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Analysis of Industry 4.0 and the Building Inspection System in the Republic of Türkiye's Applications

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Highlights

- Integrating industry 4.0 technologies with the building inspection systems.
- Industry 4.0 technologies solve the deficiencies in the building inspection system.
- Focused on establishing a more reliable building inspection system with Industry 4.0 technologies.

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Abstract

Since the enactment of Law No. 4708 on Building Inspection, developments have taken place in the construction sector in Türkiye in terms of material production, their usage in construction sites, construction stages, project management, and implementation, which have led to the need for changes in the inspection field. In this study, the Building Inspection process was classified under seven headings within the scope of the Regulation. The fundamental problems in these headings were analyzed with research methods in the literature. Based on the information, which digital transformation technologies are included in the current practices and which ones are missing have been identified. Collaborations with which technology can solve existing problems have been interpreted, and solutions have been proposed to complete the shortcomings that may be experienced in the inspection field. It has been determined that Industry 4.0 Technologies should be adapted to every step of the inspection process for a healthy inspection system.

1. INTRODUCTION

The purpose of enacting Law No. 4708 on Building Inspection is to ensure the safety of life and property in our country by promoting the construction of buildings that comply with regulations and standards, both during the design phase and the construction process. Since its introduction in 2001 until the present year, numerous technological changes and advancements have also influenced the functioning of the inspection system. Over the approximately 21-year period, there have been developments in the construction sector in Türkiye, including material production, their use on construction sites, construction processes, and the management and implementation of projects, necessitating changes in the inspection field. Unfortunately, due to the fact that our country's building inspection system has not yet completed a process that integrates Industry 4.0 technologies, it is in a position to follow technological developments from behind. It is imperative to make the most effective use of these technologies for the system to operate more efficiently and be implemented healthily. One of the most significant drawbacks is the excessive paperwork and the fact that these processes have not yet been transferred to a digital database. In a system where many processes and procedures, approved by Building Inspection companies and authorities, are ongoing, the current functioning and solutions with Industry 4.0 Technologies are presented in the article. Due to the significant revision of the Building Inspection process in Turkey, especially after 2019, there is limited literature on this subject, and no study examines its relationship with Industry 4.0 technologies.

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1.1. Digital Transformation and the Construction Industry

In the past few years, the construction market has experienced moderate growth. However, the slight slowdown in 2019, coupled with the COVID-19 pandemic, had a negative impact on the predictions for 2020 and increased uncertainty levels for subsequent years. Like in all sectors, the construction industry has uncertainties and resulting complexities. As always, reliance has been placed on advancing technology to address these situations. It has been observed that developments in new construction technology have propelled the industry forward. Many companies' relatively slow adoption of new construction technologies is believed to be due to limited resources. For instance, drones are currently one of the most valuable tools a construction firm can possess. They meet various requirements and modernize the traditional functioning of a significant portion of the industry. One of their most popular uses is generating accurate field inspection reports and land surveys, replacing time-consuming previous methods. Other uses of drones in construction include capturing drone footage of a site and then converting it into 3D drawings that can be compared with architectural plans or measuring areas, distances, and necessary angles. Some drones are specifically designed for industrial purposes, but simple, high-quality drones generally suffice for most construction companies [1]. It is possible to provide examples of autonomous vehicles and robots compared to drones.

Digital transformation is a continuous and dynamic process; therefore, there is no universally agreed-upon definition regarding what it entails and encompasses. Transformation does not involve abandoning the old system altogether but instead adapting and upgrading the existing one to keep up with the changing process and even survive the transformation. In the context of digital transformation, humans play a crucial role in adapting people, processes, and technology, while technology, objects, and processes are the ones being adapted. This means that human beings are the primary subject in the digital transformation process, and they need to be closely involved in adapting technology, objects, and processes to ensure a successful transformation. According to this approach, where the process is the object, transformation is necessary to collect and process data, move from information to knowledge, and ultimately achieve a better future [2].

