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(Review Article)

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AI-driven smart construction for U.S. infrastructure modernization– understanding digital technology and it is tools for Architecture, Engineering, Construction (AEC) workflow: Review of literature

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Abstract

The growing integration of novel digital technologies and tools in the Architecture, Engineering, and Construction (AEC) business has resulted in substantial changes to workflow, performance, and project results. This review investigates how fundamental digital technologies, such as Building Information Modeling (BIM), Artificial Intelligence (AI), the Internet of Things (IoT), and Digital Twins, interact with specialized digital tools like Revit, Procore, AutoCAD, and Civil 3D to optimize AEC processes throughout the project lifecycle. The article conducts a methodical analysis of conventional, hybrid, and completely digital processes, evaluating their contribution to improved operational efficiency, data coordination, design correctness, and cost-effectiveness. This study uses literature synthesis, comparative analysis, and practical case references to identify how digital innovations lower error rates, promote sustainability, and transform project delivery models. Furthermore, the assessment identifies adoption benefits, such as worker preparation and fragmented data systems, and recommends collaborative solutions for maximizing digital value. By differentiating and integrating digital technologies and techniques (tools), this study adds to a comprehensive framework for developing smart building and modernizing infrastructure delivery.

Keywords: AEC; Smart construction; Artificial intelligent; Digital; BIM; IoT; Technology; Digital Tools

1. Introduction

The architectural, engineering, construction, and facility management (AEC/FM) industry in the USA is undergoing digital transformation, with digital assets such as construction management tools, BIM, and technologies realities emerging to support the production and delivery of physical assets [1]

Throughout history, the construction sector has dealt with classic problems, including budget overruns, time-based delays, and issues related to safety [2]. Current problems in construction receive solutions from the implementation of innovative construction technologies. AI, BIM, IoT, workflows tools and robotics join forces today to reconstruct construction procedures through efficient project management and reduced-cost implementation [3]. The successful development of a building or infrastructure has been revolutionized using modern construction technology and methods. It has a tremendous influence on improving and enhancing construction functions, cost, and digitalization processes.[4]

Civil engineering (AEC/FM) has historically been critical to the development of infrastructure, urbanization, and economic growth in Africa, Europe, South America, and North America (AESN). Technology and process digitization connected with the so-called Fourth Industrial Revolution have dramatically altered AEC methods across the world. A

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new, more digital work approach has driven the civil engineering business to adopt it, and with good implementation, it might provide profitable chances for AESN. The usage of digital technology workflows in industrial processes and ordinary human activities has lately risen [5].

Innovative construction practices deliver substantial economic benefits by reducing costs and improving competitive edges. According to multiple case studies, digital technologies have proven useful in the Architecture, Engineering, and Construction (AEC) industry due to their diverse benefits to project stakeholders, such as enhanced visualization, better data sharing, reduction in building waste, increased productivity, sustainable performance, and safety improvements [6]. Both on-site and off-site construction works coupled with digital technologies associated with the industry 4.0 concept can offer a higher rate of productivity and safety [7].

Common typical digital technologies are building information modeling (BIM), radio frequency identification devices (RFID), global positioning systems (GPS), the Internet of Things (IoT), geographic information systems (GIS), sensors, augmented reality (AR), virtual reality (VR), photogrammetry, laser scanning, artificial intelligence (AI), 3D printing, robotics, big data, and blockchain, and why digital tools are Procore, Monday.com, GIS, Revit, Civil 3D, Fieldwire, and so on [7]. Online courses have gained in popularity as a result of the use of digital technology in education, whilst traditional teaching confronts unprecedented problems. The fast rise of digital technology has become a powerful factor in rearranging resources, restructuring economic institutions, and altering global competitive patterns. Only those who can adapt and embrace digital technology and artificial intelligence may prosper in the future [8,9,10].

Innovative construction technology has ignited multiple debates about both potential automatic job replacement and worker skill deficit demands because continuous industry transformation becomes essential [11,12,13]

The necessity for continual industrial evolution arises because worker skills must catch up with current industry developments. Despite environmental concerns about the business, building experts say that employing modern technologies is necessary to accomplish sustainability goals alongside operational effectiveness [11].

