Exploring the Impact of COVID-19 on the United States Construction Industry: Challenges and Opportunities

Esra Dobrucali, Emel Sadikoglu, Sevilay Demirkesen, Chengyi Zhang, Algan Tezel

***Abstract*—The construction industry is one of the leading industries in the economy of any country. However, the industry is vulnerable to changes and uncertainties, either external or internal, due to its fragmented and dynamic nature. Coronavirus disease (COVID-19), which first emerged in Wuhan, China in 2019, is considered a pandemic by the World Health Organization (WHO). COVID-19 has quickly spread all over the world resulting in significant social and economic consequences. The main objective of the study is to determine the challenges and opportunities due to pandemic in the construction industry and to categorize them. Through a review of the existing literature and interviews with construction experts, the challenges and opportunities arising from the COVID-19 pandemic were listed. A questionnaire survey was designed to evaluate them. Principal Component Analysis (PCA) was utilized to group the identified challenges and opportunities. PCA was conducted with SPSS Version 25.0 software. The most critical challenges of the pandemic were determined as 'the requirement of COVID-19 protocols', 'restriction on movement and travel', 'additional safety equipment use', where the most important opportunities were found as 'hygiene programs', 'use of technological tools effectively', and 'BIM-enabled construction'. The research contributes to the body of knowledge in terms of making construction practitioners beware of the main challenges and opportunities along with leading them to act towards change and uncertainty. This study further provides general guidelines and implications for practitioners and policymakers in case of similar outbreaks.**

***Index Terms*—challenges, construction, COVID-19, opportunities, pandemic, principal component analysis.**

I. Introduction

CONSTRUCTION is a leading industry for economic growth in many countries. According to report of the World Economic Forum in 2018, construction and basic engineering services in the infrastructure and urban development industry employ more than 100 million people and account for more than 6% of the global gross domestic product (GDP) [1]. By 2025, the global construction market is expected to grow much faster than the global GDP [2]. In 2019, the construction industry in the U.S. accounted for 4.2% of the GDP and the number of workers in the industry reached 7.5 million people [3], [4].

Even though construction constitutes a significant portion of economies, its fragmented and dynamic nature brings up various challenges such as temporary project teams and varying project types. This eventually creates changes and uncertainties, which render project execution even more challenging for the fact that strategies must be developed to overcome them. The recent global outbreak of COVID-19 dramatically affected the whole world, in particular dynamic industries such as construction. Measures taken by countries such as lockdowns and isolation procedures created a considerable impact on the construction industry [5]. Most of the construction activities were partially or fully ceased since they were not considered essential except being related to public health or essential requirements [6]. Fig. 1 represents the timeline showing significant incidences related to COVID-19 in the U.S. based on Centers for Disease Control and Prevention (CDC) data [7]. It also shows case fatality rates which is the ratio of number of deaths to number of cases [8] to track the trend of the disease based on the data from Our World in Data [9]. Besides, Fig. 1 includes construction spending based on U.S. Census Bureau data [10]. This figure helps to observe the impact of COVID-19 on the construction industry. The impact of COVID-19 is shown within three phases: pre-COVID-19, peak COVID-19 and recovery period on this figure similar to the study of Rehman et al. [11]. After confirming the first COVID-19 case, the number of cases started to increase, and regulations were enforced; the effects on the construction industry have become apparent since then. In 2020, the total construction spending in the U.S. fell from $1.4 billion in February to $1.3 billion in May [10]. Fairlie [12] stated that this decline caused by COVID-19 is of the largest among other industries leading to a 27% decline

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in the number of active construction businesses in the U.S. between February and April 2020. Besides, employment in the construction industry was 7.6 million in February 2020, while it decreased to 6.5 million in April 2020 [3]. After the first shock of the pandemic, when cases were kept under control and enforcements started to be removed; recovery period began with the help of vaccination and proper treatment. Today, even though the pandemic has not come to an end yet, we observe that most cases are recovering, and bad effects are now rare indicating that going back to pre-COVID times is even more possible now.

