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APPLICATION OF CONSTRUCTION 4.0 TECHNOLOGIES: EMPIRICAL FINDINGS FROM THE TURKISH CONSTRUCTION INDUSTRY

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Aynur Hurriyet Turkyilmaz, PhD Candidate,
Istanbul Technical University, Department of Civil Engineering, Istanbul, Turkiye
ORCID: 0009-0009-6646-5381
turkyilmaza19@itu.edu.tr

Gul Polat, Professor (Corresponding Author),
Istanbul Technical University, Department of Civil Engineering, Istanbul, Turkiye
ORCID: 0000-0003-2431-033X
polatgu@itu.edu.tr

Aysegul Gurkan, Civil Engineer,
Istanbul Technical University, Department of Civil Engineering, Istanbul, Turkiye
ORCID: 0009-0009-2365-182X
aysegul.grkan@gmail.com

SUMMARY: *The construction industry is a leading sector in terms of labor force development and economic involvement on a global scale. It is widely recognized that this industry faces numerous obstacles. The digital revolution has penetrated all aspects of every organization. It could offer potential solutions to the challenges faced in the construction industry, which has been generally resistant to adopting the efficiency provided by information technologies. Multiple studies are dedicated to examining the difficulties encountered by the construction industry, as well as the advancement of technologies in this field. However, further research is required to examine the extent to which construction professionals are aware of and acknowledge new technologies, as well as their expectations regarding the problem-solving capabilities of Construction 4.0 technologies. This study investigates the degree of awareness of Construction 4.0 technologies, the significance of the primary challenges frequently encountered in construction projects, the advantages expected from these technologies, and the level of consensus among various groups of construction professionals on these matters. Based on an extensive examination of existing literature, 13 specific technologies related to Construction 4.0, 11 primary challenges and 17 anticipated advantages were identified. A survey was devised and administered to Turkish construction experts, resulting in the collection of 188 valid responses. The gathered data was subsequently subjected to statistical analyses. The investigated data led to the conclusion that there was a substantial agreement among the respondents regarding the level of recognition of Construction 4.0 technologies, the primary challenges in construction projects, and the anticipated advantages of these technologies. The results of this study can guide professionals and academics in determining which innovations to endorse, considering practical needs.*

KEYWORDS: *Construction 4.0 technologies, expected benefits, problems in construction, questionnaire, Turkish construction professionals.*

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1. INTRODUCTION

The advent of Industry 4.0 has brought about the implementation of digitization and automation technologies, which have had a significant impact on various industries, including the construction industry with numerous integrated applications (Perrier et al, 2020; Perrier et al, 2024). The Construction 4.0 was first introduced in Germany by Berger (2016), which necessitates construction companies to adapt their project management style by utilizing new technologies to capture real-time data, which is then used in the decision-making processes. Mansour et al. (2023) further emphasize the importance of incorporating these collected data into the decision-making processes. Digitization and automation technologies have the potential to help construction companies overcome common industry challenges (Gambo and Musonda, 2021). However, construction professionals, in general, are reluctant to adopt these new technologies in their operations (Oesterreich and Teuteberg, 2016; Muñoz-La Rivera et al, 2021; García de Soto et al, 2022).

Multiple studies have been conducted to elucidate these technologies and outline their potential applications in the construction industry. However, there is a scarcity of papers that specifically address the following questions:

Question 1: What is the recognition level of Construction 4.0 technologies?

Question 2: What are the main problems frequently faced in construction projects?

Question 3: What benefits can be expected from the application of these technologies?

Question 4: Do the attributes of the companies where the respondent professionals work influence their viewpoints and understandings of Q1-Q3?

This study seeks to address these research inquiries by conducting a comprehensive questionnaire survey among 188 experts in the Turkish construction industry. Mean score analysis and Mann-Whitney U test were performed on the collected data. This research makes a significant contribution by elucidating the overall level of recognition of Construction 4.0 technologies and the primary expectations of professionals in the construction industry. The findings of this study may assist professionals and academicians in comprehending the precise requirements and anticipations of the industry.

2. PREVIOUS STUDIES ON CONSTRUCTION 4.0

Forcael et al. (2020) conducted a comprehensive evaluation of 257 papers to ascertain the genesis and significance of the Construction 4.0 idea. Perrier et al. (2020) analyzed 200 research publications and determined that these technologies are primarily utilized in the pre-construction stages but have promise for the construction phases. In their study, Schönbeck et al. (2020) examined over 200 papers and determined that there was no significant increase in the quantity of research conducted on new technologies from 2015 to 2019. In their study, Newman et al. (2021) conducted a case study to examine the advantages and disadvantages of integrating these technologies and discovered that while Building Information Modelling (BIM) is widely embraced, experts' reluctance is a significant barrier. Karmakar and Delhi (2021) identified several challenges associated with implementing Construction 4.0 technologies in their literature review. These challenges include the need to align incentive mechanisms among different stakeholders, the requirement for skilling and training of personnel to effectively adopt these technologies, the integration of project lifecycles in a fragmented industry, the necessity for process-related changes to accommodate digital technologies, and the establishment of policy frameworks to ensure security and integration of data for construction projects. According to the findings of Yang et al. (2022), leaders must possess 22 essential leadership abilities in order to effectively manage digital transformation. Statsenko et al. (2023) examined 170 articles on Construction 4.0 technologies published from 2021 to 2023. Six application scenarios of Construction 4.0 technologies were established based on the domain of Industry 4.0 technology. Additionally, Adekunle et al. (2024) conducted a review of studies on digital transformation in the construction industry, identifying different aspects and a flow model for this transformation.