Transformations within the construction sector drive attention to innovative building techniques that will determine worldwide developments of infrastructure and buildings. Modern technology during the twenty-first century allows the creation of structures that fuse durability improvements with multiple functional possibilities [14,15].

The construction industry has shown significant advancements through historical developments, as well as multiple environmental influences. Throughout centuries, the sector evolved from physical labor to automated machine usage to digital technologies, which transformed the design-build-management process of buildings [16,17]

The building sector has had rapid growth, as evidenced by historical observations of industry advancements, while builders encounter multiple influencing factors [18, 19]. The industry has seen a temporal revolution from manual labour to adoption technology, which has fundamentally altered the design, construction, and administration of buildings [20,21,22].

Technological growth experienced two significant developments during the 18th and 19th centuries, with the steam engine transforming transportation and machinery and reinforced concrete, which enabled the construction of better-lasting versatile buildings [23]. The late 20th century saw the rise of computer-aided design (CAD), which transformed architectural and engineering practices, enabling greater precision and efficiency in project execution [24]. These technological advancements have been driven by economic demands for faster and more cost-effective construction methods, regulatory changes promoting safety and sustainability, and the continuous quest for innovative building techniques [25] Professionals within the industry gain enhanced comprehension of contemporary patterns and forthcoming innovations by knowing past precedents. Modern construction challenges require knowledge acquired through past experiences, which serves as the foundation for improved current practices [26] Advanced technological integration stands as a vital element in this evolution because companies use historical progress knowledge to implement innovative solutions that boost construction process efficiency and sustainability [27]. This qualitative review is to explore, teach and discuss what traditional non-digital methods are, digital technologies in AEC, digital tools in AEC and construction workflow, how they can be incorporated and how they are used together to have safe, effective, efficient, cost and time managed construction work either in the pre-construction phase or during construction or after construction phase.

Objectives and structure

The primary objective of this review study is to comprehensively discuss the following:

- Traditional (non-digital) methods of workflows in Architecture, engineering, and construction (AEC).
- Hybrid method of workflow in AEC.
- Digital technology method of workflow in AEC
- Key AEC digital workflows stages and tools are commonly used.
- How digital technologies and digital tools in AEC are interconnected.
- Benefits of digitalization in AEC.

2. Methods

This review paper stands out from past research because of its unique and comprehensive scope and methods, resulting in explaining breakdown section of digital tools or technologies used in AEC compared to what others reviewed or articles have worked on as touching digital technologies/tools. Information gathered from published papers (from DOAJ, Scopus, springer link, MDPI and other journal indexing or databases) and published articles on several AEC websites, from 1980 and 2025 using necessary keywords, no research works have holistically explained the sections of AEC technologies/tools (traditional, hybrid and fully digital) for pre-construction, during construction and post construction, how they are interconnected and their comparison. Below Table 1 shows the selected papers from the journal indexing or database (861 springer link, 720 from DOAJ, 43 from MDPI) that are close to this review but not same. Other research works have treated either digital tools or digital technologies in AEC separately or not to details which have created a gap and this review will close the gap.

Table 1 Shows a similar topic to the research review

Year of publication	Short brief on review	Topic/title	Reference
2021	The research analyzes several elements in which understanding of digital technology is linked to its use. The hype elements produce four zones that represent distinct phases of digital technology utilization and maturity in the sector.	The hype factor of digital technologies in AEC	[28]
2024	The use of BIM in conjunction with VR (virtual reality), AR (augmented reality), VDC (virtual design and construction), and the CDE (common data environment) technologies provide enhanced labor productivity, higher design quality, and a decrease in costs and project implementation time.	Digitization of AEC Industries Based on BIM and 4.0 Technologies	[29]
2025	This study intends to analyze the dynamics of digital technology uptake and integration within different industries, using the modified TAM as a framework for analysis.	Digital Technology Knowledge Transfer Enablers Amongst End-Users in Architecture, Engineering, and Construction Organizations: New Zealand Insights	[30]
2023	This essay addresses this gap by focusing on technology breakthroughs and skills related to Industry 4.0 and Construction 4.0 ideas.	Identifying Emerging Technologies and Skills Required for Construction 4.0	[31]
2024	This research provides a bibliometric analysis of the literature on DT for FM.	Digital twin-enabled smart facility management: A bibliometric review	[32]
2023	It provides a complete assessment of the most recent robotic development specialized to mass-timber building, including both on-site and off-site applications.	Digital technologies and robotics in mass-timber manufacturing: a systematic	[33]