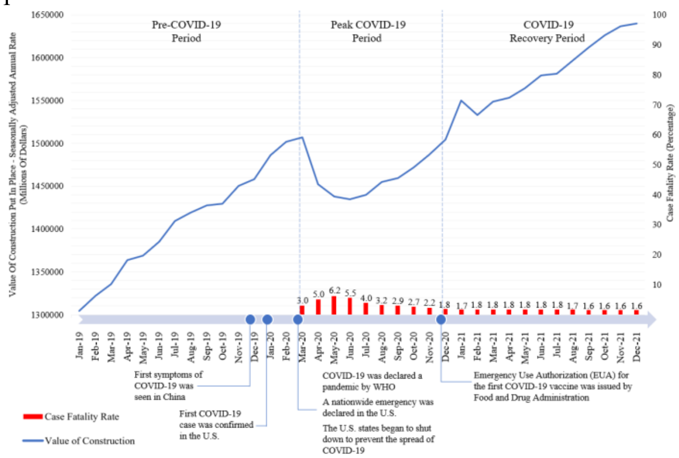

Fig. 1. Construction spending and COVID-19 case fatality rate in the U.S.

Considering the importance of construction for the U.S. economy, it is necessary to understand the effects of the COVID-19 pandemic on the industry [5]. The pandemic is still in effect, and its consequences are not fully known and foreseen yet. Hence, exploration of COVID-19 in the construction industry is needed. There are some studies in the literature investigating the impact of COVID-19 on the construction industry. Jeon et al. [13] utilized the Purdue Index for Construction (Pi-C) to measure health of the construction industry. They found the impact of COVID-19 on economy and stability dimensions of the U.S. construction industry was obvious. Choi and Staley [14] reviewed challenges and opportunities of COVID-19 in terms of health and safety issues in the U.S. construction industry. Ebekozien et al. [15] investigated the challenges of COVID-19 and possible solutions in terms of sustainable development goals considering stakeholder perspectives in Nigerian construction industry. Previous studies are mostly cross-sectional and retrospective, and they do not propose broad measures and guidelines regarding to major outbreaks, which might help construction companies to be prepared for unexpected events in future. Very few studies provide guidelines recently. Iqbal et al. [16] proposed a crisis management framework for safety practices considering COVID-19 impacts. Ogunnusi et al. [17] provided lessons learnt from COVID-19 based on data collected from several countries.

In this respect, this study aims both (i) to provide a better understanding of the COVID-19 consequences and impacts on the construction industry for practitioners and researchers based on qualitative and quantitative approaches to revise and revisit their plans and strategies accordingly and (ii) to generalize the findings and guide the stakeholders in case of similar future outbreaks with a prospective approach. The following research questions are aimed to be answered in this study: (i) What are the main challenges due to COVID-19 in the U.S. construction industry? (ii) What are the main opportunities that can be benefitted considering the lessons learnt from COVID-19 in the U.S. construction industry? (iii) How the challenges and opportunities can be categorized? (iv) What are the implications of lessons learnt from COVID-19 that can be generalized to similar future outbreaks?

The structure of the study is as follows. Second section presents research background including relevant literature review for challenges and opportunities of COVID-19. Third section explains research methodology providing information about (i) semi-structured interviews with industry practitioners and academics, and (ii) questionnaire survey. In fourth section, analysis of the collected data is presented including (i) descriptive statistics and (ii) Principal Component Analysis (PCA) to group them into components. Fifth section discusses challenges and opportunities and provides recommendations to the construction industry in case of similar outbreaks. In the sixth section, main conclusions, and contributions of the study along with its limitations and future research ideas are mentioned.

II. Research Background

Coronavirus disease (COVID-19), which first emerged in Wuhan, China at the end of 2019, was accepted as a pandemic in March 2020 [7]. The characteristics and transmission mode of COVID-19 made it easy to spread rapidly all over the world within a few months, resulting in significant social and economic consequences. It has recently been reported that more than 412 million people have been infected in the world, where 79 million are in the U.S. [18]. Industries are suffering from COVID-19 and facing with serious problems such as unbalanced supply and demand, disruption in supply chains and shutdowns [16]. Observations on pandemic impacts on sectors show that service-oriented sectors experienced harsher impacts compared to manufacturing sectors, where the agriculture sector was not affected very much [19].