Craveiroa et al. (2019) conducted a study specifically on additive manufacturing, whereas Sepasgozar (2021) provided a comprehensive evaluation of additive manufacturing within the framework of the digital twin. Calvetti et al. (2020) established the notion of Worker 4.0, whereas Yap et al. (2022) argued that the safety of construction projects may be improved by integrating more technical solutions offered by Construction 4.0. Dardouri et al. (2023) investigated Radio Frequency Identification (RFID) as a Construction 4.0 technology and found that it facilitates real-time material management, leading to cost and time savings. Begić and Galić (2021) asserted that the majority of Construction 4.0 technologies are interdependent. Ali and Bandi (2022) examined the association between the generation of large amounts of data and BIM technologies and discovered a robust correlation between the output of extensive data and the data related to materials, design, and planning in BIM. Akinradewo et al. (2023) found that the successful use of BIM in maintenance management is closely linked to the leadership of construction companies. Hire et al. (2024) introduced a framework for early site safety management that uses BIM technology to automatically check for safety hazards during the design stage. This framework includes guidelines, time management, corrective actions, and virtual environment reports to identify hazards in construction projects. Furthermore, it has been argued that BIM has the potential to positively impact Supply Chain Management, as suggested by Selvanesan and Satanarachchi (2023). Khan et al. (2024) studied RFID technologies, their integration with the Internet of Things (IoT), and security measures to address issues related to RFID systems throughout the supply chain in the construction industry.

Osunsanmi et al. (2018) administered a questionnaire survey to South African construction professionals to assess their preparedness for these technologies and their awareness of the significance of construction 4.0 concepts. It was discovered that construction professionals lack familiarity with these concepts, and there are no notable distinctions between consulting and contracting organizations in terms of adopting Construction 4.0 technologies. Hossain and Nadeem (2019) identified a lack of training and a deficiency in digital culture as the primary obstacles hindering the integration of the Construction 4.0 concept within firms. When examining the progress of technology adoption in construction organizations, three steps can be identified: information analysis, verification, and selection. Osunsanmi et al. (2020) conducted a questionnaire study with 91 construction experts in South Africa to assess the preparedness of the construction industry in adopting Construction 4.0 technology. It was discovered that the building industry is prepared, but the primary obstacle is the insufficient comprehension of these technologies. Arowoiya et al. (2021) examined the key characteristics that contribute to the successful adoption of augmented reality in the construction industry. They conducted a survey with 166 participants to gather data. Furthermore, they recommended that stakeholders demonstrate openness to technological innovation and novel advancements, while also proposing that the government help in the adoption and utilization of new technology. García de Soto et al. (2022) conducted a case study which indicates that Construction 4.0 will require greater professional diversity and the emergence of novel positions in both the implementation and management aspects of the industry. Aghimien et al. (2022) administered a survey to 86 construction experts in South Africa to examine the extent of digitalization in construction enterprises. Construction companies have not yet embraced digital cooperation. Nevertheless, when employed efficiently, pooled digital resources can offer construction enterprises a significant advantage in competition, improved project execution, and mitigation of risks. Muñoz-La Rivera et al. (2021) examined the methodological and technological framework of Construction 4.0 technologies. Based on their research, the integration of individuals, processes, and goods is identified as a major challenge. Data security is another challenging aspect of integrating Construction 4.0 technology, and de Soto et al. (2022) highlight cybersecurity applications in the construction industry using a literature review research. In their study, Wernicke et al. (2023) examined the framework for assessing the digital maturity of construction site processes. They concluded that digital maturity is contingent upon the incorporation and integration of technology inside both the organization and site operations. Their findings indicate that these implementations enable the organization of assessment processes and offer long-term improvements to project portfolios. Additionally, Dolla et al. (2023) have proposed that the processes within the construction sector will go through transformation within the context of Construction 4.0. Based on the findings of a survey conducted among 63 construction professionals in India, it has been determined that integration of stakeholder, redesign of processes, training of activities, and the requirement for federated data generation are identified as the foremost strategic interventions in the field of project management. Sajjad et al. (2024) administered a survey in China regarding Industry 4.0 digitalization methods for sustainable construction management. Their research offers empirical proof that Industry 4.0 digitalization has a positive influence on sustainability, design enhancement, technology application, functional upgrades, resource control, and managerial effectiveness.

3. RESEARCH METHODOLOGY

The research methodology comprises five main steps: (1) literature review, (2) questionnaire design, (3) data collection, (4) data analysis, and (5) discussion (Figure 1).

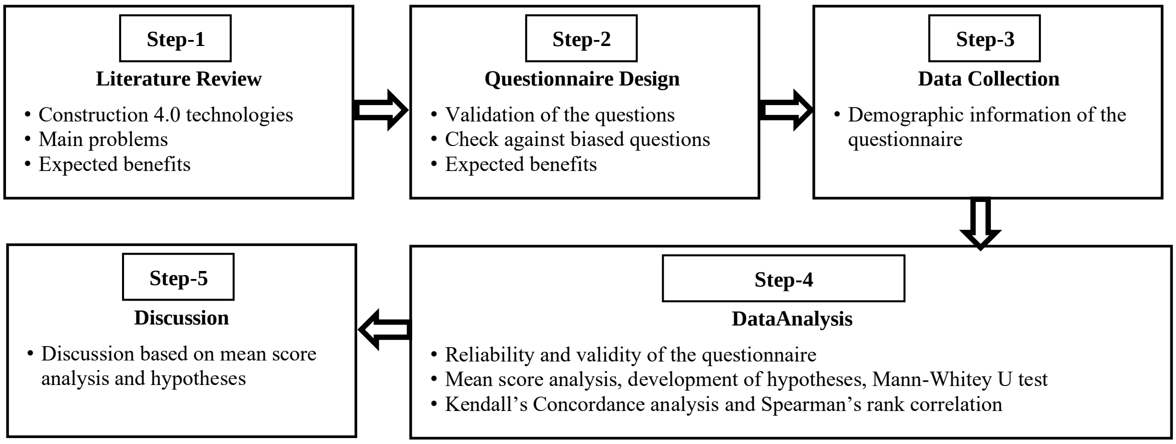

Figure 1: Steps of the Research Methodology.