		literature review on construction 4.0/5.0	
2024	This study serves practitioners by offering insights on how to use DTs to enhance project management techniques, while academics gain by indicating topics for further research and development in the DT domain.	Digital Twins for Construction Project Management (DT-CPM): Applications and Future Research Directions	[34]
2025	This research combines BIM, HBIM, Digital Twins, and IoT as interconnected technology domains and analyzes their convergence in constructing intelligent, data-driven infrastructure within the AEC industry.	Three Decades of Innovation: A Critical Bibliometric Analysis of BIM, HBIM, Digital Twins, and IoT in the AEC Industry (1993–2024)	[35]
2022	This document presents an up-to-date review on the use of TLS in the AEC sector.	Application of Terrestrial Laser Scanning (TLS) in the Architecture, Engineering and Construction (AEC) Industry	[36]
2024	This paper seeks to accomplish the following goals: (1) Identify publication trends in artificial intelligence research in the AEC industry over the last two decades; (2) Present an overview of existing applications of artificial intelligence in the AEC sector over the last two decades; and (3) Propose promising research directions for the field's future.	Applications of artificial intelligence in the AEC industry: review and future outlook	[37]

3. Results and discussions

A digital workflow in construction is a systematic and technology-driven approach for managing a construction project's whole lifespan. It entails integrating digital tools and technology to improve communication, collaboration, and data management among several stakeholders, including as architects, engineers, contractors, and project managers [38]. Workflows in construction are used by organizations to assign tasks to personnel and explain the sequential processes required to fulfil them. A building workflow is a sequence of events that are built on each other until the task is completed [39]. Moving data from one piece of software to another and producing meaningful results takes several stages as shown in figure 1. Design practice procedures can vary depending on experience, funding, technological restrictions, and other factors. [40].