Digital transformation is the comprehensive transformation of organizations, encompassing human resources, business processes, and technology elements to provide more effective and efficient services and ensure user satisfaction in line with evolving societal needs facilitated by rapidly advancing information and communication technologies [3]. Industry 4.0, which is the digital industrial revolution, is the integration of information technologies and industry as a collaborative whole. It involves a system where cyber-physical systems communicate, exchange data without operator support, sense through sensors, perform data analysis, make decisions with artificial intelligence, and add a new dimension to production through 3D printers [4].

Thanks to the technology of digital twins, one of the Industry 4.0 technologies, any design idea, revision request, maintenance, or repair in a construction project can be created, tested, and simulated in a digital environment with multiple virtual instances. While testing every possibility can, in reality, lead to significant time, cost, and labor losses in the construction sector, achieving more accurate results is possible through controls in virtual environments. In the case of malfunctions or issues encountered in a structure, the Digital Twin can utilize its stored historical data to provide analysis and present solution alternatives, including cost comparisons among the other options. This demonstrates a highly advanced document management approach. By making predictions about potential errors and issues in the future, it can reduce risks throughout the process [5].

The example application areas of digital transformation technologies in the construction sector shown in Figure 1 can be explained as follows;

Smart Robots: Ground and aerial robots can be used in the construction industry to enhance efficiency, safety, and quality, as well as to monitor production processes.

Cloud Computing: This includes visualization methods to help employers better understand the project and systems created for real-time tracking of the construction process.

Internet of Things (IoT): IoT involves collecting and analyzing building data, determining site characteristics for the construction, and making decisions based on factors such as local temperature and precipitation.

Digital Twin: Simulation allows for modeling the situation and conducting risk analysis. It enables the identification of potential issues during the production phase, leading to cost reduction.

Additive Manufacturing: After integrated project planning, this technology allows for production with fewer errors and less labor on the construction site.

Blockchain: With the growth of construction projects and the increasing complexity of project management, blockchain is used for its advantages of transparency and auditability.