3.1 Step 1- Literature Review

During this phase, a review was conducted on Construction 4.0 technologies, wherein the primary challenges faced in construction projects were highlighted. Furthermore, an examination was carried out to determine how these technologies can assist professionals in effectively addressing these challenges.

3.1.1 Construction 4.0 Technologies (CTs)

CTs refer to advanced technological tools and systems used in the construction industry. Various CTs were introduced in the literature. A list of the most commonly mentioned technologies can be found in Table 1 (e.g., Oesterreich and Teuteberg, 2016, Zhong et al, 2016, 2017, Sakin et al, 2017, Altaf et al, 2018, de Soto et al, 2018, Han and Wang, 2018, Wang et al, 2018, Zhang et al, 2018, Li and Liu, 2019, Boje et al, 2020, Liu, 2020, Nnaji et al, 2020, Hasan et al, 2021, García de Soto et al, 2022).

Table 1: Construction 4.0 technologies (CTs).

ID	Construction 4.0 Technologies
CT1	Prefabrication and modularization
CT2	Radio Frequency Identification (RFID)
CT3	Building Information Modelling (BIM)
CT4	Internet of Things (IoT)
CT5	Internet of Services (IoS)
CT6	Big data
CT7	Cloud computing
CT8	Augmented Reality (AR) and Virtual Reality (VR)
CT9	3D printing
CT10	Wearable technologies
CT11	Cyber Physical Systems (CPS)
CT12	Robots
CT13	Drones

3.1.2 Main Problems Encountered by Professionals in Construction Projects (MPs)

Construction experts frequently encounter several challenges in construction projects. This section identifies the difficulties that can be partially resolved by utilizing Construction 4.0 technologies. The MPs are documented in Table 2, with references to various studies conducted by Assaf and Al-Hejji (2006), Sambasivan and Soon (2007), Laufer et al. (2008), Enshassi et al. (2009), Monteiro and Martins (2013), Zhang et al. (2013), Choi et al. (2015), Agarwal et al. (2016), Oesterreich and Teuteberg (2016), Wang et al. (2016), Osunsanmi et al. (2018), Craveiroa et al. (2019), and Nguyen et al. (2022).

Table 2: Main problems encountered by professionals in construction projects (MPs).

ID	Construction 4.0 Technologies
MP1	Low productivity of laborers
MP2	Ineffective usage of machinery
MP3	Delays
MP4	Cost overruns
MP5	Communication problems among stakeholders
MP6	Interrupted information flow between construction site and office
MP7	HSE problems
MP8	Clashes in design documents and constructability problems
MP9	Material wastes
MP10	Quantity take-off errors
MP11	Reworks due to quality problems

3.1.3 Benefits Expected from Construction 4.0 Technologies (EBs)

Once the key difficulties were identified, the expected benefits of implementing CTs to address these issues were established. The EBs are outlined in Table 3, citing Agarwal et al. (2016), Oesterreich and Teuteberg (2016), Osunsanmi et al. (2018), Ebekozien and Aigbavboa (2021), and Elrefaey et al. (2022).

Table 3: Benefits Expected from Construction 4.0 Technologies (EBs).

ID	Construction 4.0 Technologies
EB1	Increased productivity
EB2	Effective usage of machinery
EB3	Time savings
EB4	Cost savings
EB5	Improved information flow between construction site and office
EB6	Obtaining real-time information on the project’s progress
EB7	Quick response to the encountered problems in the project
EB8	Increasing safety
EB9	Timely detection of inadequacies of the project
EB10	Minimizing waste amount
EB11	Improving sustainable operations
EB12	Reducing human errors
EB13	Enhancing quality
EB14	Easy access to places where human access is difficult
EB15	Increasing customer satisfaction
EB16	Achieving competitive advantage in the market
EB17	Being a pioneer in the market

3.2 Step 2- Questionnaire Design

Interrogations regarding the professional history of both the respondents and building companies were posed at the onset of the questionnaire. The questionnaire had three primary sections. The initial section sought to examine the degree of recognition of CTs. The objective of the second section was to get an understanding of the significance of MPs. The final section examined the EBs.

The questionnaire was subjected to review by five experts with over a decade of experience in construction. Their feedback was used to make necessary revisions before distributing the questionnaires, in order to validate the identified CTs, MPs, and EBs. In addition, only straightforward questions were posed and any questions that could potentially influence the responses were excluded in order to avoid any bias in the answers.

3.3 Step 3- Data Collection

The size of the specific demographic, consisting of Turkish construction professionals, was obtained from the Turkish Statistical Institute (TUIK). The official data indicates that the construction business in Turkey employs a total of 930,000 individuals who receive compensation for their work. The study (Gamil et al, 2020) utilized the random sampling technique, whereas the required sample size was determined using Equation (1) (Albuainain et al, 2021).

$$n_{req} = \frac{Z^2 p(1-p)}{e^2} = \frac{1.96^2 \times 0.5 \times 0.5}{(0.08)^2} = 150 \qquad \text{Equation (1)}$$

The variables in the equation are as follows: n_{req} represents the necessary sample size, Z is the critical value of the normal distribution at $\alpha/2$, p represents the sample proportion, and e represents the margin of error. Given a population size of 930,000, a significance threshold of $\alpha = 0.05$, a sample percentage of 0.5, and a margin of error of 8%, the necessary sample size was determined to be n = 150.

The questionnaire was created using Google Forms and then shared with 2500 members of the Union of Chambers of Turkish Engineers and Architects (UCTEA). 193 responses were obtained, and after excluding 5 invalid surveys, the remaining data was examined. The sample size of 188, with a response rate of 7.5%, exceeds the minimum required sample size of 150. Consequently, the sample size is deemed sufficient for data analysis.