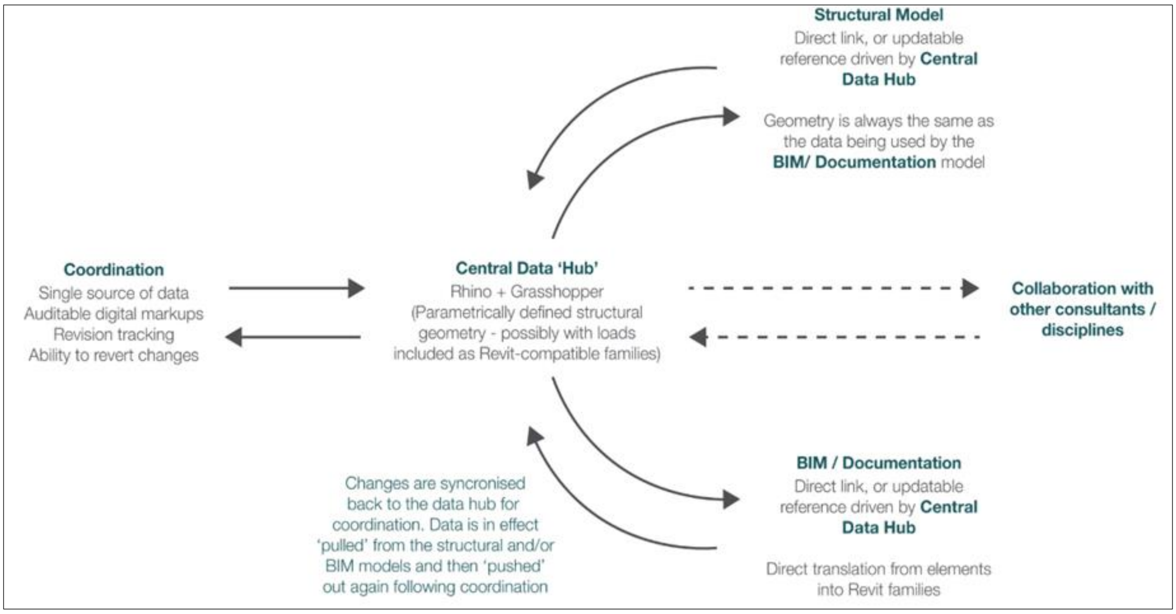

Figure 1 An example of information flow between structural engineer and architect [40]

The AEC workflow is based on a series of coordinated and interconnected events [41]. A workflow is a series of steps taken by the stakeholders of an organization to achieve an objective. The digitization of these workflows involves the seamless integration of various steps in a process, enabled by digital tools [42]. Figure 2 below shows the flowcharts on how digital workflows work and how it can be uploaded to cloud or submitted by mail and any parties involved are carried along compared to analog method.

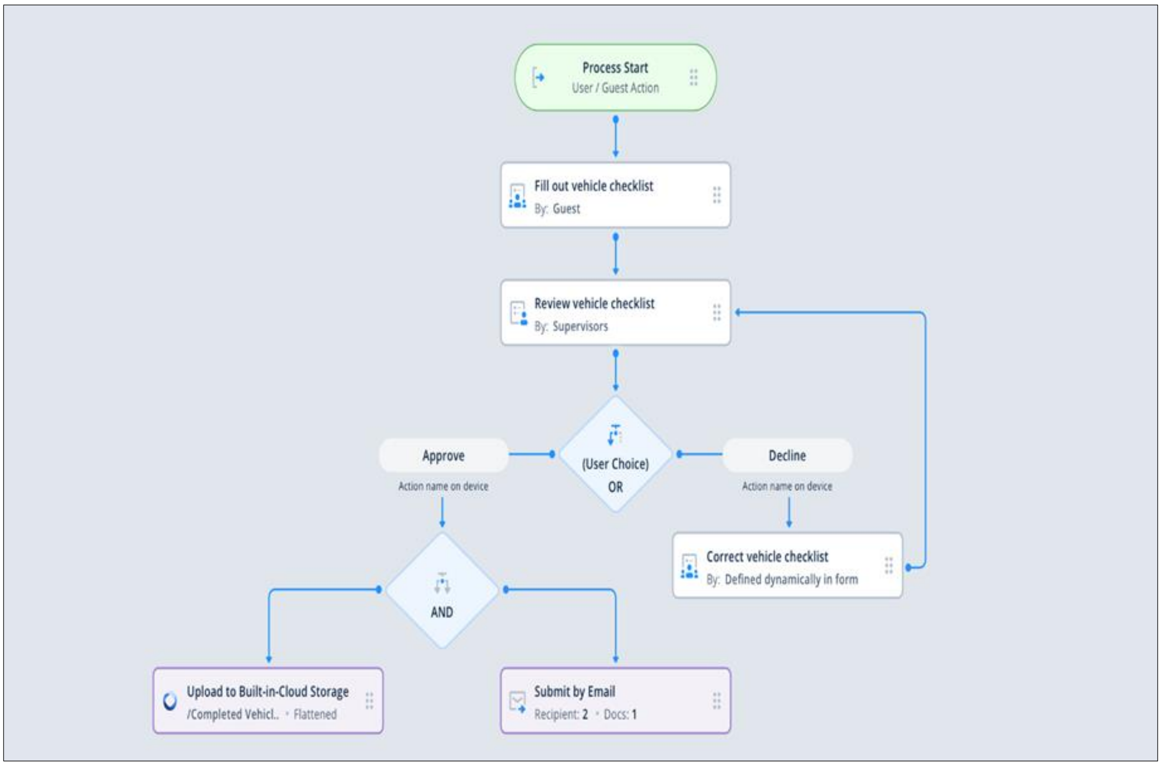

Figure 2 Flowchart for checklist digital workflow [42]

3.1. AEC Workflows

A process project management might indicate how to proceed with construction planning and scheduling, or it could outline how to complete the foundation work. A workflow may be used to execute any task required for a construction project [39].

