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Leveraging Digital Science for Improved QA Methodologies

Mouna Mothey
Independent Research Scholar, USA.

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ABSTRACT

Products and processes are using digital technology to increase manufacturing efficiency and quality. The digital revolution of the industrial industry is primarily driven by intense competition and changing customer expectations. Manufacturers may improve customer experiences, save costs, and boost speed and efficiency by using digital technologies. The application of related individual digital technologies has not been thoroughly assessed and combined to achieve adequate QA in the building sector, and as a result, it has received limited attention, despite the expanding rich and fragmented literature focusing on Industry 4.0 and Quality Assurance (QA). Therefore, the purpose of this study was to collect, assess, and synthesize the existing literature on specific digital technology uses in quality assurance in the construction sector and suggest future lines of inquiry. Deming's cycle concept and a literature review methodology were used in this study to answer the following four research questions: (1) what is the literature's current state-of-the-art? (2) Which digital tools have been used in the construction sector for quality assurance? (3) Which QA process areas have seen the use of digital technology, and what are their uses? (4) What are the shortcomings of the current study and potential avenues for further investigation into digital technology for quality assurance in the construction sector? According to the data, since 2017, there has been a growing trend of study on digital technologies for quality assurance in the construction industry. Using six distinct study methodologies published throughout 18 different publishing sources, this spans 23 nations. Based on their functionality, four types of digital technologies were identified as having been used for quality assurance in the construction industry: data gathering technologies, decision-oriented technologies, collaboration technologies, and technologies linked to security and transparency. The use of digital technologies have a high degree of application during the "do" phase, enhancing the quality management procedure throughout construction towards reaching pre-stated quality standards, according to evaluation using Deming's cycle framework.

Keywords- Digital Technology, Deming's Cycle Framework, Security-Related Technologies, Construction Industry, Collaborative Technologies, Quality Assurance (QA), Manufacturers.

I. INTRODUCTION

Widespread implementations based on technological change have been made possible by the quick and ongoing development of personal smart devices and digital network infrastructures. As a result, the amount of big data produced by different smart digital devices has increased significantly [1]. Large-scale heterogeneous data handling has been made easier by artificial intelligence (AI)-driven large-scale data processing techniques that make use of deep learning, machine learning, and pattern recognition [1, 2]. AI-powered inventions based on generated data are made possible by AI-driven big data processing. This has been used in a variety of industrial areas, including those covered in e-government services, education, and medical applications [2].

Systems for digital transformation produce a lot of data, which opens up a wide range of possibilities for possible innovation, especially those powered by artificial intelligence [2, 3]. Organizations have access to an unparalleled amount of data due to the sheer volume of data generated by these systems, which AI algorithms can use to their advantage [3]. Applications driven by Artificial Intelligence (AI) can process and analyse this data to reveal hidden patterns, gain deep insights, and forecast the future developments [3, 4]. Organizations may make data-driven choices, streamline operations, and bring about revolutionary change because to this capacity to glean meaning from enormous volumes of data. AI enables businesses to rethink conventional business models, increase productivity, and automate repetitive tasks [4, 5]. Additionally, AI-driven innovation can increase customer engagement and loyalty by providing seamless, personalized experiences [5]. Organizations can access a world of limitless opportunities for development, competitiveness, and and long-term success in the constantly changing digital landscape by embracing AI's potential in their journey toward digital transformation. AI-powered innovation in the digital revolution has resulted from this [5].

Internet technology, tools, and services are a "social phenomena, a tool, and additionally a (field) location for research," as stated by the International Association for Internet Research [5]. Different epistemological, practical, and ethical issues will arise depending on how the internet is used in the study endeavour or how the researcher views it [5]. As a result, it can be concluded that digital research, in its broadest sense, includes the use of digital technologies, tools, and services as research objects (e.g., social networking pages, blogs, virtual worlds, virtual communities, and instant messaging spaces), as tools for developing novel methodical practices (e.g., software or hardware devices for developing, designing, and implementing research methods), and as the actual space where research is situated and from which researchers can obtain study resources and data (e.g., online databases and databases, search engines, [6], data aggregators, etc.). Study on the affordances, content, and users of social networking websites on the internet is one example of how digital technologies may be used as both objects and tools at the same time [6, 7], impacting not just data collecting and analysis but also study design.