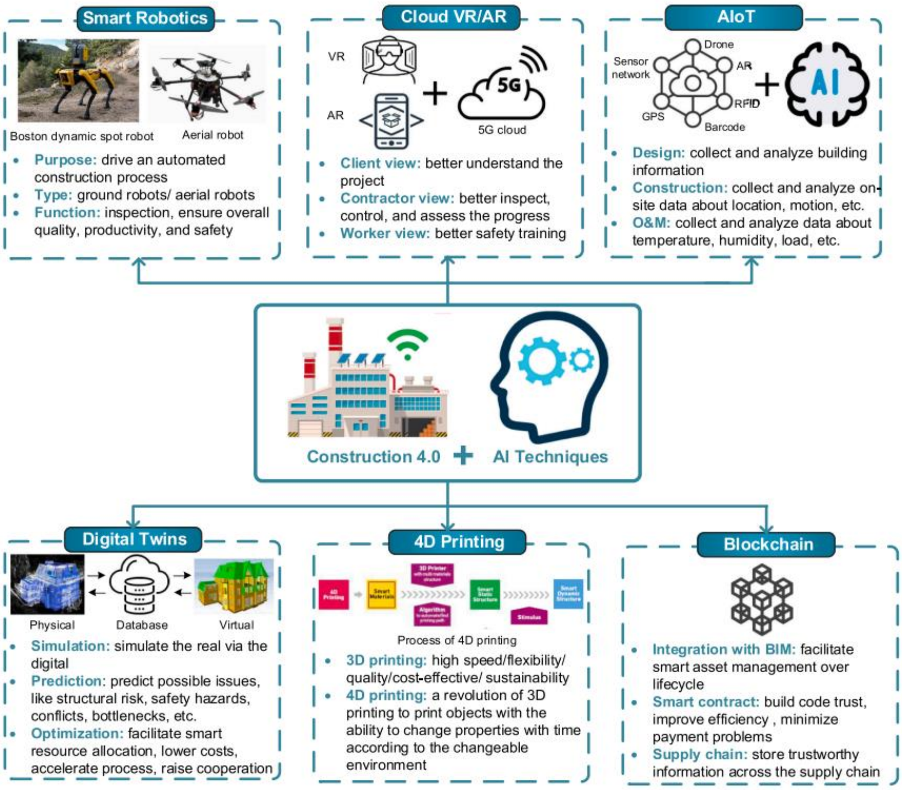

***Figure 1**. The digital transformation technologies in the construction sector* [6]

In advanced countries, the main obstacle in digital transformation applications is the need for a qualified workforce. In Türkiye, however, the shortage of skilled personnel comes after investment costs and uncertainty about the return on investment. Companies need a more competent workforce to manage the new production systems shaped around digital technologies effectively. Therefore, it is essential to establish long-term training programs to provide additional skills that create value for the existing workforce. The increasing demand for a skilled workforce in different disciplines will create new employment opportunities. Proactive planning is crucial, considering the time required for creating, disseminating, and training the workforce through educational programs. Recognizing this situation will enable Türkiye to prevent the problem from escalating by engaging in effective planning.

2. MATERIAL METHOD

In this study, the Building Inspection process was classified into seven categories under the legislation scope. The legislative scope includes the Building Inspection Law in force in the Republic of Türkiye; the Building Inspection Implementation Regulation published by the Ministry of Environment, Urbanization and Climate Change; the Communiqué on the Principles and Procedures for the Determination of Building

Inspection Organizations to Sign Contracts with Building Owners; the Communiqué on the Monitoring and Inspection of Processes for Sampling Fresh Concrete, Conducting Tests, and Reporting under the Building Inspection Law No. 4708. Based on the information obtained, the inclusion of which digital transformation technologies in current practices and the points where they are lacking were identified. It was interpreted which technology collaborations could provide solutions to the existing problems as well.

2.1. The Transformation Stages of the Building Inspection Process

The fundamental step in the digitization process of the Building Inspection System was taken in 2007 with the introduction of the software system in the computer environment. Version 1.0 (Date: 30.08.2007) is the initially released version of the Building Inspection System. Initially, the software system was accessed through the (no longer accessible) website www.yigm.gov.tr. At its implementation, the building inspection system was applied in 19 pilot provinces in Türkiye and had not yet reached all 81 provinces. These provinces were Adana, Ankara, Antalya, Aydın, Balıkesir, Bolu, Bursa, Çanakkale, Denizli, Düzce, Eskişehir, Gaziantep, Hatay, Istanbul, Izmir, Kocaeli, Sakarya, Tekirdağ, and Yalova. The software system's user manual specifies that the system is a software automation system [7].

On November 5th, 2018, a crucial amendment was made to the law to address possible misuses arising from commercial relationships between companies participating in the construction control mechanism. The amendment was aimed at increasing transparency and preventing potential conflicts of interest within the building control system. According to this amendment, building control service agreements can be signed electronically between building owners and building control institutions determined by the Ministry of Environment and Urbanization to prevent possible misconduct. As of January 1st, 2019, the Ministry of Environment and Urbanization has decided that building control service agreements can only be terminated under specific circumstances, as outlined in the new Regulation [8].

In order to implement this amendment, a significant change has been made in the software system, and the interface of the system has been modified. A rating system has been established for each firm. The software program is responsible for distributing tasks and assigning jobs to the firms based on their ratings, enabling task distribution automation. As a result, the margin of error in the rating calculation has been minimized.

Another significant development is the implementation of the Electronic Concrete Monitoring System (EBİS). EBİS is a system created using RFID technology, QR-coded barcodes, and internet infrastructure to track fresh concrete samples used in buildings subject to Law No. 4708. In accordance with the "Communiqué on Monitoring and Inspection of the Processes of Sampling, Testing, Reporting, and Supervising Fresh Concrete in Buildings Subject to the Law on Building Inspection No. 4708," EBİS was implemented nationwide as of December 25, 2018. The aforementioned Communiqué was amended on November 14, 2020, and the regulation regarding the application of labels on ready-mix concrete mixers and QR codes on delivery notes came into effect on November 30, 2020.

In order to enable the electronic monitoring of concrete used in construction, the Ministry of Environment and Urbanization conducted Research and Development (R&D) work. They carried out a pilot application in the provinces of Afyon, Düzce, and Karaman to determine the concrete tags (RFID chips) to be used in the system. Based on the findings obtained from the pilot application, a roadmap for the system was established. On January 4, 2018, a collaboration protocol was signed between the Presidency of Defense Industries and the Ministry of Environment, Urbanization, and Climate Change. Within the scope of this protocol, 650 devices weighing 1,200 kg with a compressive strength capacity of 3,000 kN were produced, equipped with RFID readers, video cameras, power sources, and a lock system to prevent tampering. The devices were installed and calibrated in certified laboratories authorized by the Ministry of Environment, Urbanization, and Climate Change. The procedures were conducted in provincial directorate laboratories across all 81 provinces.

