRISMA method about 234 articles were found associated with the identified keywords from 2010 to 2022.as Figure 3.

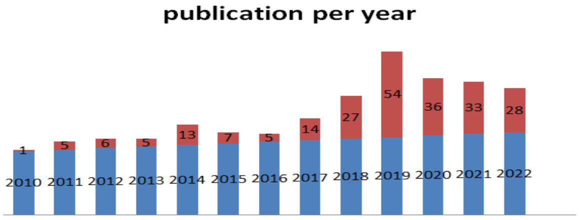


Figure 3: publication articles per year of the keywords “BIM” and augmented reality.

The following chart illustrates the selected articles from the previous method, before applying inclusion and exclusion criteria. Moreover, these articles are categorized into five phases based on the design process including conceptual design, design, pre-construction, construction, operation, and maintenance. Figure 4 illustrates the number of articles based on the design process.

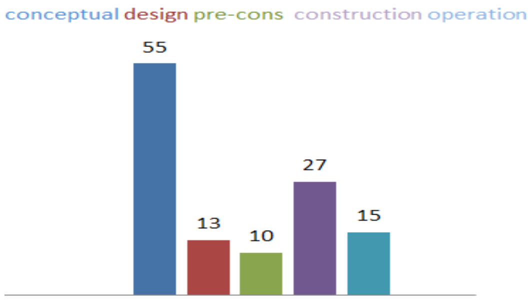


Figure 4: Number of articles based on the design process.

Data collection: This research is focused on identifying AR research and applications in architectural practice and education based on previous studies. Academic journal and conference publications from 2010 to 2022 were primarily evaluated for paper retrieval. For scanning, the most comprehensive academic databases, Scopus, and Web of Sciences, were employed. The keywords set includes AR, AEC industry, architecture education, BIM-aided AR.

Data analysis: A few keywords are used to examine the selected papers. The keywords were taken from a few previous content analysis studies. This study's keywords include augmented reality in AEC, the concept of augmented reality, and applications. Data is categorized under the architectural discipline, where augmented reality is deployed.

5 Augmented reality: use cases and benefits

This study will focus on AR_BIM through the design stage among different projects it will be divided into architecture design cases and engineering and construction including the design phase revisit of suggested solution, and construction stage tracking of project construction.

However other pertinent utilize scenarios, such as layout enhancement, excavation, placement, inspection, coopera tion, supervisory, and
commenting, must be considered, as noted by earlier theo rists[50].

Various representative utilizes cases are defined throughout the preceding sub-sections. focused on construction projects (tunnels, railways, and bridges) and an office complex A BIM-specific software device was used in each of the provided use cases to obtain BIM models in addition to using the fully integrated AR solution [51]. The phone applications make use of a BIM-shared information environmental solution, which serves as a central gateway for all individual interaction, information sharing, and other functions [52].

AR has evolved into a powerful visual tool for architectural learning and education, and it is currently undergoing significant growing research [53]. AR models have been utilized in learning and design environments to present learners with previously unavailable real-life experiences. Once architectural designers use VR, they will be able to rapidly understand the spatial features of their projects[54]. They will be able to comprehend their creations by strolling around the augmented area and seeing the colouring and textures of the given materials, the proportion of the spatial structure, and the aesthetic representation.[55]. Furthermore, interactive, and immersive virtual augmented reality (AR) technology assisted its building industry clients in the design, simulation, branding, and new project sales by conducting a pre-construction walk-through in the augmented townhouse where last-minute design concepts were evaluated. AR will be crucial in the teaching of cultural structures. Designers can use AR technology to create a training application in which they can engage with virtual objects to learn how to construct traditional buildings. Furthermore, research on the adoption of AR revealed that the architecture was changed, employee happiness rose, and costs were reduced [56].AR may encourage some of the same behaviour as virtual reality and practical mock-ups, such as decision-making, alternative, descriptive, and interpretive, in design and buildability analysis sessions, and problem-solving actions [57].