As a consequence of digital transformation, departments and enterprises are now using digital technology. It has facilitated the creation of new business processes, added value to everyday tasks, encouraged creativity, and improved chances for client interaction. Whether it involves developing completely new goods or radically reimagining existing procedures, digitalization is cantered on employing technology to enhance corporate performance [6]. It outlines a business's strategy for developing new technological advantages and the methods it will use to achieve these breakthroughs. Smart methods, statistical analysis, [6, 7], and connected devices are helping manufacturers significantly increase their accuracy, productivity, and efficiency as the manufacturing industry goes through a digital transition. In addition to how manufacturing and supply chains run, adhere to protocols, and utilize energy, digitalization is changing how things are conceived, manufactured, consumed, and maintained. The capacity of businesses to adapt and become more sensitive to changing customer demands and market situations is one of the primary drivers of digitalization. Manufacturers may reduce waste and customer dissatisfaction by aligning the amount they produce calendars with demand across the academic year [7].

By moving away from manual activities and using automated solutions, it is possible to enhance processes, tracking of performance, and making decisions while preventing rework, downtime, mistakes, and bottlenecks [7, 8]. This is going to save time and money. Manufacturers are now dealing with a variety of operational challenges and shortcomings as a result of the epidemic. For example, they understand how important it is to have possession of real-time supply-chain information so that they can respond to changes in supply and demand faster. In order toward accomplishing supply chain efficiency via better and more reliable operating approaches, the industrial industry may now effectively use digital technology thanks to modern technology [8, 9]. The digital evolution of the supply chain has linked technologies that may help manufacturers collect equipment data via the application of AI and predictive analytics [9]. They may now operate the dispersed value chain and industrial processes using real-time information that was collected [9].

The function of Quality Assurance (QA) has a special relevance in the transparent and cooperative world of open-source improvement, where community of varied contributors come together to produce software solutions [9, 10]. In order to understand the intricacies, difficulties, and cutting-edge trends that characterize the quest to achieve software superiority in this dynamic environment, this review paper sets out to investigate the diverse landscape of QA procedures within open-source projects [9, 10]. The core of open-source is the collaborative work of people, each of whom contributes their knowledge and abilities to jointly develop and improve software. In this situation, QA procedures play a crucial role in guaranteeing the overall quality, robustness, and dependability of the software currently being developed [11].

The convergence of QA with the cooperative nature of open-source projects presents both benefits and difficulties that need careful attention as these projects grow in complexity, scale, and scope [11]. This article explores the essential elements that characterize quality assurance in open source, [11], such as the integration of continuous processes like Continuous Integration (CI) and Continuous Deployment (CD), the community-driven testing methodology that leverages the collective intelligence of contributors, and the critical role that code review procedures play in preserving code quality [11, 12]. Furthermore, the study delves into new developments such as shift-left testing, integrating DevOps methods into the QA framework, and using AI and machine intelligence. For software initiatives to be successful, software quality is essential [11]. Open-source projects have difficulties include managing varied contributors with different skill sets and ensuring consistency across platforms, even though they thrive on being inclusive and diverse [11,12]. In order to overcome these obstacles, the paper examines best practices, [12], stressing open communication, the use of tester-driven development (TDD), [12], and the need of thorough documentation and knowledge exchange [13].

1.1 Key Components of Open-source QA

The team-based and decentralised nature of the open-source process fosters the production of strong and dependable software, which is why quality assurance (QA) techniques in open-source projects are distinguished by a number of essential elements [12]. The essential components that characterize quality assurance in open-source projects are examined in this section.