Furthermore, a data recovery center has been established to store the information to be loaded nationwide securely. As part of the project, an internet-based (EBIS) Elektronik Beton İzleme Sistemi (Electronic Concrete Monitoring System) Central Monitoring Software and EBIS Mobile Application Software, which can be used on mobile devices, have been developed. The "Concrete Testing Device" and software were tested through a pilot application carried out in Eskişehir for one month. In 2018, training sessions and regional meetings were organized in 11 provinces to inform personnel working in the central and provincial organizations of the Ministry of Environment, Urbanization, and Climate Change about the EBIS Project and its applications. With EBIS, it is possible to access information such as which class of concrete is used in which construction site, which concrete mixer the concrete is obtained from, the date and time of collection by which personnel from which laboratory, the amount of admixture and cement used in the concrete, the number of samples prepared for testing, which laboratory and by whom the tests were conducted, whether building inspection officers participated in the concrete pouring, whether the samples were stored in suitable conditions following the specified durations at the construction site and curing pool, whether the samples were crushed in the specially produced concrete testing presses on the day of testing, and whether the test results comply with the standards. EBIS can be centrally monitored and tracked through its two software applications (mobile and internet-based) and the specially designed concrete crushing device.

The calibration of concrete crushing devices is carried out at least once a year, free of charge, by a calibration organization accredited by the Turkish Accreditation Agency (TÜRKAK), which is exclusively used by organizations receiving EBIS services. The calibration procedures are conducted by the Turkish Standards Institution (TSE). The test results obtained by laboratory organizations regarding the samples taken from fresh concrete are electronically transferred to the system without any intervention or manipulation. If the obtained results do not meet the required criteria after the test, the construction of the structure is halted by the building inspection organizations. Subsequently, core samples are taken from areas that will not cause damage to the structure. If the core samples also fail to provide the desired strength, a structural analysis of the load-bearing system is conducted, and measures such as strengthening the structure or demolishing the necessary floors are carried out. Since November 30, 2020, ready-mixed concrete producers have also been included in EBIS through barcode-labeled delivery notes and truck mixer labels. This enables the recording of concrete production from the central process, monitoring the concrete production process, and preventing losses and deficiencies that may occur in concrete [8].

If we provide examples from various countries, in Germany, structures are inspected by special inspection engineers who are granted extensive authority. Engineers who pass the examination and obtain an inspection certificate work under the Construction Directorates affiliated with local authorities. In Japan, local governments are responsible for construction inspections. Architects are responsible for both the design and the control during the construction phase. In England, similar to Japan, local authorities take on the responsibility of construction inspections. Additionally, private inspection and insurance companies are involved. Building regulations form the basis of the system. In Belgium, local governments are held responsible for construction inspections. Architects have significant responsibilities, similar to those in Japan, and they are also accountable for the construction process. A system identical to that in Europe is followed in the United States, assigning responsibilities to local governments. An architect is appointed to establish all connections and ensure project coordination during the design and permitting stages. In France, construction inspections are carried out by independent inspection firms in collaboration with municipalities and ministries [9].

2.2. Digital Transformation Components Used in the Building Inspection Process

The stages of the construction supervision process, determining the levels of construction, can be classified as follows, based on studies conducted in the field: [10-16]

Project Phase: Preparation of projects by authors, Review of projects' compliance by auditors, Communication of points to be corrected by construction inspection to authors, Checking of revisions, and preparing them for submission for administrative approval.

Permit Phase: The version of projects to be submitted for administrative approval, Gathering necessary documents, and Preparation of the permit by the relevant authority.