Tables 4 and 5 present the demographic attributes of the participants and their corresponding organizations, respectively.

Table 4: Demographic profiles of the respondent professionals.

Category	Response	Frequency (N=188)	Percentage (%)
Educational Level	Bachelor (BA)	99	52.66
	Master of Science (MSc)/ Doctor of Philosophy (PhD)	89	47.34
Work Experience (years)	1-9	74	39.36
	10-24	73	38.83
	≥25	41	21.81
Professional Title	Company owner/partner	39	20.75
	Project manager, construction manager, and site manager	58	30.85
	Planning, procurement, and technical office engineer	58	30.85
	QA/QC-HSE specialist	16	8.51
	Site Engineer	17	9.04

Table 5: Demographic profiles of the respondents' company.

Category	Code	Response	Frequency (N=188)	Percentage (%)
Field of specialization		Main Contractor	111	36.39
		Construction/Project Management Services	79	25.9
		Engineering and Design	59	19.34
		Subcontractor	35	11.48
Specialized project type		Residences	120	30.46
		Commercial Structures	99	25.13
		Industrial Facilities	82	20.81
		Infrastructure Projects	67	17.01
		Other	26	6.6
No. of operating years in the construction sector		1-10	33	17.55
		11-20	58	30.85
		21-30	36	19.15
		≥31	61	32.45
Company scale (CS)	CS1	Micro/Small	95	50.53
	CS2	Medium/Large	93	49.47
Market region (MR)	MR1	Only national projects	72	38.3
	MR2	Mostly international projects	116	61.7
IT staff availability (IT)	IT1	Unavailable	93	49.47
	IT2	Available	95	50.53

3.4 Step 4 - Data Analysis

The data obtained from 188 valid questionnaires was entered into the Statistical Package for Social Sciences (IBM SPSS, Version 28.0). Given that ordinal data, namely Likert scale data, was gathered, non-parametric statistical tests were utilized to analyze it (Corder and Foreman, 2014).

3.4.1 Reliability and Validity Analysis of the Questionnaire

Cronbach's α is the predominant metric employed to assess the internal consistency of a questionnaire and determine its reliability. The Cronbach's α coefficient falls between the range of 0 to 1. If the coefficient exceeds 0.60, the reliability can be deemed good (Pallant, 2011).

The Cronbach's α coefficients for the CTs, MPs, and EBs were determined to be 0.837, 0.915, and 0.957, respectively. Given that all Cronbach's α coefficient values exceed 0.6, it may be inferred that the internal consistency within the dataset is deemed adequate.

Content validity and construct validity are crucial aspects of research validity, which pertains to the degree of accuracy in study. To ensure topic validity, the questionnaire for this study was prepared based on a comprehensive literature review and reviewed by five experts before distribution. This approach aligns with the methodology used by Gambo et al. (2016) to achieve content validity. Construct validity seeks to ascertain whether the created questionnaire accurately measures the intended construct (Bagozzi et al, 1991). The suitability of the sampling and sufficiency of the collected data for further analysis were assessed using the Kaiser-Meyer-Olkin (KMO) test and

Bartlett's test of sphericity. A KMO value greater than 0.60 is deemed acceptable according to Kaiser (1974). The KMO test yielded values of 0.837, 0.918, and 0.933 for the recognition level, primary difficulties, and expected benefits, respectively. These results suggest that the intercorrelations are satisfactory. The Bartlett's test of sphericity yielded Chi-square values of 748.817, 1064.813, and 2847.983 for the CTs, MPs, and EBs, respectively. The levels of significance corresponding to the analysis are p = .000, indicating that the correlation matrix is not an identity matrix (Hair et al, 2019).

3.4.2 Mean Score Analysis

The rankings of the CTs, MPs, and EBs were classified into three distinct categories: (a) "company scale" (CS), (b) "the primary market region in which the firm operates" (MR), and (c) "the availability of IT staff within the firm" (IT). The mean scores for CTs, MPs, and EBs in each group were computed and compared to ascertain the variations between respondent groups.

3.4.3 Kendall's Concordance Analysis (W)

The purpose of Kendall's concordance study was to ascertain the level of consensus across several groups of participants regarding their rankings, which were derived from mean scores (Kvam et al, 2022). The Kendall's coefficient of concordance W value ranges from 0 to 1, with 1 representing complete agreement and 0 indicating no agreement among the group about the ranking of specific factors. If the Kendall's coefficient of concordance W value is statistically significant at the 0.05 level (p-value < 0.05), it can be inferred that there is a satisfactory level of agreement among a group of respondents (Kvam et al, 2022).

3.4.4 Spearman's Rank Correlation (R)

The Spearman's rank correlation coefficient (r_s) was computed to quantify the degree of association between the rankings of two distinct respondent groups (Fellows and Liu, 2008). The Spearman's rank correlation coefficient (rs) varies from +1 to -1. A value of -1 shows a perfect negative association (i.e., complete disagreement), 0 represents no correlation, and +1 implies a perfect positive relationship (i.e., complete agreement). If the Spearman's rank correlation coefficient (r_s) is statistically significant at the 0.05 level (p-value < 0.05), it indicates a substantial relationship between the two groups regarding the ranking of the variables in question (Fellows and Liu, 2008).

3.4.5 Mann-Whitney U Test

The null hypotheses were formulated based on the data from Q1, Q2, and Q3:

- **Hypothesis 1:** There are no significant differences in the recognition level of CTs among different groups of (a) "CS", (b) "MR", and (c) "IT";
- **Hypothesis 2:** There are no significant differences in the MPs among different groups of (a) "CS", (b) "MR", and (c) "IT";
- **Hypothesis 3:** There are no significant differences in the EBs among different groups of (a) "CS", (b) "MR", and (c) "IT";
- To address Q4, the Mann-Whitney U test was conducted to determine if there were any significant disparities in the viewpoints and understandings of the professional participants about research questions Q1, Q2, and Q3.