5.1 Case studies of augmented reality projects

This study includes fifteen case studies in the AEC industry. Even though the construction sector is among the earliest and most vital in the world, new tools for employment frequently perform poorly to gain traction. There is a lack of articles which are consisted of AR_BIM case studies and projects[58]. On the other hand, author has collected the most significant and available case studies in this field case studies selected and justified by Table 3:

Case	Real site problem
1	Provide data before going to the high-safety risk zone underground the construction site
2	Hard Topography in the location to perceive design heights
3	The shift towards modernist architecture covered the importance of saving historical buildings
4	The challenge of different materials and components in one staircase
5	There were concealed items under the plumping system which makes the design imposed
6	It was difficult to educate graduates in prototyping a specific design in a physical location by traditional learning
7	The environment around this construction project was unsafe besides the infrastructure was covered with mud
8	During Coved pandemic exhibition and galleries were shut off.
9	Design waste by users was at the maximum stage
10	Designers must present their works in a certain location, and users traveling was necessary
11	Exhibition carbon emission was high at the physical enrolment.
12	Project teams are from around the world and not on the same site.
13	Coordination by Google map was not enough to design and position and scaling
14	Imagination that was based on calculation is difficult to be generated by a human
15	Difficulties in site topography and perceptions in mocking up design.

Table 3: Design problem-solving through case studies.

The selection process of case studies and the project is based on identifying AEC projects of augmented reality which is implemented in the design process specifically as a representation tool adding that the adoption of AR must be integrated into BIM.

1. Lukasz Carnot Mercantile Hotel

The planned structure is the current Mercantile Hotel. The suggested AR app process for monitoring and inspecting the construction phase will be analysed by viewing the segmental accomplishment of construction operations on the projected development of the current Mercantile Hotel. AR technology is employed to overlay the intended 3-D model on the actual world to lead the construction crew through the assessment and monitoring of planned worksite operations. The approach starts by combining the BIM with the construction program to produce construction sequences animations to observe and track the construction phase enabling the identification of important project stages and the communication of the anticipated project timetable to all project participants [59].

The application's key advantage is its marker-based innovation, which enables the user to match the suggested BIM rapidly and accurately with the actual environment, as illustrated in Figure 5. The following are the tasks conducted by the researcher to evaluate the procedure and the augmented reality app for tracking work progress.[59]

Figure5: Proposed hotel and marker-based tech in the real environment.

2. IGA 2017 Berlin channel

A digital walk by this area was created by radar. The RADAR system was created by the Kaiserslautern Research Artificial Intelligence Centre (DFKI) as shown in Figure 6. RADAR is a platform that allows people to place their own geo-information on a map and link it to related information and material. The geo-referenced material may then be delivered to AR browsers such as Layer. The RADAR system provided clients with an easy program that allowed them to quickly materialize their concepts [60].

Figure 6: Channel of IGA Berlin 2017 between the conceptual AR and executed project.

3. Building culture Saarbrucken projects in the 1950s (vision)

The town of Saarbrucken intended to employ innovative methods to educate and sensitize property owners about the unique features of this building. Especially with certain "poor" modernizations going on by the property owners or a large amount of outdoor advertising on the street level, the city's effort is critical to keeping the heritage alive[61]. Original color photos from the 1950s were exhibited in the current scenario on the phone's screen to examine what the town looks like at the period. As augmented information upon that façade, features of 1950s design were emphasized. Images of the stairs were also presented as overlaying data on the exterior to indicate what type of treasure the structures hide on their insides. As shown in Figure 7, the users can take a virtual walk through the project, gain a sense of the past, and learn how the town of Saarbrücken aims to bring the vibe again into modern-day life on the streets. Apart from the walking tour around Saarbrucken's streets, there was additionally an essential information station in the marketplace that allowed everyone to stay informed before, during, and after the event by using augmented brochures and flyers. Individuals who were unable to attend the physical tour seemed to have the opportunity to explore the town as a virtual three-dimensional model. With common CAD application. every station that uses AR seems to have four points marker which helps users to enjoy light and shadow during the day[62].