In construction, workflows undertaken by manual, hybrid and digital software typically revolve around planning, design, scheduling, execution, and facility management. Here is a breakdown of key construction workflows methods.

3.1.1. Traditional (non-digital) method of workflows in AEC

Non-Digital (Traditional) / Workflows practices demonstrate lower environmental impact using locally sourced materials. These strategies frequently stress local resources, manual labor, and sustainable practices, helping to preserve regional identities while lowering environmental effect [43]. Traditional workflow has formed the foundation of many industries for decades. They rely on manual processes, tangible documentation, and face-to-face meetings. Traditional processes frequently include paperwork, physical meetings, and hierarchical structure. Despite the advent of digitalization, many firms continue to rely on old procedures for familiarity and perceived security [44]. The phrase "manual assembly" refers to a procedure in which human operators employ their intrinsic dexterity, ability, and judgment to integrate pre-existing pieces into a finished product or a unit of a finished product [45].

These include manual or analog methods still in use, especially in smaller or less tech-integrated firms:

- Hand drafting and sketching
- Paper-based site diaries and inspection forms
- Manual surveying and leveling (non-GNSS tools)
- Whiteboard scheduling on-site.
- Physical BOQ sheets and calculators

3.1.2. Hybrid method of workflow in AEC

Many firms employ a mixed strategy, combining manual takeoff for easy jobs and digital tools for more complicated areas. This enables teams to benefit from both strategies while increasing accuracy and efficiency [46].

In practice, many construction sites operate hybrid workflows, combining traditional processes with digital tools:

For example:

- Using tablets for site inspections but keeping a physical site diary as backup.
- Taking manual measurements but inputting data into Excel or Prota for analysis.
- Drawing by hand first, then modeling in Revit or AutoCAD

3.1.3. Digital Technology method of workflow in AEC

Digital technology is the use and implementation of computerized methods in all activities of AEC whether on-site or off-site, which improved the ways the workflows are conducted. The assumption that the building sector is slow to accept contemporary technology is no longer accurate. The engineering and construction industries have exhibited extraordinary durability and adaptability, owing to their use of construction technology and emphasis on long-term growth. This success has allowed the sector to execute ambitious innovations, establishing itself as a leader in modernizing processes and satisfying global expectations [47].

3.1.4. Key AEC digital workflows stage and tools

The key AEC digital construction workflows can be categorized into three stages or phases which are pre-construction (conceptual, designing, planning), during construction (scheduling, execution) and post construction (maintenance).

3.1.5. Pre-construction stage

Design and Drafting Workflow

This stage involves architectural and structural design, modeling, and documentation. The following are the common design and drafting software's, but they are not limited to the listed.

- AutoCAD – 2D drafting and detailing.
- Revit – Building Information Modeling (BIM) for architecture, structure, and MEP.
- Prota Structures – Structural modeling, analysis, and design (especially for reinforced concrete and steel structures).
- Tekla Structures – Advanced 3D structural modeling and detailing.
- SketchUp – Conceptual 3D design and visualization.

Structural Analysis and Design Workflow

Used to ensure structures are safe and optimized for cost and materials.

- ETABS – Structural analysis and design for buildings.
- SAP2000 – General-purpose structural analysis.
- STAAD.Pro – Structural design and analysis.
- SAFE – Foundation and slab analysis.
- Prota Structures – Integration of modeling and design in one platform.

Quantity Takeoff and Cost Estimation Workflow

Used for bill of quantities (BOQ), cost planning, and budget control.