1. **Community-Driven Testing:** A varied group of contributors' combined knowledge is advantageous to open-source projects. Using the community to find, report, and fix bugs, vulnerabilities that and usability worries is known as community-driven testing [13]. Managing diverse degrees of testing expertise, coordinating testing efforts among contributors in various time zones, and guaranteeing thorough test coverage.
2. **Continuous Integration (CI) and Continuous Deployment (CD):** Significance: By automating testing and deployment procedures, CI/CD approaches guarantee quick feedback loops and the early identification of integration problems. Given that open-source projects often undergo code modifications, this is especially important [13, 14].

Challenges include adjusting CI/CD pipelines to various project architectures and processes and finding a balance between automated and human involvement [14].

3. **Code Review Practices: Significance:** For open-source projects to maintain code quality, code reviews are essential. It entails carefully reviewing code modifications, spotting any problems, and encouraging information sharing among participants. One of the main pillars of project development, requirement collection [14], is a crucial phase when a project's success or failure is often predicted. [14, 15].

The goal of quality assurance (QA) is to show that an good or service satisfies all quality standards and can satisfy the final customer. QA is known as "manage quality" because, in accordance with the Project Management Board of Knowledge (PMBOK), it refers to the actions required to manage a project's quality [15]. The two definitions are used in this research since the QA idea is similar. Before being supplied to the customer for use, QA activities are conducted in building projects to instil trust among stakeholders that the quality standards will be met [15]. QA guarantees stakeholders that systems, materials, structures, or components will function successfully throughout the course of their whole service life and fulfil predetermined quality requirements. In the construction sector, adherence to quality standards and documentation of attained quality is crucial [15].

This is the outcome of many people working together, guaranteeing efficient cooperation to guarantee that the correct item is done first and prevent mistakes. Although some academics have used QA and quality control interchangeably, it is important to recognize the distinctions in this research since quality assurance is product-oriented while QA focuses on enhancing final goods by locating and resolving flaws, including specialized teams who test the items. However, quality control, in which each completed sub-work is inspected and tested to confirm quality before moving on to the next sub-work, may also be a significant component of QA procedures [15, 16]. QA becomes the main focus of this research as it looks at the methodical procedure and the actions involved in making sure the building project satisfies quality standards [16, 17].

However, with the advent of Industry 4.0 and its support of digital technologies, there are still chances to enhance the QA procedure in the construction industry. A few technological advances have been included into QA procedures in the construction sector [17] to guarantee efficacy and sufficiency in quality management. This is shown by the quick uptake and incorporation of digital technology into construction procedures to maintain operations in the face of current COVID-19 threats [17, 18]. Previous research has focused on documenting how digital technologies are applied to certain QA issues.

Learn to comprehend the advantages of using Terrain Laser Scanner (TLS) for building quality assurance in terms of both cost and time. Because it takes less time to gather data, the TLS-based QA technique is more effective than the traditional QA strategy, according to the results [18, 19]. Building Information Modelling (BIM) and indoor position technologies are used to provide a web-based collaborative solution that enhances the building quality assurance process [19, 20]. The suggested approach was shown to be reliable for project participants to adhere to quality management requirements while guaranteeing effective cooperation and communication amongst the participants [20, 21]. However, there is little use and assessment of digital technologies in QA, and they are often at a low technological readiness level [21, 22].

Since it entails a methodical procedure and procedural actions to guarantee that construction projects fulfil quality standards, such as client needs, compliance with regulations, and fit for purpose, quality is a significant concern in the construction business. Given that construction projects are carried out in accordance with specifications and are predicated on efficient QA procedures, it is an essential quality [22, 23]. QA is the collection of actions intended to show that the good or service being provided satisfies all quality standards specified in the contract [22].