Figure 7: Augmented architecture elements of 1950s structure in Saarbrucken

4. Railway footbridges

Council members approved the second stage of the plan to preserve the railway line at Dawlish, which will result in significant advancements to a historic Brunel train station. Network Rail is adopting AR Technology to communicate future architectural projects to the public, designing the city and allowing the audience to be actively engaged from an early stage of the design choice through construction. AR enables the improved alignment between construction and design. also, it supports the diversity in materials selection between clients and designers. The key variable in this design is the long span of the footbridge which was solved by the mock scaling that AR offers during design, each footbridge was visualized over various spans. Figure 8 shows the final design visualized in the real environment; it shows alternatives for one design [63].

Figure 8: Railway footbridge alternatives designed by AR_BIM.

5. Plumbing system

Maintenance employees must quickly learn a wide range of skills. Instead of discovering usable data from a vast number of plans or damaging existing buildings, sophisticated technical tools may swiftly locate the maintenance location in a considerable number of concealed engineering as shown in Figure 9. As companies make improvements to buildings and outdoor areas, AR systems may allow maintenance personnel to avoid concealed items such as underground plumbing, electrical cables, and structural components. This has the potential to either accelerate maintenance and reconstruction activities while also reducing the amount of unintended harm they typically cause. A "see-through" component for tracking the position of piping and ventilation system behind walls and panels, as well as other hidden components like walls and beams, might make maintenance tech and reconstruction easier [64].

Figure 9: Review plumbing system mapping using AR_BIM in site.

6. Studio project

This was a small project to educate architects in prototyping the same design using augmented reality, first the project was modelled through BIM and then visualize through augmented reality, then multi options for the same design came based on location, and weather, Figure 10 illustrates that AR helps the designer to set the scheduling step exactly where the green colour views the items that under process. the construction of this project was implemented on time with the help of mixing AR into BIM. As for this study some advantages were seen by AR implementation as follows: it sets the existing building beside the real environment and identifies colours and materials also it identifies construction materials in detail. [65].

Figure 10: AR-BIM model for a studio project.

7. Warsaw Road swing bridge

Warsaw Road Swing Bridge was built in 1956. According to city employees, around 10,000 cars cross the Warsaw Road Swing Bridge per day. According to engineering examinations, this bridge was reaching the end of its usable life. Parks Canada offered a bridge repair as a component of the infrastructure upgrades along the Waterway National Historical Site in 2020, following a period of study and design work. The goal of this initiative is to improve historical, tourist, waterway, and roadway assets inside national heritage landmarks, national parks, including national coastal nature preserves to provide safe, rising visitor experiences [66]. Figure 11 illustrates the integration of AR_BIM in a real site plan.

Figure11: Warsaw Road swing bridge design progress by AR.

8. RIXC Centre for New Media Culture

Senses Art was released by the RIXC Centre Culture in 2021. It is a Navigation augmented reality application that invites users to virtual exhibitions hosted outside. It presents digital art collections housed close to the Latvian National Art Museum near Riga. Figure 12 illustrates that Individuals may experience the outdoor exhibit securely and on their own time[67].

Figure12: RIXC Center exhibition through AR.

9. AUGMENTED BERLIN artwork exhibition

Anika Meier has produced an augmented reality art show as in Figure 13; Fashion Week This interactive group show including augmented reality art encourages virtual guests using a phone or tablet to put eight artworks by Berlin artisans in public spaces or even in their local walls. Such augmented reality program does not necessitate users to travel. Rather, people all over the globe are encouraged to utilize the application in their local communities to bring artwork by Berlin designers out of their local homes or public space[68].

Figure 13: Berlin exhibition using AR.

10. The seeing the invisible exhibition

The unique exhibition of its sort created in partnership with a botanic garden as well as art organizations from all around the globe as seen in Figure 14, Seeing the Invisible is a collaboration between the Jerusalem Botanic Garden as well as the Outset Art Collection Found that will take place in Twelve gardens around the world between September 2021 to August 2022. The exhibition includes Thirteen pieces by artisans using augmented reality. Visitors can join the exhibition by using a tablet or smartphone application that is enabled at the local gardens. Even though all gardens feature an identical exhibition, the artworks are presented in various places, providing spectators with diverse viewpoints depending on their location in the world. Because of the structure of AR, there has been little disruption to the grounds of the participating botanic garden, and the exhibition's carbon emissions have been reduced to a minimal[69].