The Mann-Whitney U test was used to evaluate the following two hypotheses for each identified group:

- **H_0:** Null hypothesis: there is no difference between the groups; thus, they share the same mean;
- **H_1:** Alternative hypothesis: a difference exists between the groups.

A significance level of 5% was deemed to indicate a statistically significant difference in ranking between the two groups. Put simply, a p-value below 0.05 signifies a significant discrepancy between two groups, indicating a lack of consensus on a shared ranking.

4. FINDINGS

4.1 Results of Mean Score Analysis

According to the findings in Table 6, the technologies "Internet of Services (IoS)" (CT 5), "Drones" (CT 13), and "Cloud computing" (CT 7) were identified as the top three recognized technologies in Construction 4.0. This ranking was consistent among all respondents and various categories of respondents.

Table 6: Mean score analysis of construction 4.0 technologies (CTs).

CTs	Overall Respondents N=188		Company Scale				Market Region				IT Staff			
	Mean*	Rank	CS1* N=95	Rank	CS2* N=93	Rank	MR1* N=72	Rank	MR2* N=116	Rank	IT1* N=93	Rank	IT2* N=95	Rank
CT1	2.346	5	2.326	5	2.366	5	2.208	5	2.431	5	2.269	5	2.421	5
CT2	1.697	12	1.621	12	1.774	12	1.528	12	1.802	12	1.570	12	1.821	12
CT3	2.277	6	2.147	7	2.409	4	1.972	7	2.466	4	2.075	6	2.474	4
CT4	2.170	7	2.158	6	2.183	7	2.014	6	2.267	7	2.043	7	2.295	7
CT5	2.707	1	2.737	1	2.677	1	2.653	1	2.741	1	2.710	1	2.705	1
CT6	1.824	11	1.758	11	1.892	10	1.737	10	1.879	11	1.753	11	1.895	10
CT7	2.473	3	2.495	3	2.452	3	2.417	3	2.509	3	2.430	3	2.516	3
CT8	1.963	8	1.916	8	2.011	8	1.917	8	1.991	8	1.914	8	2.011	8
CT9	2.367	4	2.400	4	2.333	6	2.361	4	2.371	6	2.398	4	2.337	6
CT10	1.920	9	1.874	9	1.968	9	1.889	9	1.940	9	1.849	9	1.989	9
CT11	1.468	13	1.432	13	1.505	13	1.319	13	1.560	13	1.409	13	1.526	13
CT12	1.840	10	1.832	10	1.849	11	1.736	11	1.905	10	1.828	10	1.853	11
CT13	2.543	2	2.505	2	2.581	2	2.500	2	2.569	2	2.505	2	2.579	2

* On a scale of 1 – 3, where "1" - "Unaware," "2" - "Neither aware or unaware," and "3" - "Aware"

Table 7: Mean score analysis of main problems encountered in the construction industry (MPs).

MPs	Overall Respondents (N=188)		Company Scale				Market Region				IT Staff			
	Mean *	Ran k	CS1* N=95	Ran k	CS2* N=93	Ran k	MR1* N=72	Ran k	MR2* N=116	Ran k	IT1* N=93	Ran k	IT2* N=95	Ran k
MP1	2.723	3	2.800	2	2.645	4	3.083	1	2.500	4	2.860	2	2.589	5
MP2	2.234	9	2.284	9	2.183	10	2.431	9	2.115	8	2.301	9	2.168	10
MP3	2.920	1	2.853	1	2.989	1	3.001	2	2.871	1	2.892	1	2.947	2
MP4	2.851	2	2.747	3	2.957	2	3.000	3	2.759	2	2.680	4	3.021	1
MP5	2.681	4	2.621	5	2.742	3	2.903	5	2.543	3	2.677	5	2.684	3
MP6	2.560	5	2.516	7	2.602	5	2.736	6	2.450	5	2.516	7	2.600	4
MP7	2.287	8	2.484	8	2.086	11	2.709	7	2.026	11	2.505	8	2.074	11
MP8	2.559	6	2.653	4	2.462	7	2.917	4	2.336	7	2.688	3	2.432	7
MP9	2.548	7	2.526	6	2.570	6	2.708	8	2.448	6	2.581	6	2.516	6
MP10	2.223	10	2.180	10	2.269	8	2.403	10	2.112	9	2.247	10	2.200	8
MP11	2.202	11	2.179	11	2.226	9	2.375	11	2.095	10	2.226	11	2.179	9

* On a scale of 1-5, where "1" – "not important", "2" – "slightly important", "3" – "moderately important", "4" – "very important", and "5" – "extremely important"

The analysis of mean scores for all respondents is provided in Table 7. "Delays" (MP 3), "Cost overruns" (MP 4), and "Low productivity of laborers" (MP 1) were identified as the top three issues faced in construction projects, in descending order. Nevertheless, there is a lack of agreement regarding this ranking among various groups of participants. For example, the ranking of "Low productivity of laborers" (MP 1) varied.

Table 8 indicates that the top three anticipated advantages of Construction 4.0 technologies, as ranked by all participants in descending order, are: "Obtaining real-time information on the project's progress" (EB 6), "Improved information flow between construction site and office" (EB 5), and "Being a pioneer in the market" (EB 17). Although both all respondents and different groups of participants ranked "Obtaining real-time information on the project's progress" (EB 6) and "Improved information flow between construction site and office" (EB 5) as the top benefits, there is a slight variation in the ranking of "Being a pioneer in the market" (EB 17) among different groups of respondents.

Table 8: Mean score analysis of benefits expected from Construction 4.0 technologies (EBs).