Before quality control and after quality planning, the PMBOK called quality assurance "manage quality." QA procedures are successfully carried out from conception to project delivery [22, 23] to guarantee that procedures and services satisfy contractual criteria, including the demands of the customer. As a result, QA is predicated on successful collaborative efforts from multiple parties involved in a given project [22]. This gives stakeholders the assurance that a system, component, substance, service, or structure satisfies established quality criteria and has a high likelihood of keeping the client satisfied for the duration of the service life [22, 23]. Therefore, QA's goal is to independently verify that construction and related services are being carried out in accordance with all contracting codes, specifications, [23], standards, and laws. These rules aid in clarifying the precautions that must be taken before a technology is widely used in order to ensure its quality [23].

The rules and guidelines could guarantee that the technology is morally and safely sound and does not violate the rights of workers in the pursuit of excellence. As a result, quality is confirmed by inspections, checks, and observation. Although QA procedures are carried out separately from individual contractors, manufacturers, subcontractors, material suppliers, [24], and end users, the outcomes must be connected. Therefore, when conducting quality assurance in the construction industry, efficient teamwork and communication are crucial [25].

Figure. 1 Digital technologies in QA in the construction industry. [25]

Although the phrases are often used interchangeably, quality assurance and control are not the same [25]. Process-oriented, quality assurance (QA) aims to improve methods and procedures to create a high-quality project by including all members of an organization in defect avoidance. Contrarily, quality control involves specialized teams who evaluate the goods and is product-oriented, with the goal of enhancing final products by locating and resolving flaws [25, 26]. QA becomes the subject of this research since it focuses on the methodical procedure and procedural actions that guarantee the building project satisfies quality criteria. A crucial component of QA procedures may also include quality control, in which each completed sub-work is reviewed and checked to ensure quality before moving on to the previous sub-work [21].

II. A FRAMEWORK FOR UNDERSTANDING THE APPLICATION OF DIGITAL TECHNOLOGIES FOR QA

Previous study has shown the efficacy of using system methods in comprehending the intricacies of technological advances in the building industry. To comprehend the use of digital technology in building quality assurance procedures, a framework is required. This paper examines the research on technological advances for QA by extending the framework of Deming's cycle in QA [11, 13], which comprises of interconnected stages in QA. Deming's theory is used in this research to comprehend the application field of technological advances for construction QA, or how they have been utilized to enhance QA procedures in the construction industry [12].

The four logical steps of Deming's cycle—plan, do, check, and act—make up this continuous quality improvement paradigm [PDCA]. When compared to previous models that have been offered, this one has the advantages of being useful in any context, requiring little teaching, encouraging continuous progress, and allowing for control and analysis via iterative improvement [11]. Undefined definitions that result in improper usage might be one of the alignment drawbacks. Deming's cycle continuously enhances the procedures needed to guarantee quality, which interacts with other models of quality management [11]. Deming's cycle aids in creating an ongoing loop for managing and enhancing construction procedures in order to meet customer and legal criteria in the sector [11, 16]. By breaking down the building processes into fundamental phases, this enhances procedures and gets rid of mistakes that keep happening [11, 16].

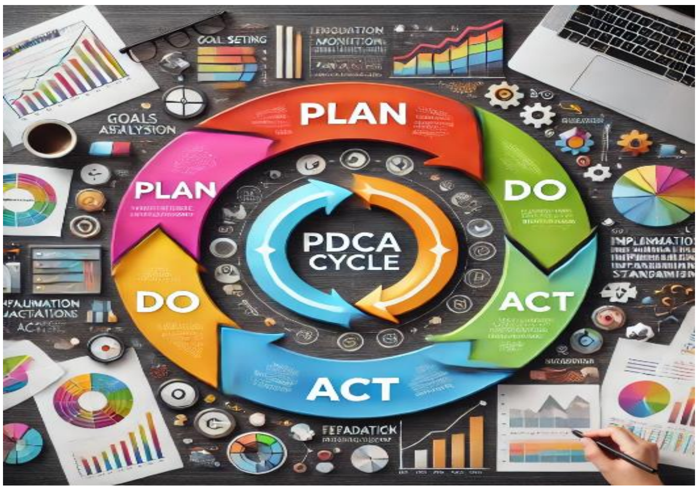

Figure. 2 Conceptual framework based on Deming's cycle. [17]