Figure14: The seeing exhibition using AR.

11. Historical storytelling (L'Aquila Historical Centre)

Due to the 2009 earthquake, the town of L'Aquila's urban layout has changed dramatically. There is a distinct gap between the physical ultimate reality of places, the result of history which has brought it to the current, and the dimension of the invisible as the junction of memories and daily existence Figure 15 clarify AR application in designing façade.[70].

Figure15: L'Aquila Historical Centre using AR.

12. Iskra Mehanizmi Brnik industrial building

"Industrial and commercial building Iskra Mehanizmi Brnik" is split into three main blocks, the commercial part which includes reinforced structure, and the other two parts regarding storage and production units constructed by prefabricated concrete. This case study focuses on the office building part, this case clarifies AR adoption along the lifecycle as shown in Figure 16. Different data was available and includes the BIM model connected with the augmented reality part. BIM model includes geometrical and non-geometric design data including geography through location (3D), technical requirements(4D) as doors and windows manufacturers, and professional maintenance (5D). The correlation of the three-dimensional model BIM and augmented reality is accomplished through three key components: the three-dimensional BIM on its own, the entire readout, and the transition of the information for analysis in AR via a suitable app on a portable device, such as a tablet for this case. The 3d BIM provides and receives BIM data, including such installation modification needs and project planning evaluation, to allow visualization on the AR system, enabling the user to engage with three-dimensional model BIM as well as other participants of the construction team. In actual environments[71].

Figure 16: Industrial Building using AR.

13. Railway project

This is a construction project as a second railway track from Divaa to Koper, which comprises the construction of much more than 17.4 kilometres of roads leading with different structures functioning as service areas for tunnels, retaining structures, and a 35-meter-long bridge. It is one of Slovenia's major infrastructural projects [18]. This case study fits under design and planning stage of the whole life cycle, allowing AR to see the construction project structure in addition to the entire building in the real surroundings. this case aimed to investigate how AR and its application in the chosen smartphone app may be utilized in infrastructure projects which are defined by great distance[72].

To evaluate this case study, a tablet device with an augmented reality app was utilized in two distinct sites a few kilometers apart as shown in Figure 17. However, in a design model on tablets. Both are mapped and correctly integrate the needed information in the three-dimensional model. It deploys AR technology to see 3D interactive simulations on site. It was able to inspect the tunnel entrance and MEP systems, in addition to the train line to be built, in addition to the overall magnitude and difficulty of the building site[73].

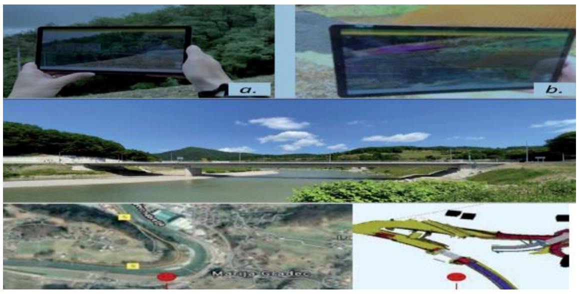


Figure17: Geo position by Google map and coordination by BIM model and AR.

14. Gravity Garden by Ivo Ambrosi

Gravity Garden is a natural space created by applying external forces to a basic pre-defined shape as shown in Figure 18. The architecture is defined by the algorithm that describes its genetic code. The optimization of the mathematic algorithm that generates the structure, determined by software, defines its ultimate shape, much as nature uses the bones of a creature or the leaves of a tree. The size and dimensions are related to what is required for its survival[74]. There is little opportunity for the architect's creativity, and the "inventor" goes a step further in this evolutionary process, watching and controlling the continual progress of his product from the outside. And manipulating project size and scale[75].

Figure 18: Gravity Garden by AR –BIM.