The construction industry is one of the most negatively affected industries by the pandemic [14], [16]. The construction industry is labor-intensive and requires well-set safety procedures. Since construction workers work together at a close range, they are at a high risk of being exposed to COVID-19 [20]. Lan et al. [21] reported that approximately 35% of the construction workers surveyed in their study contracted COVID-19 in their work environment. Pasco et al. [22] found that the risk of hospitalization of construction workers was five times higher than non-construction workers in Austin, Texas. Moreover, workforce shortage is reported as one of the serious negative impacts of the pandemic [13], [23]. Workforce shortage has always been an issue for the construction industry; however, the pandemic worsened the situation [24]. Araya [25] noted that the spread of COVID-19 among construction workers would reduce the workforce by 30% to 90% based on different scenarios, exacerbating the global labor shortage in construction. According to survey conducted by Associated General Contractors of America (AGC), there is a shortage in skilled labor and construction firms have difficulty in filling craft positions and salaried positions such as project managers and supervisors [26]. In the long term, workforce shortage may intensify considering the effect of pandemic that led people working from home, and phenomena similar to great resignation.

COVID-19 led to serious delays or cancellation of many projects [17], [26]. Jallow et al. [27] reported that closed construction sites in the U.K. led to serious delays. Gamil and Alhagar [23] concluded that the most important impact of the pandemic is the suspension of projects. Another important impact is supply chain disruptions, leading to project suspensions [28], [29]. Financial uncertainty and restrictions imposed by local governments also resulted in the cancellation of several construction projects [30]. One other significant result of the pandemic is time and cost overruns [23]. King et al. [31] implied that suspension of projects reduce income, and shortages in supply chain and labor are problematic for productivity. These shutdowns, together with the uncertainty about the future, also caused a financial burden on companies [23]. Similar challenges have been reported for different countries [32], [33].

Besides the negative impacts, the crises might come along with some opportunities as well. Alsharef et al. [28] mentioned that COVID-19 had led to the development of new safety measures intended for worker health and safety, revised safety training content for COVID-19, implemented social distancing, and remote working initiatives. Stiles et al. [34] stated that COVID-19 had brought up opportunities such as creating safer work practices, developing an awareness for hygiene and safety risk, and considering work redesign to improve safety leading to motivating leadership. They further mentioned that the pandemic had caused organizations to reconsider their tasks for better work design, adopt new technology, and adapt to changes rapidly. Denny-Smith et al. [35] discussed that COVID-19 might have helped employers create collaborative endeavors resulting in increased social value as well as providing opportunities for learning and feedback for employees. Megahed and Ghoneim [36] discussed that the digital transformation in construction would accelerate post-pandemic. They also highlighted that sustainable architecture and designing safe buildings are essential after considering what pandemic has already brought in for the industry. Ebekozien and Aigbavboa [37] reported that Building Information Modeling (BIM), augmented reality, and simulation are suitable technologies for compliance with COVID-19 rules on construction sites.

Given this background, it is seen that pandemics pose serious challenges for the industry due to several reasons such as loss of workforce, cost and time overruns, and health and safety issues. Considering the importance of construction, more research is needed regarding the early and long-term impacts of the COVID-19 pandemic on the construction industry. Hence, this study focuses on identifying a set of challenges and opportunities arisen due to COVID-19 for the construction industry. This study further generalizes the findings and provides recommendations for future outbreaks.

III. Research Methodology

In this section, research methodology steps are detailed. Firstly, the challenges and opportunities due to COVID-19 for the U.S. construction industry from the existing literature were identified. After literature review and semi-structured interviews, a comprehensive list of challenges and opportunities was composed. To assess the items, an online questionnaire was designed and administered to construction companies operating in the U.S. The basis for utilizing the mixed method approach including both qualitative and quantitative data collection is to improve validity and reliability of the results and enhance the contributions of the study [38]. In data analysis, Principal Component Analysis (PCA) was utilized.