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According to Deming's cycle, a plan entails assessing the existing state of affairs, obtaining information, and formulating strategies for improvement [17]. To completely comprehend the kind of quality required on a project, the present status of projects or services on a project is examined. The important question at this stage or location is,
"Which issues have you recognized, and how can you effectively resolve them?"

The project's present state is ascertained before addressing them. This makes it possible to precisely define quality concerns and ascertain how the quality might be attained [17, 18].

The planning stage is followed by the do phase. Now is the time to follow the instructions and gather information as you go. It calls for a designated individual to carry out responsibilities in accordance with instructions on enhanced procedures, and efficient oversight is carried out to guarantee that there are no deviations from the requirements [17, 18]. Therefore, efforts are made to enhance QA procedures by addressing quality issues and guaranteeing that services and goods are provided in accordance with established quality standards [18].

III. RESEARCH METHOD

In accordance with the Preferred Reporting Materials for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, a two-step literature review methodology was used for this investigation, which included gathering and analysing pertinent literature [18, 19]. This method is used in construction management and engineering to gather and synthesize data in order to comprehend the phenomena, suggested patterns, and gaps. The method is explained by concentrating on construction quality assurance in connection to certain technological fields that have been used, as shown in Figure 3 [19, 20].

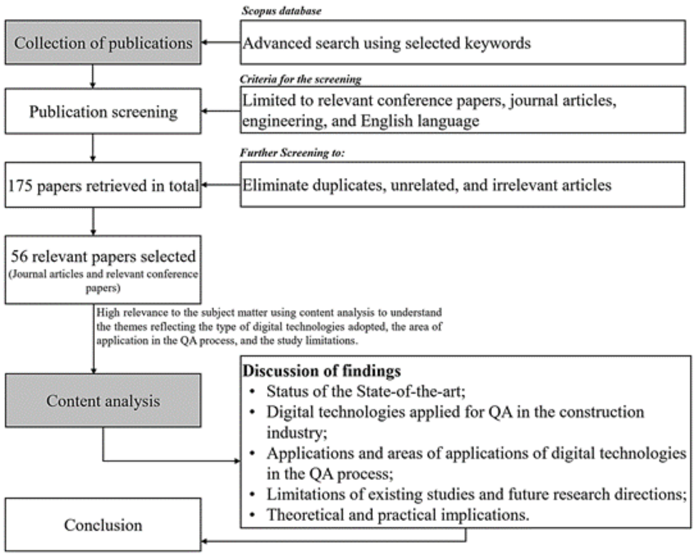

Figure. 3 Examine the workflow. [20]

- ***Step 1: Publication Collection***

The Web of Science (WoS) and Scopus indexes were searched using keyword strings like TITLE-ABS-KEY ("digital technology" OR "Industry 4.0" OR "construction 4.0") to gather papers. (EXCLUDE (LANGUAGE," Chinese") OR EXCLUDE (Language, "German") OR exempt (LANGUAGE," Russian") AND TITLE-ABS-KEY ("building industry" OR "construction administration" OR "building science and technology" OR "build") AND TITLE-ABS-KEY ("excellence assurance" OR "managing excellence" OR "sustainable excellence assurance") [11, 20]. The Booleans "AND" and "OR" made this possible. Only peer-reviewed conference papers, articles published by peer-reviewed journals, and English-language content were included in the search. Consequently, 175 papers were obtained, including 62 from Web of Science (WoS) and 113 from Scopus, and they were identified as having been published between 2003 and 2023 [20].