EBs	Overall Respondents (N=188)		Company Scale				Market Region				IT Staff			
	Mean*	Rank	CS1* N=95	Rank	CS2* N=93	Rank	MR1* N=72	Rank	MR2* N=116	Rank	IT1* N=93	Rank	IT2* N=95	Rank
EB1	3.803	8	3.811	8	3.801	7	3.794	10	3.810	7	3.742	8	3.863	7
EB2	3.862	5	3.876	5	3.849	5	3.903	6	3.836	6	3.806	6	3.916	5
EB3	3.702	12	3.632	12	3.774	10	3.821	8	3.629	13	3.634	12	3.770	10
EB4	3.351	17	3.200	17	3.505	15	3.361	17	3.350	16	3.183	17	3.516	15
EB5	4.000	2	4.042	2	3.957	2	4.042	2	3.974	2	3.989	2	4.011	2
EB6	4.191	1	4.211	1	4.172	1	4.236	1	4.164	1	4.226	1	4.158	1
EB7	3.910	4	3.937	3	3.882	4	3.935	4	3.897	4	3.892	4	3.928	3
EB8	3.410	15	3.337	16	3.484	16	3.472	15	3.371	15	3.366	16	3.453	16
EB9	3.851	6	3.874	6	3.828	6	3.861	7	3.845	5	3.828	5	3.874	6
EB10	3.378	16	3.432	15	3.323	17	3.431	16	3.345	17	3.387	15	3.368	17
EB11	3.569	14	3.568	13	3.570	14	3.722	13	3.474	14	3.602	13	3.537	14
EB12	3.649	13	3.505	14	3.799	8	3.667	14	3.638	12	3.527	14	3.768	11
EB13	3.718	10	3.690	9	3.753	12	3.819	9	3.657	10	3.656	11	3.779	9
EB14	3.814	7	3.832	7	3.796	9	3.944	3	3.733	8	3.796	7	3.832	8
EB15	3.707	11	3.687	10	3.731	13	3.792	11	3.655	11	3.720	9	3.695	13
EB16	3.723	9	3.684	11	3.763	11	3.736	12	3.716	9	3.699	10	3.747	12
EB17	3.915	3	3.895	4	3.935	3	3.931	5	3.905	3	3.903	3	3.926	4

* On a scale of 1-5, where “1”– “very low”, “2” – “low”, “3” – “medium”, “4” – “high”, and “5” – “very high”

4.2 Results of Kendall’s Concordance Analysis (W)

The Kendall's concordance analysis yielded the following results: W value of 0.313 for the rankings of CTs, 0.109 for MPs, and 0.091 for EBs among all respondents. The significance levels for all of these rankings were found to be less than 0.001. Thus, it can be inferred that there was substantial consensus across all groups of respondents.

4.3 Results of Spearman’s Rank Correlation (R)

The degree of consensus among the participants about the hierarchy of CTs, MPs, and EBs was assessed using the Spearman's rank correlation (R) test. The findings are displayed in Table 9. According to the Spearman's rank correlation coefficient (rs) values, it can be inferred that there are significant correlations in the perceptions of CTs, MPs, and EBs among all pairs of respondent groups (i.e., CS1-CS2, MR1-MR2, IT1-IT2).

Table 9: Results of Spearman's rank correlation test on the CTs, MPs and EBs between respondent groups.

Variable	Comparison of Rankings	r_s	Asymp. Sig.	Degree of Agreement
CTs	CS1-CS2	0.956*	<0.001	Positive, Very high
	MR1-MR2	0.956*	<0.001	Positive, Very high
	IT1-IT2	0.973*	<0.001	Positive, Very high
MPs	CS1-CS2	0.818*	0.002	Positive, High
	MR1-MR2	0.782*	0.004	Positive, High
	IT1-IT2	0.700*	0.016	Positive, High
EBs	CS1-CS2	0.909*	<0.001	Positive, Very high
	MR1-MR2	0.897*	<0.001	Positive, High
	IT1-IT2	0.936*	<0.001	Positive, Very high

* Correlation is significant at the 0.05 level (2-tailed).

4.4 Results of Mann-Whitney U Test

The Mann-Whitney U test results in Table 10 indicate that there are only a small number of statistically significant differences (e.g., $p < 0.05$) in the recognition level of Construction 4.0 technologies among the groups.

Table 20: Mann-Whitney U test statistics of construction 4.0 technologies (CTs) for “company scale”, “market region” and “IT Staff”.

CTs	p-values of the Mann-Whitney U Tests		
	Asymp. Sig. (Company Scale)	Asymp. Sig. (Market Region)	Asymp. Sig. (IT Staff)
CT1	0.651	0.008**	0.116
CT2	0.155	0.012**	0.015**
CT3	0.014**	0.000**	0.000**
CT4	0.849	0.010**	0.010**
CT5	0.442	0.131	0.783
CT6	0.138	0.153	0.114
CT7	0.394	0.306	0.406
CT8	0.368	0.507	0.362
CT9	0.294	0.994	0.376
CT10	0.33	0.625	0.156
CT11	0.472	0.013**	0.144
CT12	0.793	0.051	0.721
CT13	0.451	0.534	0.475