A. Semi-structured Interviews

To better observe the impact of pandemic, 13 semi-structured interviews with 8 industry practitioners and 4 academics were conducted to complete and validate the literature review. The interviewees were selected based on their level of experience in the construction industry (a minimum of 10 years and three construction projects). Each interview took around 30 minutes and open-ended questions were addressed to the interviewees to get their prospective about the impacts of the pandemic on the construction industry and future expectations on the industry due to change in dynamics. In the interviews, the survey items were discussed in terms of content validity and reliability. They were revised with respect to the feedback of the interviewees. In the beginning, a total of 29 challenges and 21 opportunities were identified based on the literature review. After the semi-structured interviews, some strongly associated variables were merged, and some unnecessary variables were removed. 20 challenge and 13 opportunity items were included in the final list after careful consideration of the recent studies and discussions with the industry experts and academics. For example, work related uncertainties and social life uncertainties were included as two separate items but these two were merged as a single item as work and life related uncertainties as per the recommendation of the interviewees. For the opportunities, increased performance was rather listed as increased productivity following the recommendation of the interviewees. Technology transformation was removed instead use of technologies in an effective manner was included in the list again following the recommendations of the interviewees. The final list of items can be seen in Table 1 along with relevant references.

B. Questionnaire Survey

Based on the final list of items, an online questionnaire was administered. The respondents were selected from the firms listed in the 400 Top Contractors by Engineering News-Record (ENR) in 2019. A nonprobability sampling approach was adopted along with the convenience and snowball techniques

TABLE I
CHALLENGES AND OPPORTUNITIES OF COVID-19 FOR THE CONSTRUCTION INDUSTRY

Challenges	Suspension of projects (Gamil and Alhagar [23], Alsharef et al. [28], Biswas et al. [29])
	Workforce shortage (Gamil and Alhagar [23], Araya [25], Ogunnisi et al. [39], Biörck et al. [46])
	Time and cost overruns (Rehman et al. [11], Gamil and Alhagar [23], Pamidimukkala and Kermanshachi [24], Bohannon [30], Kabiru and Yahaya [33], Ogunnisi et al. [39], Rajabi and Bheiry [40], Raoufi and Fayek [41])
	Financial and economic impact (Gamil and Alhagar [23], Alsharef et al. [28], Bohannon [30])
	Shortage of supplies (Gamil and Alhagar [23], Pamidimukkala and Kermanshachi [24], Alsharef et al. [28], Bsisu [42])
	Poor planning and scheduling (Gamil and Alhagar [23], Alsharef et al. [28], Quezon and Ibanez [43])
	Restriction on movement and travel (Rehman et al. [11], Gamil and Alhagar [23], Ogunnisi et al. [39])
	Problems related to legal issues (Rehman et al. [11], Gamil and Alhagar [23], Kabiru and Yahaya [33], Rajabi and Bheiry [40], Sihombing [44])
	Socioeconomics impact (Gamil and Alhagar [23])
	Work and life-related uncertainties (Gamil and Alhagar [23], Pamidimukkala and Kermanshachi [24], Ebekozien and Aigbavboa [37])
	Impact on research and technology (Gamil and Alhagar [23], Ogunnisi et al. [39])
	Additional safety equipment use (Bohannon [30], Raoufi and Fayek [41], Stride et al. [45])
	Requirement of COVID-19 protocols (Bohannon [30], Raoufi and Fayek [41])
	Health insurance risks (Majumder and Biswas [20], Bohannon [30], Raoufi and Fayek [41])
	Uncertainties in contracts and payments (Rehman et al. [11], Gamil and Alhagar [23], Bohannon [30], Kabiru and Yahaya [33], Rajabi and Bheiry [40], Raoufi and Fayek [41])
	Less skilled personnel (Ogunnisi et al. [17], Araya [25], Bohannon [30], Stride et al. [45])
	Problems with adopting COVID-19 precautions (Ebekozien and Aigbavboa [37], Bsisu [42], Stride et al. [45])
	Less efficient site work (Ogunnusi et al. [17], Alsharef et al. [28], Kabiru and Yahaya [33])
	Revisiting existing strategies (Jallow et al. [27], Stride et al. [45])
	Work culture change (Stride et al. [45], Biörck et al. [46])
Opportunities	Worker education (Alsharef et al. [28], Ogunnisi et al. [39], Hollingsworth [47])
	Hygiene programs (Ogunnisi et al. [17], Raoufi and Fayek [41], Hollingsworth [47])
	BIM-enabled construction (Jallow et al. [27], Ogunnisi et al. [39], Zhou et al. [48])
	Modular construction technology (Megahed and Ghoneim [36], Ogunnisi et al. [39], Stride et al. [45], Zhou et al. [48])
	Reduced waste (Stride et al. [45], Zhou et al. [48])
	Increased productivity (Ogunnisi et al. [17], Bsisu [42], Stride et al. [45])
	Use of technological tools in an effective manner (Rehman et al. [11], Ogunnisi et al. [17], Jallow et al. [27], Megahed and Ghoneim [36], Ogunnisi et al. [39], Sihombing [44], Biörck et al. [46])
	Increasing cross-sector collaboration (Jallow et al. [27])
	Improved in-house training (Jallow et al. [27], Denny-Smith et al. [35])
	Academic collaborations for greater success (Jallow et al. [27], Denny-Smith et al. [35])
	Improved leadership programs (Jallow et al. [27], Denny-Smith et al. [35])
	Improved communication with project employees (Jallow et al. [27], Raoufi and Fayek [41], Stride et al. [45])
	Sustainable architecture (Megahed and Ghoneim [36], Ogunnisi et al. [39], Daniela et al. [49])