- ***Step 2: Content Analysis***

As shown in Supplementary Table 2 [22], the chosen empirical papers were further studied to explain the results in accomplishing the study's goal via extensive analysis and demographic analysis. To learn more about the quality and history of the chosen empirical publications, a demographic analysis is first carried out. Finally, a thorough analysis is carried out while keeping in mind the primary findings of the research in order to comprehend the results of the current investigation. This covers the kind of digital technologies used, the field in which they are used in QA procedures, and the present constraints of the research that has already been done. Supplementary Table 2 displays the content analysis's comprehensive findings [11, 22].

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IV. FINDINGS AND DISCUSSIONS

4.1 Background Analysis of Relevant Literature

The publications' nations, types, years of publication, and research methodologies were taken into account while extracting detailed information from the papers. Figure 4. In order to answer the first question, [22], it is crucial to look at the articles' demographic information in order to understand the current state of the art in literature [23].

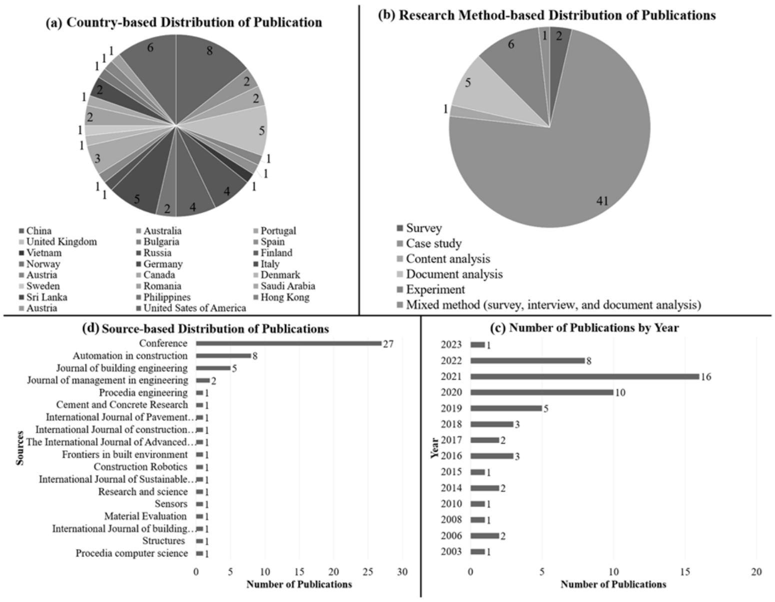

Figure. 4 Background data about the chosen publications. [24]

4.2 Digital Technologies for QA

The research findings in Table 1 demonstrate how various digital technologies may be used for quality assurance in the construction sector. Given that the majority of accepted technologies are known to be decision-oriented [25], digital technologies may be included into QA procedures to enhance quality decision-making, as shown in Table 1, [24]. According to the report, BIM-based technologies for communication are widely used across all individual technologies to provide efficient cooperation amongst pertinent parties throughout the quality assurance process [25]. It is also evident that data gathering technologies might be included into technology collaboration to enhance QA procedures by using AI, ML, and other effective decision-making tools. Previous research has mostly concentrated on the use of BIM technology, with little attention paid to integrating additional technology [25, 26].

Table 1. Digital technology categories used for QA according to functionality. [26]

Category	Technologies
Data collection	Laser scanning on land
	Digital technology on the go
	Three-dimensional modeller
	IoT
	VR/AR
	System for radiofrequency identification
	Physical-cyber system
	Aerial photography with drones
	System for indoor positioning
	Multi-rotor drones with thermal lenses
	Test instrument for geodetic surveying
	Test instrument for digital inspection
	Robotic system
	The online inspection system that uses automatic vision
	Ultra-wide caster with intelligence
	System of condition-based monitoring
Decision-oriented	System for real-time performance data