- CostX – BIM-based cost estimation and takeoff.
- Planswift – 2D takeoff and estimating.
- Bluebeam Revu – PDF-based takeoff and markup.
- Candy – Estimating, planning, and project control.

3.1.6. During construction stage

Construction Planning and Scheduling Workflow

Focus on time and resource planning.

- Primavera P6 – Advanced scheduling and project management.
- Microsoft Project – Project timeline and resource management.
- Asta Powerproject – Gantt charts and progress tracking tailored for construction.

Construction Management and Site Supervision Workflow

Helps monitor progress, coordinate teams, and manage site operations.

- Procore – Comprehensive project management (RFIs, submittals, daily logs).
- Builder trend – Scheduling, communication, and budgeting for contractors.
- Autodesk Build (BIM 360) – Field collaboration, punch lists, RFIs, and inspections.
- Field wire – Task management and site coordination.

BIM Collaboration and Integration Tools

To connect workflows and ensure coordination across disciplines:

- Navisworks – Clash detection and model coordination.
- Solibri – Model checking and quality assurance.
- BIM Collab – Issue management and collaboration.

GIS and Surveying

Used for geospatial data integration and analysis.

- ArcGIS – Mapping and spatial analysis.
- QGIS – Open-source GIS for mapping and planning.
- Civil 3D – Civil engineering design software with GIS features.

3.1.7. Post construction stage.

Facility and Asset Management Workflow

Used after construction for maintenance and lifecycle management.

- Archi bus – Facility and infrastructure management.
- IBM Maximo – Asset lifecycle and maintenance.
- Planon – Space and maintenance management.
- Trimble Connect – 3D model collaboration in the cloud.

3.2. Digital Technologies and Digital Tools in AEC

3.2.1. Digital Technologies in AEC

Broad technological systems and concepts used to digitally transform the AEC industry. Digital technologies such as Building Information Modelling (BIM), data analytics, and artificial intelligence are reshaping the AEC industry [48]. Table 2 below shows a comprehensive explanation of digital technologies in AEC. Figure 3 explains the digital technologies and connection with digital tools software’s.