with stratification to arrive at the respondents. These techniques are commonly utilized in construction research to obtain significant responses from industry practitioners [38]. Out of the 200 questionnaires sent out, data were collected from 74 respondents some of whom were involved in more than one project. Respondents provided data for 285 projects in total. This resulted in a response rate of 37%.

1) General Information about the Respondents and Responding Companies

The first part of the questionnaire gathered general information regarding the respondents such as age, educational level, nationality, location, years of experience in the construction industry and current role in the company. The age of the respondents is 44 on average, ranging between 25 and 66. Considering the nationality of the respondents, 41% of the respondents are from the U.S., where 24% are from Latin America, 22% are from Europe, and 13% are from the Far East. The respondents are located in an array of the different states such as Texas (33%), California (25%), Illinois (13%) and New York (11%). 60% of the respondents hold a BSc degree, 22% have a diploma or a certificate, and 19% have a M.Sc. or Ph.D. degree. 27% of the respondents have more than 20 years of experience in the construction industry, where 32% have between 15 to 20 years. The data shows that most of the respondents are educated and highly experienced in the construction industry. When the respondents' current role is inspected, respondents have different role such as project manager (23%), project coordinator (12%), board member (12%), engineers (10%), vice general managers (10%) and architects (8%). This indicates that the respondents present a mix of field, middle-management and upper-management roles who are likely to provide relevant information about the COVID-19 impacts on their companies or projects.

When responding companies are inspected, the average annual turnover is $233.5 million ranging from $0.5 million to $4 billion. The main business areas of the responding companies are commercial (33%), residential (24%), industrial (22%), and infrastructure (21%). Considering years of operation, 38% of the responding companies have been operating in the construction industry for more than 20 years, where 32% between 15 to 20 years. Detailed information regarding respondents and responding companies can be found in Table 2.

2) General Information about the Projects Affected by the Pandemic

In the second part of the survey, general information about the projects affected by the pandemic was collected. The number of projects affected by COVID-19 ranges between 1 to 10, where the average number is 3.9 per company. The type of projects affected by the pandemic are commercial (31%), infrastructure (26%), industrial (21%), residential (18%) and others (5%). The projects affected by the pandemic are located in California (32%), New York (20%), Texas (15%), Illinois (12%), Missouri (9%), Michigan (7%), and Ohio (5%). Further information about the projects affected by the pandemic was requested from the respondents such as project duration, project budget, number of employees, and the losses in terms of time, budget and employees in the