15. Extended building

Site Vision uses a BIM model to demonstrate how to envision a building using augmented reality, completely textured together with the environment. Because the house is on a slope, Site Vision displays how the model would seem in this difficult context as is seen in Figure 19. AR includes: - To use the "Create New Model" tool, place one of the border pegs. Setting up over a known point allow local coordinate system to operate with; the Sketch-Up axes will be in this place. - Obtaining points - How the structure interacts with other structures. AR it is useful in assisting your design process and displaying how the design interacts with the real world with the location workflow [76].

Figure 19: Building integration with site.

According to previous studies, AR_BIM benefits are summarized into a list as shown in Table 3

AR benefit code	AR benefit
B1	Real-time visualization
B2	Design making
B3	Improve collaboration
B4	Spatial interaction
B5	Detect errors
B6	Problem-solving
B7	Client's feedback
B8	Reduce waste
B9	Improve productivity
B10	Improve the quality of the design
B11	Improve safety
B12	Present details
B13	Improve communication
B14	Collect data easily
B15	Spatial aspect detection

Table 3: AR benefits through selected case studies

The fifteen cases are selected based on AR_BIM adoption, two main parameters were fulfilled through; form and function, each parameter has a specific reflection in designing a project, as shown in Table 4.

No.	Parameters included through AR		No.	Parameters included through AR	
	Parameter	(A)Form/(B)function		Parameter	(A)Form/(B)function
1	Geometry alternatives- A		8	Reduce time and effort A	
2	Movement track B		9	Pick colours A	
3	Geometry /shade/shadow- A, B		10	Pick plants /shade /shadow B	
4	Accessibility – B		11	Track movement B	
5	Infrastructure – B		12	Building orientation – A	
6	Geometry /materials/orientation-A, B		13, 14	Façade reconstruction -A, B	
7	Ensure safety- B		15	Decrease waste – B	

Table 4: AR case studies parameters

Figure 20 illustrates AR_BIM projects that concentrate on function, form, form, and function together; this was an indication that the majority of AR_BIM cases are reflecting function issues, most of these cases are related to construction and engineering:
(Form)A: 5 cases almost 33 %
(Function)B: 7 cases almost 47 %
(Form and function) AB: 3 cases almost 20%

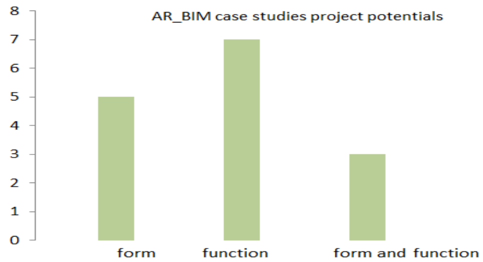


Figure 20:AR_BIM projects potentials in form, function, form, and function.

To discover the uses, advantages, and challenges of AR throughout the phases of the building project's lifetime, a literature review was accomplished involved a thorough scan of the literature by using the Google Scholar search engine Several terms, including Augmented Reality, AR, utilization applications, advantages, literature evaluation, construction stages, construction projects lifecycle, design, construction, and maintenance to mention a few. This search produced with 120 papers gathered from conferences and journals between 2010-2022 as shown in Table 5 [77][78][79].

Reference 1-79	AR-BIM phase code	AR-BIM benefits included in papers	Phase
25	CD	1. visual construction details (MEP system. 2. underground visualization 3. system mockup real-time project modeling connect the project with surrounding conceptual layout overlay 3D design into the physical world	Conceptual design
13	D	1. prepare 3D models 2. select materials and colors	Design
10	PRE	1. Review along design 2. clash detection 3. sequence planning 4. clarify design early 5. operate equipment and set them 6. full site scale 7. safety orientation	Pre-constructio n
17	CON	1. Visualizing models in the field 2. layout preparation 3. site layout 4. 4D simulation 5. monitoring workflow	Constructio n
13	OM	1. locate building contents that need maintenance 2. Compare alternative's pros and cons	Operation and maintenanc e

Table 5: AR_BIM references in design phase including benefits. Reference (1-79)

Table 6 illustrates the selected projects that adopted AR_BIM in design phase; each case study has recorded specific benefits through adopting augmented reality application into BIM. The selected cases are categorized as Architecture (A) or Construction (C). The project was varying into small projects, mega projects, or details inside a project. A small conclusion was defined by the authors correlated with AR-BIM including the main aspects and benefits.