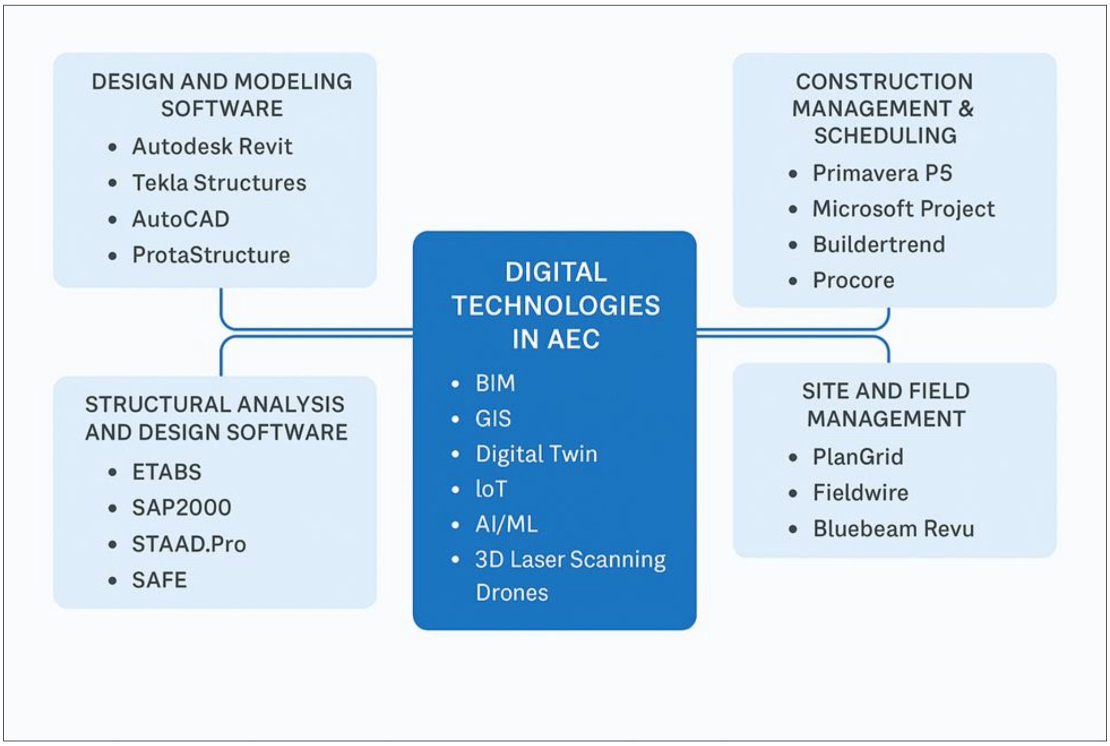

Figure 3 Digital technologies and digital tools in AEC

3.2.2. Digital Tools in AEC

Software applications are used to perform specific tasks in design, analysis, estimation, and management. Digital tools are software and internet resources that enable users to complete a variety of activities with ease. They include word processing and spreadsheet tools, as well as graphic design, data analysis, and project management software as explained in Table 2 [49].

Table 2 Shows the summary of digital tools and digital technologies in AEC

Aspect	Digital Construction Tools	Digital Technologies in AEC
Definition	Software applications are used to perform specific tasks in design, analysis, estimation, and management.	Broad technological systems and concepts are used to digitally transform the AEC industry.
Examples	Revit, AutoCAD, Tekla, ETABS, Primavera, Procore, Civil 3D	BIM, GIS, Digital Twin, IoT, AI/ML, 3D Laser Scanning, Drones
Purpose	To execute a part of the construction process digitally.	To enhance, automate, or optimize processes across the lifecycle.
Scope	Task-specific (e.g., modeling, scheduling, analysis).	Strategic and system-wide (e.g., integrating BIM with IoT for Digital Twins).
User Interaction	Hands-on software usage for drawing, modeling, analyzing.	Often a framework or platform powered by one or more tools.
Integration Level	Usually part of a larger tech ecosystem.	They enable or orchestrate the use of many tools together.

3.3. Digital Technologies in AEC relationships

3.3.1. Artificial Intelligence (AI) and Machine Learning (ML)

These technologies enable construction companies to create facilities that maximize human usability and find issues in project plans before they become permanent issues. The use of these technologies creates operational efficiency that decreases project expenses. The deployment of AI and ML solutions in construction sites operates as operational supervision during daily procedures to protect workers and provides project managers with real-time project tracking capabilities. AI- or ML-powered robots take on tedious and strenuous on-site tasks that include bricklaying and welding work. The implementation allows expert personnel to dedicate their efforts toward value-based activities. Construction organizations activate the data from AI and ML analytics to develop permanent enhancements of their operational effectiveness. Analysis of surveillance video allows field personnel to identify employee safety deficiencies together with workplace safety concerns. Building systems data from the past helps these tools design new projects that optimize parameters such as Energy Efficiency and Air Quality performance metrics. AI and ML systems identify the optimal time to perform maintenance on construction machinery while also analyzing when building systems, such as electrical systems, need servicing or replacement. The system stops equipment from breaking down, thus preventing project delays and increased expenses.

3.3.2. BIM (Building Information Modeling)

Core technology that forms the foundation for integrating AR, VR, and IoT in construction.

A 3D model-based process that includes geometry, spatial relationships, quantities, schedules, and lifecycle information.

How it connects:

- Used in design, analysis, scheduling, costing, and facility management.
- Platforms like Revit, Navisworks, Tekla support BIM.
- BIM feeds data into AR/VR for immersive visualization and into IoT systems for real-time monitoring.

Example: A Revit BIM model can be viewed using a VR headset or overlaid on-site with AR for walkthroughs.

3.3.3. AR (Augmented Reality)

Overlays digital content (like BIM models) on the physical world using mobile devices or AR glasses.