Structural System Inspection: Conducting laboratory tests for iron standards, controlling the foundation limits by a survey engineer and the authority, checking the foundation formwork and steel reinforcement for compliance with the project, completing any deficiencies if found, and conducting re-inspection, accompanying concrete pouring and approving the obtained fresh concrete samples, checking the conformity of the poured floor concrete's fresh sample results to the standards, examining the conformity of column, beam, and floor slab to the formwork and reinforcement plan, ensuring timely removal of formworks, notifying the authorities of any fresh sample results that do not comply with the standards and requesting a halt to construction activities, ensuring the extraction of core samples, resuming construction activities after obtaining satisfactory results.

Non-compliance Detection: In case of any non-compliant implementation with the project, notify the authority within three days of the authority deciding on the construction site.

Finishing Works Inspection: In the inspection of finishing works, the examination of whether the construction is carried out in accordance with the project begins after reaching approximately 60% completion of the construction. The inspection includes checking if the walls are built according to the project outputs and verifying the materials, thickness, and other elements for compliance with the project requirements.

Occupancy Permit: The process of obtaining an occupancy permit for the building has reached its final stage, making it compliant with the landscape plan. An application has been submitted to the authorities for the building to receive occupancy approval. The authorities and inspection personnel will conduct on-site inspections based on the project outcomes. The occupancy permit will be prepared by the authorities.

Building Identification System: When the building reaches the occupancy stage, the digitally approved versions of the project documents, which serve as the basis for the permit, are uploaded separately for each discipline into the UYDS(Building Identification System) software by the authorities. The building owner is responsible for paying the fee for the building identification sign. Once completed, the authorities will approve the request for project completion.

Table 1. *Stages of Building Inspection System and Its Relationship with Industry 4.0 Technologies in the Republic of Türkiye*

	Building Inspection System Stages						
Industry 4.0 Technologies	**Project Stage**	**Permit Stage**	**Structural System Inspection**	**Detection of Non-Compliance**	**Inspection Finishing Works**	**Certificate of Occupancy**	**Building Identification System**
Cloud Computing	✓	✓	✓			✓	✓
Additive Manufacturing							
Virtualization Technologies	✓						
Wireless Communication, Network Technologies	✓	✓	✓			✓	✓
Data Analytics and Artificial Intelligence							
Mobile Technologies			✓	✓			
Sensors			✓				✓
Cyber Security		✓					

The relationship between the stages of building inspection systems and Industry 4.0 technologies is indicated in Table 1 above, based on the study by Saricioglu, Ilerisoy, and Soyluk (n.d.) [17]. Cloud computing, wireless communication, and network technologies are utilized in various stages, such as the design phase, permit phase, structural system inspection, obtaining an occupancy permit, and building identification system. Among these stages, the structural system inspection is most influenced by Industry 4.0 technologies. The weakest relationship established is with the inspection of finishing works. The quality of finished work inspection is low, leading to higher penalties imposed on companies. The lacking aspect in the utilization of Industry 4.0 technologies is the lack of autonomy in the system, which makes it susceptible to interpretation and errors.

As mentioned in the study by Kural and Unal [18], the approach of relevant authorities towards existing works can vary depending on individuals and companies. According to the survey conducted by Bayram, Aydinli, Budak, and Oral [14], the most common problems encountered in construction are architectural in nature. It is often observed that the construction of walls deviates from the project requirements, while design and implementation issues related to the structural system have significantly decreased. This situation can be attributed to the integration of digital transformation technologies into the rough construction inspection process, while the inspection of finishing works is not fully incorporated.

2.3. Assessment of Issues in Building Inspection and Seeking Solutions within the Scope of Digital Transformation

The deficiencies in integrating the building inspection system stages specified in Table 2 with Industry 4.0 have been identified. The main reason behind this is mostly the lack of technological competence. The haphazard progression of the steps, such as the review of projects prepared by authors by inspectors, requesting necessary corrections, and ensuring reevaluation during the project phase, reduces the quality of control. In the licensing phase, requiring projects approved as compliant with the regulations by the inspection company to be submitted as six copies for architectural disciplines and five copies for other engineering disciplines, according to Article 57 of the Planned Areas Zoning Regulation, not only leads to paper waste but also creates highly unfavorable situations for the storage and utilization of projects during the field control stage. ("Planned Areas Zoning Regulation," n.d.) [19]. Large-scale projects cannot be effectively utilized on a human-scale field. Regarding structural system inspection, the inspection and control of reinforcement and formwork entirely rely on the discretion of the inspector and control engineer. There is currently no autonomous system in place to ensure their control.