TABLE II
CHARACTERISTICS OF RESPONDENTS AND RESPONDING COMPANIES

	Categories		Percentage (%)
Respondents	Location	Texas	33
		California	25
		Illinois	13
		New York	11
		Florida	8
		Missouri	6
		Colorado, Oregon, Arizona	4
	Years of experience	0 – 5	5.4
		5 – 10	12.2
		10 – 15	23.0
		15 – 20	32.4
		> 20	27.0
	Current role	Project Manager	23.0
		Board Member	12.2
		Project Coordinator	12.2
		Vice General Manager	9.5
		Engineer	9.5
		Architect	8.1
		General Manager	6.8
		Department Chief	6.8
		Facility Manager	6.8
		Chairman	4.1
		Other	1.4
Responding Companies	Annual turnover (in $ million)	0 – 10	4.1
		10 – 50	27.0
		50 – 100	18.9
		100 – 250	17.6
		250 – 500	18.9
		> 500	12.2
	Years of operation	0 – 5	0.0
		5 – 10	9.5
		10 – 15	17.6
		15 – 20	35.1
		> 20	37.8
	Number of employees	0 – 50	9.5
		51 – 250	31.1
		251 – 500	17.6
		501 – 1,000	13.5
		1.001 – 2,000	20.3
		> 2.000	8.1

TABLE III
INFORMATION ABOUT PROJECTS AFFECTED BY THE PANDEMIC

	Maximum	Minimum	Average
Duration of projects (year)	8	1	2.6
Budget of projects ($ million)	2200	0.01	159.2
Number of employees in the projects	1205	57	145
Time loss for the projects (%)	55	12	23
Budget loss for the projects (%)	65	10	22
Workforce shortage (%)	39	4	14

affected projects which can be found in Table 3.

3) Challenges and Opportunities arising from the COVID-19 Pandemic

The third part of the questionnaire is designed to collect information regarding the extent to which the companies have been affected by the challenges identified and benefitted from the opportunities arisen. A 5-point Likert Scale was adopted to rate the items similar to studies of Gamil and Alhagar [23] and Ogunnusi et al. [39] where 1: not important, 2: slightly important, 3: moderately important, 4: very important, and 5: extremely important.

C. Principal Component Analysis (PCA)

To categorize the challenges and opportunities, PCA method was adopted by using the Statistical Package for the Social Sciences (SPSS) software 25.0 version. PCA and factor analysis (FA) are used to create subsets from a set of variables [50]. PCA and FA are multivariate statistical methods used to reveal variables associated with some independent components or factors representing the combination of variables [51]. They help group variables by representing the degree of association between interrelated variables. Even though their underlying theory is similar, PCA creates components, where FA creates factors. The components represent the aggregates of the variables, which are empirically associated rather than reflecting an underlying theory. On the other hand, factors represent the underlying constructs [50]. PCA, which is an exploratory tool, is recommended when the purpose is classification. Nevertheless, FA is used for theory development or theory testing. In this study, PCA was employed to determine subsets of the COVID-19 challenges and opportunities. The main reason for preferring PCA over FA is that the items are attempted to be classified based on empirical data rather than theory development or theory testing.

To assess the reliability of the survey, Cronbach's alpha value was investigated as the most common measure used for internal consistency and reliability. Values of Cronbach's alpha greater than 0.7 represent acceptable reliability [52], [53], [54].

IV. DATA ANALYSIS

Data from 285 projects were considered after eliminating the incomplete or missing data. Then, the descriptive statistics of the ratings provided by the respondents were inspected. Table 4 presents the descriptive statistics regarding the challenges and opportunities. According to the table, a significant portion of the responding companies has been seriously affected by the pandemic for the challenges listed. The most important challenges that affected the companies are requirement of COVID-19 protocols (mean rating: 4.9), restriction on movement and travel (4.6), additional safety equipment use (4.5), and work culture change (4.5). Among the 20 challenge variables, the average rating for 10 of them is higher than 4, whereas 9 of the challenges are rated higher than 3 on average. This shows the gravity of the challenges for the responding companies' projects. The most significant opportunities due to the pandemic are hygiene programs (mean rating: 4.1), the use of technological tools in an effective manner (3.5), and BIM-enabled construction (3.5).