How it connects:

- Visualizes BIM models on the construction site.
- Helps with on-site coordination, checking installations against designs.
- Improves quality assurance by comparing actual vs planned elements in real time.

Example: Using HoloLens or tablets to view HVAC or rebar placement inside walls before physical installation.

3.3.4. VR (Virtual Reality)

Immersive, digital simulation of construction environments — often used in design reviews, stakeholder presentations, and safety training.

How it connects:

- Integrates with BIM for immersive design visualization.
- Allow clients, architects, and contractors to experience a building before construction.
- Enables virtual training for dangerous tasks (e.g., crane operations, confined space entry).

Example: Walking through a Revit model in Unity using a VR headset like Oculus Quest for design validation.

3.3.5. IoT (Internet of Things)

Sensors and connected devices collect and transmit real-time data from construction sites or buildings.

How it connects:

- Can feed data into BIM for real-time monitoring of buildings (smart BIM or 6D BIM).

- Enhances site safety, equipment tracking, environmental monitoring (humidity, dust, temperature).
- Used in facility management (e.g., predictive maintenance).

Example: Embedding sensors in concrete to monitor curing or tracking equipment usage via GPS.

Table 3 How they all work or interrelated together

Digital Technology in AEC	What It Does	Digital Tools That Implement It
BIM (Building Information Modeling)	Centralizes data and models for design, construction, and facility management.	Revit, ArchiCAD, Tekla Structures, Navisworks
GIS (Geographic Information Systems)	Provides spatial/geolocation intelligence for civil works and urban planning.	ArcGIS, QGIS, Civil 3D
Digital Twins	Real-time virtual replicas of physical assets for monitoring and optimization.	BIM + IoT platforms, Revit + Azure Digital Twins, Twin motion
AI/ML	Automate planning, safety prediction, cost estimation, etc.	Integrated into tools like Procore (via smart dashboards), Autodesk Construction IQ
IoT (Internet of Things)	Real-time sensor data for monitoring equipment, structures, and environments.	IoT dashboards, Smart Helmets, connected with BIM platforms
Drones and 3D Scanning	Site surveying, progress tracking, and digital terrain modeling.	Drone Deploy, Leica, Trimble, integrated with GIS/BIM
AR/VR (Augmented/Virtual Reality)	Enhance visualization and walkthroughs of models.	Unity, Unreal Engine, Enscape, Twin motion

3.4. Benefits of digitalization in AEC

Digitalization has proven beneficial in Architecture, Engineering, and Construction (AEC) in the USA industry because it provides a variety of benefits to project stakeholders, including improved visualization, better data sharing, reduced building waste, increased productivity, sustainable performance, and safety improvement [6]. Digital technology has rapidly transformed construction sites. Construction specialists may now gain real-time knowledge on the quality and quantity of work by comparing data collected by sensors such as cameras and laser scanners to a 3D model of the planned output. We are eliminating waste in the field by ensuring that each team gets the exact information, resources, and equipment required for the work on a lean, just-in-time basis [50]. Digitalization in AEC facilitates better communication and coordination among project teams; it improves design accuracy and quality, resulting in fewer errors and delays; and it enables better resource and cost management, resulting in greater efficiency and savings [51]. Machine learning algorithms may utilize this data to anticipate future patterns and anomalies, resulting in a proactive management tool. Civil engineering solutions like artificial recharge and advanced irrigation systems are critical for sustainable consumption and replenishment [52].

4. Conclusions

From the review, it can be concluded that digitalization in AEC is not only about digital technology but also the digital tools or software's that complement it to be effective, efficient, and timing for AEC projects. The following can also be concluded on,

- Digital technologies are different from digital tools in AEC but can be integrated to work as a single entity.
- There are currently three methods of AEC workflows stage which are traditional, hybrid and full digital workflows method.
- Smart Construction is particularly important as it helps in cost management, reduction of materials wastage and double handling.

Limitations

The limitations on this review are as follows

- It doesn't explain the digital technologies and tools in detail which future researchers should work on.
- More digital technologies and tools for AEC should be discussed

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