One example of the legislation being slow to adapt to technology is the method of notifying inspectors about assigned tasks. The paragraphs below are stated in Article 16 of the Building Inspection Implementation Regulation [20].

"(4) The construction inspection organization takes necessary measures to inform the inspectors, architects, and engineer inspectors about their responsibilities. For this purpose, monthly briefing schedules are prepared and communicated to the relevant personnel with their signature."

"(5) (Amended: Official Gazette - 29/12/2018-30640) Inspectors, architects, and engineer inspectors are responsible for appropriately assigning and supervising the assistant control personnel who are working on the same tasks under their responsibility. Inspectors, architects, and engineer inspectors prepare monthly reports regularly for the assistant control personnel under their supervision regarding the tasks under their responsibility and submit them to the construction inspection organization."

In the fourth paragraph, instead of the practice of delivering notices against signature, assignment invitations are now sent to inspectors through the software system. Inspectors then enter the software system with their e-government information and approve the assigned tasks. Therefore, this provision is no longer necessary but still exists in the legislation.

In case any discrepancy is detected in construction works, according to the regulations, the findings are distributed to the relevant administration, and the construction contractor is notified to rectify the work within a specified period through registered mail. If the deficiencies or discrepancies are not resolved within the given timeframe, they are again reported to the administration via registered mail. These processes have occurred during the pandemic period with unpredictable delays. The delivery of registered mails has been delayed and unsuccessful when the addressees were unavailable. The administration's decision-making process regarding the construction works on the site and notifying the parties about it unnecessarily prolongs the construction activities.

Table 2. *Stages of Building Inspection System and Integration Problems with Industry 4.0 Technologies in the Republic of Türkiye*

	Building Inspection System Stages	(A)	(B)	(C)
Project Stage	• Preparation of the projects by the authors,		✓	
	• Review of the compliance of the projects by the auditors,	✓	✓	
	• Notification of the points to be corrected by the building supervision to the authors,	✓	✓	
	• Checking the revisions and making them ready to be sent to the administration for approval	✓	✓	
Permit Stage	• Projects to be sent to the administration for approval		✓	
	• Collection of necessary documents		✓	
	• Preparation of the license by the relevant administration		✓	
Structural System Inspection	• Laboratory tests for iron standards		✓	
	• Checking the foundation boundaries by the mapping engineer and the administration	✓		
	• Checking the foundation formwork and iron reinforcement in accordance with the project, completing the deficiencies, if any, and checking again	✓	✓	
	• Accompanying for concrete pouring, approval of wet concrete samples taken			✓
	• Checking the conformity of the poured floor concrete wet sample results with the standards	✓		
	• Examining the conformity of column, beam, and floor slab to the mold and reinforcement plan	✓	✓	
	• Ensuring that the molds are dismantled at the appropriate time	✓	✓	
	• Notification of the administrations of the wet sample report, the results of which do not comply with the standards, and the request to stop the construction site activities	✓	✓	
	• Ensuring that core samples are taken			✓
	• Continuation of construction site activities after the appropriate result is obtained		✓	
Detection of Non-Compliance	• In case of detection of an application contrary to the project, notification to the administration within three days	✓	✓	
	• Decision of the administration about the construction site		✓	
Inspection Finishing Works	• In the inspection of fine works, after 60% of the construction, it starts to be inspected whether the manufacturing is carried out in accordance with the project.	✓	✓	
	• By examining the project outputs, it is inspected whether the elements, such as the laying of the walls, material, and thickness, are in accordance with the project at the construction site.	✓	✓	
Certificate of Occupancy	• The building has reached the stage of occupancy; it has been made in accordance with the landscape plan	✓	✓	
	• Making an application to the administration for the building to be occupied		✓	✓
	• On-site control of the administration and audit staff over the project outputs	✓	✓	✓
	• Preparation of the occupancy license by the administration		✓	

Building Identification System	• When the building reaches the stage of occupancy, the digital version of the approved projects based on the license is uploaded to the UYDS software by the administrations separately for each discipline. The fee is paid by the building owner for the building identification sign board, and the administration approves the work completion request after completion.			✓
(A)The lack of autonomy; (B) The lack of technological maturity; (C) The slow adaptation of regulations to technology				

In the inspection of fine works, conducting on-site examinations with large-scale drawings leads to poor quality control. Moreover, according to the regulations, the site manager or the contractor should inform the construction inspection company at least one day in advance. Still, in practice, they often fail to provide such notification. As a result, the inspection company identified deficiencies or discrepancies approximately one month after the construction of the walls started. In such cases, modifications are made to the projects, causing further delays in the construction activities on the site.