To utilize PCA, the sample size requirements were checked first. According to Hair et al. [52], the sample size should be bigger than 100, and as a rule, should be at least five times the number of variables for a sound analysis. In this study, the number of variables is 33, which requires at least 165 responses. Hence, the sample size (data of 285 projects) is found to be satisfactory. The suitability of the data was further checked by performing the Kaiser-Meyer-Olkin (KMO) and Bartlett's sphericity tests. The KMO test shows the extent to which a variable is accurately predicted by other variables. In KMO test, the measure of sampling adequacy (MSA), both total MSA and individual MSA values, are inspected. KMO test helps to control the suitability of data for PCA. MSA values range

TABLE IV
DESCRIPTIVE STATISTICS: CHALLENGE AND OPPORTUNITY VARIABLES OF COVID-19

	Variables	Mean	Std. Dev.
Challenges	Requirement of COVID-19 protocols	4.9	0.4
	Restriction on movement and travel	4.6	0.6
	Additional safety equipment use	4.5	0.5
	Work culture change	4.5	0.7
	Shortage of supplies	4.4	0.8
	Problems adopting COVID-19 precautions	4.4	0.8
	Time and cost overruns	4.4	0.7
	Revisiting existing strategies	4.1	0.8
	Work and life related uncertainties	4.0	0.9
	Financial and economic impact	4.0	0.6
	Workforce shortage	3.8	0.9
	Suspension of projects	3.7	0.7
	Less efficient site work	3.7	0.9
	Health insurance risks	3.6	0.7
	Uncertainties in contracts and payments	3.5	0.9
	Poor planning and scheduling	3.4	0.8
	Socioeconomics impact	3.2	0.9
	Problems related to legal issues	3.0	0.8
	Less skilled personnel	3.0	0.8
	Impact on research and technology	2.8	0.8
Opportunities	Hygiene programs	4.1	0.6
	Use of technological tools in an effective manner	3.5	1.1
	BIM enabled construction	3.5	1.0
	Modular construction technology	2.9	1.0
	Reduced waste	2.8	0.8
	Worker education	2.8	0.7
	Increasing cross-sector collaboration	2.5	0.8
	Increased productivity	2.5	0.8
	Improved in-house training	2.5	0.9
	Improved communication with project employees	2.3	0.9
	Improved leadership programs	2.2	0.9
	Sustainable architecture	2.2	0.8
	Academic collaborations for greater success	1.6	0.7

between 0 to 1 where higher test values indicate more reliable analysis and a higher possibility of producing different components. Hair et al. [52] stated that MSA values greater than 0.5 are considered to be acceptable. Additionally, Bartlett's test checks the correlations among variables, and a statistically significant value ($p < 0.05$) is needed for the justification of satisfactory correlations between variables [52].

In this study, the results of KMO statistics, total MSA values, were found as 0.616 for the challenge variables and 0.750 for the opportunity variables, which are higher than 0.5. Barlett's test produced chi-square values of 2041.566 for the challenge variables and 2120.069 for the opportunity variables with small significance levels ($p < 0.0001$). However, the individual MSA values were problematic. Even though the individual MSA values were higher than 0.5 for the opportunity variables, several variables were violating the rule within the challenge variables. According to the recommendation of Hair et al [52], the variable with the lowest MSA value was eliminated, which is C14, health insurance risks. It was observed that the individual and total MSA values were improved. However, there were still few variables violating the threshold. Hence, the variable with the lowest MSA value which is C15, uncertainties in contracts and payments, was removed as well. As a result, the total MSA value improved to 0.677 and the values indicated that PCA is an appropriate method for the dataset.

PCA was conducted by using the principal components extraction method. Several rotation methods were tested and the varimax rotation was utilized. Components were formed based on the initial eigenvalues, variance, and cumulative variance. For the challenge components, even though 6 components were extracted considering the components have eigenvalues higher than 1, the sixth component included only one variable and its eigenvalue was very close to 1 (which was 1.003). Components, by definition, should be composed of more than one variable [55]. Besides, Thompson [55] emphasizes that the judgment of researchers is important for components that have eigenvalues close to 1. Moreover, an eyeball test was performed to identify the full set of factors and determine whether there is an apparent drop off between the components. Based on this, it was detected that there was an acceptable fap between 5th and 6th components. Hence, PCA was conducted considering 5 components for the challenge variables. Table 5 presents the total variance explained by the challenge components. As a result, the challenges are composed of five factor groups with 18 variables as can be seen in Table 6. For the opportunity components, the same rules were followed. The total variance explained by the opportunity components can be seen in Table 5. The opportunities are composed of four factor groups with 13 variables as can be seen in Table 7. Component groups were named by applying researcher judgment and intuition which can be seen in Table 6 and 7.