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	As-bulk point cloud of work
	Big data
	Vision with photogrammetry
	Barcode
	Cloud computing and fog
	C-Suit level
	Technology for digital twins
	Geological model in two dimensions
	AI
	ML, deep learning, and neural networks
Collaborative	Technology for communication based on BIM
Transparency and security-relative	Blocks and other security measures

4.3 Data Collection Technologies

Throughout the QA process, data gathering is important since its interpretation aids in determining if a product or service satisfies quality standards. Data was previously gathered manually during construction quality assurance (QA) by on-site documentation and in-person observation [26, 27]. When a building project is complicated and requires a large amount of paperwork and observations, this manual method becomes time-consuming and tedious [27]. This may sometimes increase the effectiveness of QA procedures in meeting project quality standards [27, 28].

4.4 Decision-Oriented Technologies

Data collected throughout the QA procedures is further analysed to understand the level of quality that an ongoing building endeavour has attained [28, 29]. Following data collection, decision-making concerning the project quality is crucial in QA processes [28]. When a complex project is involved, a large amount of data is collected, making manual interpretations tiresome and laborious.

4.5 Collaborative Technologies

Given the many stakeholders and parties engaged in creating goods to meet the demands of the customer, collaboration is important in the construction industry's quality assurance procedures [28, 29]. Working together may also guarantee that construction services adhere to all government legislation, contractual requirements, and standards [29]. To guarantee that the final product satisfies the specified quality standards, project-related data and information are therefore disseminated among the stakeholders [28, 29]. Therefore, an efficient system of collaboration may be set up to enable active and efficient interaction between the parties or stakeholders to ensure that information is shared and that parties are aware of each other's work on the project. The customer, designer/architect, quality engineer/auditor, authorized agency, etc., may all be involved in this interaction [28, 29].

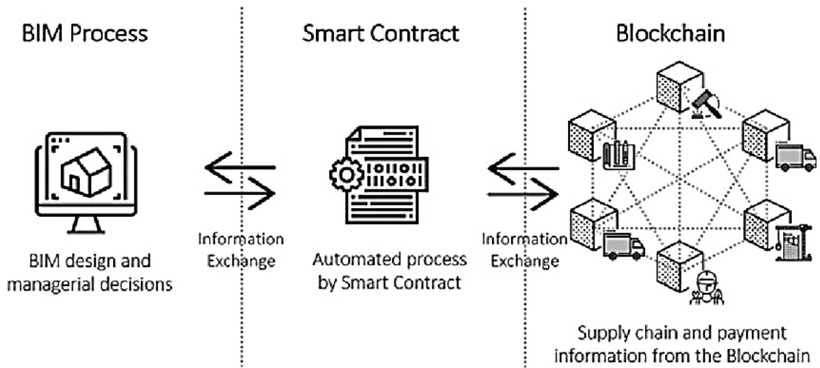

Figure. 5 Transparency and Security-Related Technologies. [29, 30]

When data is exchanged between parties, security and transparency are crucial. Since information on quality assessments and inspection on building sites is crucial, it must not be changed [30, 31]. Obtaining unbiased information on the calibre of goods or services may guarantee major progress and aid in decision-making. Security is thus crucial to guaranteeing the openness of the information gathered about the services and goods during QA [31, 32].

V. LIMITATIONS AND FUTURE RESEARCH

By synthesizing the results from the study's first three questions, this section aims to address the fourth question [32, 33].

5.1 Limitations of Existing Studies

There has been little research in the topic, as shown by the 56 empirical papers that the study found. A review of the chosen available research revealed certain advantages and disadvantages [33]. The applications that have been thoroughly examined in the direction of a conceptual framework for comprehending digital technology for quality assurance in the construction sector were identified as the studies' strong points. Therefore, the strength is found in the results of previous study and the capacity to report using the chosen research methodologies [33, 34]. Nonetheless, the limits of the previous study were analysed, and the findings might guide future lines of inquiry.