During the occupancy permit stage of the building, compliance with the project at the completed construction site is checked by the administration using large-scale drawing outputs, and it is left to the discretion of the person performing the inspection. With the introduction of the building identification system, the approved digital versions of the project plans of buildings at the occupancy permit stage are uploaded to the construction inspection software system by the authorities. However, after the implementation, it was observed that the legislation and the technological application were incompatible in this regard.

3. RESULTS AND DISCUSSION

In Türkiye, building owners enter into contracts with construction inspection firms that hold permission certificates issued by the Ministry. During the contract period, the inspection firms are responsible for ensuring that the construction and licensing of the building comply with the regulations. They are legally obligated to be responsible for the structural system for 15 years after the completion of the project and for other non-structural components for two years. Unlike many other countries, in Türkiye, architects only take responsibility for the project's design phase. The site manager is primarily responsible for ensuring the construction is carried out under the project. Unfortunately, in many construction sites, the role of the site manager is still only on paper. Communication gaps among authors during the design phase are also significant issues. The coordination among all projects and establishing connections with official institutions during the design phase are left to the construction inspection firms. In order to achieve this, the current processes need to be revised. With the introduction of the Building Identification System, the digital versions of all officially approved projects at the occupancy permit stage are uploaded and stored in the construction inspection software system. Keeping projects not only in hard copy but also digitally provides easier access and creates an infrastructure that can support multiple control mechanisms. The following steps following the implementation of such a system for projects during the licensing process would lead to the automation of project control as programs can be developed utilizing artificial intelligence for the control mechanisms. Thus, achieving autonomy in project control would be a significant step in reducing the margin of error. During the construction phase of the building, on-site inspections such as reinforcement delivery, formwork checks, and verification of compliance with the project are currently conducted through documentation. This process needs to undergo digital transformation, utilizing location services or defined fingerprint programs for approval to digitize and automate the system. To eliminate the issue of construction inspection firms that do not conduct on-site inspections, such transformations in the inspection activities are inevitable [8].

During the certification process of project and application inspectors, they are not subjected to any legal examination. In terms of age, they are not actually of the age to work on construction sites. Additionally, due to the inadequate budget allocations of inspection firms for engineers who will work on construction sites, the inspectors appearing in the system are often only visible in the system but not actively present in practice [21]. The certification requirements need to be revised, and then, utilizing the possibilities of digital transformation, qualified engineers should be assigned as the actual inspectors on construction sites. In the building inspection process, systems that can be integrated into the software should be implemented to ensure the presence of both the site manager and the control engineers on the construction site. When necessary, the inspection area can be monitored by the Ministry of Environment, Urbanization, and Climate Change through the use of digital cameras. A functioning inspection mechanism can be established by increasing the control mechanism and automating the processes [22].

Table 3. *Building Inspection System Stages and Solution Suggestions within the Scope of Industry 4.0 in the Republic of Türkiye*