Case /project	Phase Architecture/ construction	The main aspect fulfilled through AR-BIM	conclusion
1	C	1. project timeline 2. presentation 3. monitoring site progress 4. compare design workflow 5. geometric sequence	When the suggested workflows were compared to the existing ways, it was agreed that the construction industry may be ready for the use of augmented reality mixed with BIM models for day-to-day duties on a worksite. And developed a solution for the visualization of a construction site
2	C	1. movement tracking for the chairlifts 2. check how the building fit surrounding 3. site layering 4. put geo-located information and heights	The level of detail in AR model was highly adopted compared to a real project
3	A, C	1. convenience way to persuade architects through AR to preserve the cultural the style of this city 2. guided tour into the project 3. Adopted daylighting and shadow through the experiment.	The AR experiment includes project layering of color, texture shade, and shadow
4	A	1. identify the specific area as 3D design	AR helped the team with materials components as more exposure to design experiment
5	A	1. rapid maintenance 2. see behind hidden infrastructures	Maintenance through the AR_BIM system is easier than referring to many drawings
6	A	1. presentation technique better than traditional 2. prototyping based on weather and location 3. identify design scheduling 4. locating construction materials on site	80% of architects who designed this studio affirm that design was constructed with time of scheduling by the aided

				AR
7	C		1. reduce errors 2. improve productivity 3. simplify fieldwork 4. redesign and renovation 5. improve heritage	AR simplified reconstruction of this bridge and ensure the safety of users
8	A		1. reduce efforts and time in visiting the station of this museum 2. give a sense of place for individuals who participate in this experience 3.promotes new forms of arts by AR	There is no need for physical attendance to be an audience in a museum
9	A		1. AR helps in designing Berlin fashion week 2. control colors 3.no physical attendance	The technology of AR makes social distance bearable
10.	A		1. presentation of arts through gardens 2. pick the appropriate kind of plants 3. check shade and shadow	Exhibition carbon emissions were reduced to about 35 % compared to the physical exhibition
11	C		1. junction of memories and actual design 2. best design façade	AR enables full design planning with fewer design costs
12	A		1. project planning evaluation 2.useres engagement in design	AR enables users' and client's engagements
13	A		1. facade reconstruction 2. intersection between history and memory	In this case, AR carries the façade design workflow step by step aligning historical points and hypotheses from design (layering)
14	A		1. generate design shapes 2. life-size model 3. assess of light 4. walkthrough model	Walk through the scale of the project
15	A		1. facilitate workflow for construction site due to the difficult slope 2.provide accurate data to smooth design	Identify construction although slopes

Table 6: design stage for the selected case studies reference: (7,8,9,11,14,20,25,30,41,53,58,75,61,69)

This paper includes five design stages: conceptual, design, pre-construction, construction, and operation. Each stage is given ten points including criteria that it concerns. According to these criteria, points are given for each phase in the selected cases as shown. Figure 21 illustrates design process checklist for conceptual design, design, preconstruction, construction, operation, and maintenance. The authors conducted this checklist based on the previous theorist.[9]

Design process /identify stage /points

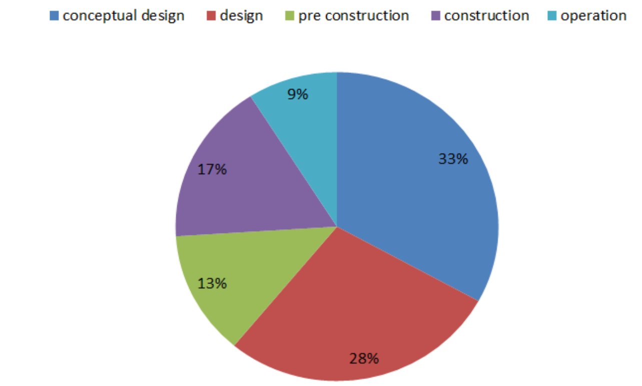
Case no	Conceptual design %	Design%	Pre-construction %	Construction %	Operation and maintenance %
1	0	0	10	50	40
2	50	40	10	0	0
3	60	40	0	0	0
4	10	10	30	40	10
5	0	10	20	20	50
6	60	40	0	0	0
7	10	10	20	30	30
8	50	50	0	0	0
9	50	50	0	0	0
10	50	50	0	0	0
11	10	20	30	30	0
12	20	20	20	20	20
13	10	10	20	30	30
14	40	60	0	0	0
15	20	20	30	30	0