Table 2 Limitations of recent research on QA spanning Deming's cycle. [22]

Limitation	**Deming's cycle**			
	Plan	**Do**	**Check**	**Act**
Technology-oriented				
The limited scope of technological preparedness.	✓	✓	✓	✓
Insufficient emphasis on digital technology for quality assurance.	✓			
Methodology –oriented				
Insufficient technological integrations.	✓	✓		✓
Absence of accuracy and applicability testing and validation.	✓			
The effectiveness of the model is unclear.			✓	
Inefficient automatic association with construction schedules and inspector assignment with the digital system.				✓
Inability to modify the standard's check items and criteria for various application situations.				✓
High-level technicalities				✓

5.2 Technology-Oriented Limitation

The absence of a strong push for digital technologies and the narrowness of technological preparedness restrict the research that are now available. The studies' tendency to appropriately adopt and use new technologies to achieve the objectives of guaranteeing QA in a building project [34, 35] is indicative of a low degree of technological maturity. Existing research on the technological maturity of various digital technology kinds revealed discrepancies and a lack of standard discussion [35]. This leads to a lack of commitment from senior management to promote the use of digital technologies in the QA process and a lack of faith in these technologies' ability to make QA sufficient [34].

VI. CONCLUSION

Performance surveillance, ongoing training, statistical analysis, statistical analysis, and creative product creation have all been carefully integrated into AI-powered innovation frameworks in this research. Together, these elements provide a strong basis for organizational effectiveness by promoting functionality optimization, fostering a culture of constant improvement, and strengthening well-informed decision-making.

AI's quick development has been a major factor in the transformation of many different businesses and lifestyles, having a big impact on fields like healthcare, finance, education, maintenance prediction, transport, and agriculture, among others. As shown in our research, AI's transformational power is evidence of its function as a catalyst for innovation and global advancement. Our research has far-reaching implications, highlighting AI's critical role in digital transformation and supporting an integrated strategy for AI adoption that goes beyond simple technology advancements to incorporate a paradigm shift toward a culture of ongoing innovation and learning.

This study paves the stage for in-depth future research while shedding light on AI's pivotal role in innovation and digital transformation. Examining these opportunities in further detail can help us better understand AI's potential and act as a guide for its ethical and effective use in a variety of fields. By doing this, we support a forward-thinking approach to AI, imagining a day when it would solve ethical, social, and environmental issues while driving economic and scientific advancements. This necessitates cooperation between academics, business professionals, and legislators in order to create an inclusive, sustainable, and equitable AI-powered future.

Despite the expanding rich attention and fragmented character of the literature, the research organized and carried out a systematic review and synthesis of the individual knowledge on technological advances for QA in the construction sector, which is a gap in the topic area (literature). In research, this field receives little attention. In the meanwhile, if carried out, it may provide a strong starting point for further study. Relevant publications from 2003 to 2023 that were chosen from the WoS and Scopus databases are reviewed as part of the study. Deming's cycle in QA served as the basis for the study, which assessed the use of digital technologies for QA by taking into account four interconnected phases: plan, do, checked, and act. The main conclusions are given next.

A thorough examination of the specific demographic information of the chosen, pertinent articles provides a response to the first research question. According to the data, there has been a consistent rise in research on digital technology for quality assurance in the construction industry since 2017, with the exception of 2022, when more studies are expected to be conducted. With six distinct study methodologies published across 18 different publishing sources, this spans 23 nations. Furthermore, China seems to be the nation most actively pursuing research into the integration of different digital technologies for quality assurance, with the United States, Germany, the European Union, Italy, Russia, and France following closely behind. The case study has gained widespread acceptance among the many research methodologies used in the literature due to its utilization of real-time modelling and actual projects. Both conference proceedings and journals have been actively involved in ensuring that the outcomes are genuine and well-known to impact industrial decision-making.

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