	Building Inspection System Stages	***Solution Proposal within the Scope of Industry 4.0***
Project Stage	• Preparation of the projects by the authors, • Review of the compliance of the projects by the auditors, • Notification of the points to be corrected by the building supervision to the authors, • Checking the revisions and making them ready to be sent to the administration for approval	Projects prepared with BIM will provide an integrated design. The software can be developed by utilizing artificial intelligence and BIM for project supervision. Speed can be gained by working with cloud computing for revision processes. Approval of projects can be realized and stored in the digital environment.
Permit Stage	• Projects to be sent to the administration for approval • Collection of necessary documents • Preparation of the license by the relevant administration	The approval process of projects should be digitalised. It can be ensured that the requested documents can be used in the digital environment with e-signature.
Structural System Inspection	• Laboratory tests for iron standards	It can be ensured that the test request is made through the software and the tensile test result is entered into the system in the field.
	• Checking the foundation boundaries by the mapping engineer and the administration	The paperwork process can be digitalised.
	• Checking the foundation formwork and iron reinforcement in accordance with the project, completing the deficiencies, if any, and checking again	Controls approved on paper can be transferred to the software system and approved by the parties, including the construction site chief with a fingerprint.
	• Accompanying for concrete pouring, approval of wet concrete samples taken	Features such as fingerprint or iris recognition can be activated during concrete pouring.
	• Checking the conformity of the poured floor concrete wet sample results with the standards	The result that does not comply with the standard can go to the building inspection company with instant notification via the software.
	• Examining the conformity of column, beam, and floor slab to the mold and reinforcement plan	Digital twin models can be utilized.
	• Ensuring that the molds are dismantled at the appropriate time	With sensors that can be placed in the molds, a notification can be sent to the inspector in any process.
	• Notification of the administrations of the wet sample report, the results of which do not comply with the standards, and the request to stop the construction site activities	Time can be saved by digitizing the communication method related to these processes.
	• Ensuring that core samples are taken	Autonomous robots can be utilized in core sampling.
	• Continuation of construction site activities after the appropriate result is obtained	Notification of the continuation of activities can be made via software to gain speed.
Detection of Non-Compliance	• In case of detection of an application contrary to the project, notification to the administration within three days • The decision of the administration about the construction site	Correspondence regarding the detection can be made through the software system. Whether there is an activity in the productions on the construction site can be inspected by drone.
Inspection Finishing Works	• In the inspection of fine works, after 60% of the construction, it starts to be inspected whether the manufacturing is carried out in accordance with the project. • By examining the project outputs, it is inspected whether the elements such as the laying of the walls, material, and thickness are in accordance with the project at the construction site.	Control can be achieved with digital twin, autonomous robots, camera systems, and BIM.

Certificate of Occupancy	• The building has reached the stage of occupancy; it has been made in accordance with the landscape plan • Making an application to the administration for the building to be occupied • On-site control of the administration and the audit staff over the project outputs • Preparation of the occupancy license by the administration	Control processes should be digitalised. Application procedures should be prepared through the software system without wasting time.
Building Identification System	• When the building reaches the stage of occupancy, the digital version of the approved projects based on the license is uploaded to the UYDS software by the administrations separately for each discipline, the building owner pays the fee for the building identification sign board, and the administration approves the work completion request after completion.	It can be ensured that the building has a digital twin, routine controls are provided for specific periods, and the differences that arise can be inspected.

4. CONCLUSION AND RECOMMENDATIONS

The study suggests that incorporating Industry 4.0 Technologies into each inspection stage is crucial for establishing a robust inspection system. This approach can ensure that the inspection process is efficient and effective while minimizing error rates. In the context of construction sites, the inspection mechanism needs to keep pace with the production technology, while the latter has advanced considerably in recent times. This is crucial to ensure that the production processes are carried out without any glitches and meet the required standards of quality and safety. As Industry 4.0 technologies become more prevalent in construction production processes, there is potential for significant improvements in inspection processes. One example of this is the use of additive manufacturing to construct a simple house within 24 hours. In some cases, a mixture of concrete and glass fiber material that does not require any iron can be used in the construction. This innovative material can result in faster production times and potentially reduce costs. The advancements in 3D printing technology have drastically reduced the material requirements and increased the construction speed, making them the primary motivators for future developments in this field [1]. The advancements in 3D printing technology have drastically reduced the material requirements and increased the construction speed, making them the primary motivators for future developments in this field.

In Table 3 presented in the study, the column titled "Solution Proposal within the Scope of Industry 4.0" provides solutions for the processes in building inspection stages, addressing the problems identified in Table 2 within the scope of Industry 4.0 (lack of autonomy, inadequate technological competence, and slow adaptation of legislation to technology). The most urgent revision needed for the Building Inspection System is the digitalization of all processes. After completing this transformation, it will be able to easily adapt to the subsequent steps.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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