** The Mann-Whitney U test is significant at the 0.05 level.

Within the CS category, the CS 2 group had a greater degree of recognition for "Building Information Modelling (BIM)" (CT 3) compared to the CS 1 group. The CS 2 group has a higher level of statistical awareness of the indicated Construction 4.0 technology compared to the CS 1 group, which is not unexpected. In the majority of medium-to-large scale projects, the CS 2 group is more inclined to adopt "Building Information Modelling" (CT 3) as a result of client or government mandates. Yang et al. (2006) argued that the adoption of technology in large projects is hindered by the anticipated high costs of investment. However, Herr and Fischer (2019) contradicted this assertion by asserting that large firms actually invest more in technology compared to small ones. In addition, the MR 1 group and the MR 2 group had contrasting views on the extent of acknowledgment for five Construction 4.0 technologies: "Prefabrication and modularization" (CT1), "Radio Frequency Identification (RFID)" (CT2), "Building Information Modelling (BIM)" (CT3), "Internet of Things (IoT)" (CT4), and "Cyber Physical Systems (CPS)" (CT11). One potential explanation is that the MR 2 group primarily prioritizes foreign projects, where technological implementation is more prominent than national implementation, likely due to the specific needs of international tenders. Therefore, it is possible that they were more knowledgeable about Construction 4.0 technology compared to the MR 1 group. Furthermore, in terms of the recognition of Construction 4.0 technologies within the IT category, the IT 2 group exhibited significantly greater familiarity with "Radio Frequency Identification (RFID)" (CT 2), "Building Information Modelling (BIM)" (CT 3), and "Internet of Things (IoT)" (CT 4) compared to the IT 1 group. This finding could be attributed to the prevalence of the indicated technologies, and firms that employ IT specialists may tend to give better ratings to these technologies because of their experience with them. The CS 1 group in Table 11 had a higher grade for the "HSE Problems" (MP 7) compared to the CS 2 group.

Table 11: Mann-Whitney U test statistics of main problems (MPs) for "company scale", "market region" and "IT Staff"

MPs	p-values of the Mann-Whitney U Tests		
	Asymp. Sig. (Company Scale)	Asymp. Sig. (Market Region)	Asymp. Sig. (IT Staff)
MP1	0.258	0.000**	0.061
MP2	0.55	0.014**	0.358
MP3	0.403	0.416	0.82
MP4	0.235	0.166	0.046**
MP5	0.395	0.056	0.894
MP6	0.652	0.085	0.7
MP7	0.021**	0.000**	0.019**
MP8	0.183	0.001**	0.119
MP9	0.96	0.16	0.421
MP10	0.635	0.039**	0.55
MP11	0.68	0.074	0.906

This can be attributed to the fact that the CS 1 group consists of micro-small enterprises, which experience HSE concerns in construction projects more often than the CS 2 group due to potentially less rules, standards, and control mechanisms in micro/small projects. Furthermore, the MR 2 group assigns higher importance to "Low productivity of laborers" (MP 1), "Ineffective usage of machinery" (MP 2), "HSE Problems" (MP 7), "Clashes in design documents and constructability problems" (MP 8), and "Quantity take-off errors" (MP 10) compared to the MR 1 group. The finding can be attributed to the fact that international projects have a more intricate framework and encompass a greater number of challenges compared to national initiatives. As a result, the MR 2 group assigned higher scores to the aforementioned concerns. A comprehensive analysis comparing the primary issues encountered in a building project carried out by the IT 1 group with the IT 2 group. The IT 2 group assessed "cost overruns" (MP 4) and "HSE problems" (MP 7) more favorably than the IT 1 group. This ranking may be attributed to the tendency of firms with IT people to assign higher ratings to anticipated obstacles in construction projects.

Table 12 indicates that there is no statistically significant distinction between groups in terms of "the market region in which the firm predominantly operates" (MR) and "IT staff availability in the firm" (IT) categories.

Significant differences ($p < 0.05$) in evaluations for "Cost Savings" (EB 4) are observed only when comparing groups within the "company scale" (CS) category. This could be attributed to the fact that medium to large-scale projects often exceed their allocated budget, and therefore, cost reduction becomes a top priority for such initiatives. Flyvbjerg et al. (2002) provide more support for this claim, stating that 90% of building projects worldwide experience cost overruns. In addition, medium to large-sized enterprises have a longer history of functioning in the industry compared to smaller firms, and are likely to encounter cost overruns more frequently than micro and small-sized construction companies. As a result, individuals in the CS 2 group may achieve better scores in the category of "Cost Savings" (EB 4) compared to individuals in the CS 1 group.

Table 32: Mann-Whitney U test statistics of expected benefits (EBs) for "company scale", "market region" and "IT Staff".

EBs	p-values of the Mann-Whitney U Tests		
	Asymp. Sig. (Company Scale)	Asymp. Sig. (Market Region)	Asymp. Sig. (IT Staff)
EB1	0.922	0.829	0.546
EB2	0.987	0.641	0.514
EB3	0.368	0.199	0.495
EB4	0.049**	0.939	0.053
EB5	0.49	0.762	0.891
EB6	0.786	0.973	0.521
EB7	0.714	0.845	0.933
EB8	0.386	0.66	0.634
EB9	0.732	0.825	0.946
EB10	0.5	0.653	0.811
EB11	0.965	0.116	0.611
EB12	0.06	0.478	0.121
EB13	0.688	0.232	0.542
EB14	0.958	0.148	0.87
EB15	0.919	0.331	0.778
EB16	0.82	0.643	0.896
EB17	0.704	0.598	0.955

** The Mann-Whitney U test is significant at the 0.05 level.

In summary, Hypothesis 1, 2, and 3 were evaluated using the Mann-Whitney U test through pairwise comparisons between groups. The null hypothesis for Hypothesis 1, which states that there are no significant differences in the recognition level of Construction 4.0 technologies among (a) CS, (b) MR, and (c) IT can be rejected for five out of the thirteen Construction 4.0 technologies (specifically, CT 1, CT 2, CT 3, CT 4, and CT 11). The statistical analysis revealed a significant difference ($p < 0.05$) in the ratings of these technologies when compared pairwise within one of the three categories.

Hypothesis 2 posits that there are no substantial variations in the primary issues faced in building projects based on (a) CS, (b) MR, and (c) IT. The results of the Mann-Whitney U test show that the null hypothesis may be rejected for Hypothesis 2 in six out of the 11 major construction project difficulties, specifically MP 1, MP 2, MP 4, MP 7, MP 8, and MP 10. Based on the pairwise comparisons conducted among groups under one of the three categories, these challenges exhibited significant differences in their ratings (e.g., $p < 0.05$).