Design process checklist

Checklist	Conceptual design	Design	Pre-construction	Construction	Operation and maintenance
1	Analyze context	Meet demands	Project teams	Ensure construction duties	Building structure maintenance
2	Location	Create spaces	Project definition	Site work	Manage building system
3	Site planning	Form	Project timetable	Exterior construction	Landscaping
4	Building	Function	Site evaluation	MEP	Site improvement
5	Landscaping	Creativity	Cost estimation	Finishes	Interior maintenance
6	Sustainability	Design development	Clients agreement	Texture	Exterior maintenance
7	Build ability	Schematic design	Initial plans	Materials	Alternatives
8	risk	Construction documents	Alternatives	Cost	Operation planning
9	Boundaries	Bidding	Risks	Time	To do checklist
10	Cost information	Construction observation	Estimate time	Match between design and pre design	Safety insurance

Figure 21: case studies design stage points, and main design process checklist.

From the previous checklist of design process, each case study has adopted Augmented Reality with building information modelling along design process components. It was noted that most of the adoption referred to conceptual design at about 33% and to design phase which was about 28%, followed by 17% for construction and 13% related to pre-construction. For operation and maintenance 9%. (As shown in Figure 22).



Conceptual design 33%
Design 28%
Pre-construction 13%
Construction 17%
Operation 33%

Figure 22: Case studies and the main aspect of AR_BIM adoption in design phase.

6 Conclusion and recommendation

This paper presents an overview of Augmented Reality (AR) applications associated with BIM across the design process. According to the publications gathered from 2010 to 2022, AR offers a wide range of applications in architectural design, construction, and education. The primary applications included many scholars noted that architects found AR applications to be quite useful in overcoming a lack of time and other resources (Cannaerts, n.d). They also stated that AR assisted architects in understanding concepts in difficult courses such as buildings and surveys[81].

Employing AR for architecture designers would allow them to comprehend the spatial aspects of their designs and understand their projects by walking around the virtual world and visualize the texture as well as the colour of the allocated materials[82]. The ratios of the spatial structure and the artistic expression of the structural elements of AR improve experiential learning and provide optimal engagement levels to successfully transmit knowledge to learners when it comes to improving construction education.

Designers may use augmented reality (AR) technology to construct a learning tool that allows them to create conventional structures and interface with virtual models. Furthermore, research on the utilization of AR revealed that the architecture was changed, employee happiness rose, and expenditures were reduced. Improving construction education and promoting practical learning using AR provides appropriate engagement levels to successfully convey knowledge to learners[83]. Students and practitioners in construction must visualize various building approaches and attend field trips. This may necessitate visits to building sites to bridge the gap between theory and practice.

AR enables researchers to follow, record, and evaluate human decision-making behaviors in a controlled setting with great precision and in short periods. AR may integrate safety with construction materials and techniques instruction by offering a creative platform for spiritually enhancing hazard awareness ability, transmitting safety knowledge, and guiding learners. AR technologies have emerged for construction and have been utilized in architectural and design simulations, construction safety & health, equipment and operational duties, and analysis [84].

Reviewing design through AR_BIM is a new area of research, with scholars still investigating various aspects of its optimization. Future researchers should examine unique features of the integration to enhance its effectiveness in the future including:

- Adding BIM projects versus AR_BIM tool to figure out a variance in potentials in the design process.
- Analyze the impact of AR technology on work performance concerning its influence on quality, implementation, minimizing losses, and enhancing the productivity of human resources. Besides, there is a need to study its benefits on clients' decision-making.
- Examine case studies with the design process and capture the benefits of AR_BIM from conceptual design to operation and maintenance.

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