The null hypothesis for Hypothesis 3 states that there are no significant differences in the expected benefits of Construction 4.0 technologies among different factors, including company scale, market region, and IT staff availability. However, this null hypothesis can only be rejected for one specific expected benefit (EB 4) in the company scale category. The Mann-Whitney U test pair-wise comparison results indicate that the groups under the CS category showed statistically significant differences (e.g., $p < 0.05$) in their reported expected benefit. Moreover, none of the anticipated advantages in the MR and IT categories can have their null hypothesis disproved. These statistical data show that there is a statistically substantial agreement between the groups within categories. Out of the 17 projected benefits, 16 of them do not show statistically significant differences (e.g., $p < 0.05$) and have the same mean value.

5. DISCUSSION OF FINDINGS

The analysis results indicate that the overall recognition level of Construction 4.0 is below average among respondents (i.e., 2.12). It proves that developing technologies are not widely recognized or utilized in the construction industry. The constraints are significant, and the construction industry is sluggish in embracing innovations (Newman et al, 2021).

The barriers to adopting new technologies in the construction sector may vary based on differences in comprehension. For instance, there may be discrepancies between the skills of the workforce and the expectations of employers (Low et al, 2021). The most crucial aspects of implementing emerging technologies in construction are knowledge, abilities, cognitive agility, and competencies of the professionals (Mansour et al, 2023). Furthermore, implementing these technologies poses issues such as interoperability, consistency of data, and cooperation of stakeholders (Skoury et al, 2024). Furthermore, barriers to adopting these technologies exhibit similarities and variances based on countries. Olatunde et al. (2022) surveyed 129 experts in the construction sector in Nigeria. According to the results, the Nigerian construction industry's readiness to implement Construction 4.0 technology is at a preliminary stage. The primary obstacles to implementing Construction 4.0 technologies are a lack of standardized procedures, insufficient funding for research and development, and financial limitations. Demirkesen and Tezel (2022) concentrated on the implementation of novel innovations by construction firms. The primary hurdles in technology adoption for construction projects are reluctance to adaptation, imprecise advantages and the installation cost of these technologies. Wang et al. (2024) conducted a questionnaire survey in China and received 192 valid responses. The main barriers to implementing Construction 4.0 technologies include the absence of industry-specific norms and rules, a lack of a concise strategy, and guidance for digital transformation, and insufficient support from executives. Alwashah et al. (2024) carried out a questionnaire study in the Jordanian construction industry. They found that the primary reasons for not adopting emerging technologies include a shortage of skilled workers, the high demand for computing equipment, the substantial initial cost of these technologies, and limited investment in research and development of these technologies.

To sum up, financial constraints, insufficient research and development on technologies, and absence of standards for utilizing of Construction 4.0 technologies are key factors hindering their implementation, as evidenced by studies from multiple nations. The same causes are present in the Turkish construction industry. Turkiye is a developing country. The results from other countries are believed to be applicable in the Turkish construction industry.

There are some recommendations to enhance technology adoption in the construction industry. After evaluating 3950 abstracts, Brozovsky et al. (2024) identified the most popular technologies being explored and the countries conducted the most research on these technologies. Their research emphasized that collaboration between the construction sector and academia is crucial, along with the need for platforms to identify suitable research partners and the bureaucratic procedures required to adopt Construction 4.0 technology. These recommendations are applicable in Turkiye as well. The expectations for Construction 4.0 technologies are promising and above average among respondents, rated at 3.74. Focusing on research and development, standardizing the application and utilization of Construction 4.0 technologies, and offering funding plans could expedite their deployment.

6. CONCLUSIONS

The study has found that various cohorts of construction professionals and companies generally concurred on the relative significance of being cognizant of Construction 4.0 technology. Nevertheless, there exist statistically significant disparities among the various groupings of construction organizations in terms of their viewpoints and opinions regarding the primary challenges faced in construction projects and the anticipated advantages of Construction 4.0 technology. The primary factor contributing to this outcome is the correlation between the challenges faced by professionals in building projects and the expected benefits of building 4.0 technologies, which mostly revolve around factors such as scale, market dynamics, and the firms' proximity to advanced technology. The Mann-Whitney U tests revealed statistically significant disparities in perspectives and perceptions among 5 out of 13 Construction 4.0 technologies, 6 out of 11 primary issues in construction projects, and 1 out of 17 anticipated advantages of these technologies. Medium/large size organizations rated the recognition level of Construction 4.0 technologies and the projected benefits of these technologies higher, but offered lower ratings for the key issues in construction projects. Furthermore, construction companies who predominantly engage in international projects expressed more favorable evaluations of construction 4.0 technology and identified the main challenges. Nevertheless, the scores for expected benefits of building 4.0 were generally similar among both domestic and international companies. Likewise, companies who have IT personnel rated Construction 4.0 technology and the main challenge as more significant compared to those that do not have IT staff. Nevertheless, there was no statistically significant disparity observed among the groups in terms of their rankings of the expected advantages of Construction 4.0 technology.

The findings of this study indicated that there were variations among the groups in terms of the significance and ratings of the recognition level of Construction 4.0 technologies, primary issues in construction projects, and anticipated advantages from these technologies. However, there was a notable agreement among the overall participants. Construction professionals and decision-makers can utilize these findings to address difficulties faced in construction projects through the implementation of Construction 4.0 technology. Furthermore, experts can evaluate the construction industry's anticipated requirements for these technologies by selecting the appropriate technologies to invest in, considering factors such as company size, geographical market, and availability of IT personnel. Furthermore, researchers can utilize the results to advance their studies and create technologies that are specifically tailored for the building industry. One disadvantage of this study is that it might be expanded to include the entire global construction community, rather than simply focusing on Turkish construction experts and companies. However, the results of the study would be beneficial for future research and studies in this industry.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, [G.P.], upon reasonable request.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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