TABLE V
TOTAL VARIANCE EXPLAINED BY THE CHALLENGE AND OPPORTUNITY COMPONENTS

Components		Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
		Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
Challenge	1	4.1	23.0	23.0	4.1	23.0	23.0	2.7	15.1	15.1
	2	2.3	12.8	35.8	2.3	12.8	35.8	2.6	14.2	29.3
	3	1.9	10.5	46.3	1.9	10.5	46.3	2.4	13.6	42.9
	4	1.6	8.8	55.1	1.6	8.8	55.0	2.0	11.0	53.9
	5	1.3	7.0	62.0	1.3	7.0	62.0	1.5	8.2	62.0
Opportunity	1	4.6	35.4	35.4	4.6	35.4	35.4	3.4	26.5	26.5
	2	2.4	18.8	54.2	2.4	18.8	54.2	2.5	19.5	46.0
	3	1.6	12.5	66.7	1.6	12.5	66.7	2.0	15.1	61.1
	4	1.2	9.1	75.8	1.2	9.1	75.8	1.9	14.7	75.8

TABLE VI
ROTATED COMPONENT MATRIX FOR THE CHALLENGE VARIABLES

Challenge Component Groups	Variables	1	2	3	4	5
Productivity and Organizational Challenges (C1)	Restriction on movement and travel	**0.710**	0.134	-0.171	0.022	-0.253
	Less efficient site work	**0.701**	0.210	-0.007	0.306	0.150
	Revisiting existing strategies	**0.649**	-0.032	0.526	0.044	0.065
	Work culture change	**0.636**	0.317	0.366	-0.112	0.155
	Poor planning and scheduling	**0.567**	0.020	0.199	-0.276	-0.238
Project and Resource Related Challenges (C2)	Workforce shortage	-0.093	**0.806**	0.367	0.025	-0.032
	Suspension of projects	0.142	**0.726**	-0.162	0.202	-0.352
	Time and cost overruns	0.275	**0.631**	0.152	-0.125	0.147
	Shortage of supplies	0.105	**0.619**	0.067	-0.100	0.057
	Financial and economic impact	0.510	**0.556**	-0.227	0.098	0.105
Change and Uncertainty Related Challenges (C3)	Requirement of COVID-19 protocols	-0.042	0.023	**0.673**	-0.018	-0.054
	Less skilled personnel	0.168	0.055	**0.654**	-0.011	0.043
	Impact on research and technology	-0.236	0.125	**0.563**	0.384	0.238
	Problems with adopting COVID-19 precautions	0.324	0.265	**0.537**	0.270	0.026
Socioeconomic Challenges (C4)	Socioeconomics impact	0.033	0.027	-0.042	**0.882**	0.050
	Work and life related uncertainties	0.042	-0.106	0.188	**0.794**	0.010
Regulatory and Legal Challenges (C5)	Additional safety equipment uses	0.015	0.127	0.309	-0.075	**0.784**
	Problems related to legal issues	-0.078	-0.119	-0.324	0.281	**0.676**

Note: Rotation method: Varimax with Kaiser normalization. Bold numbers represent the highest loading values.

TABLE VII
ROTATED COMPONENT MATRIX FOR THE OPPORTUNITY VARIABLES

Opportunity Component Groups	Variables	1	2	3	4
Collaboration and Communication Opportunities (O1)	Academic collaborations for greater success	**0.852**	-0.047	-0.060	0.102
	Improved leadership programs	**0.820**	0.170	0.241	-0.231
	Improved communication with project employees	**0.813**	0.158	0.267	-0.254
	Improved in-house training	**0.750**	0.356	-0.063	0.067
	Increasing cross-sector collaboration	**0.670**	0.561	-0.015	0.150
Occupational Safety and Education Opportunities (O2)	Hygiene programs	0.034	**0.808**	0.232	-0.081
	Reduced waste	0.215	**0.772**	0.158	0.122
	Worker education	0.223	**0.694**	-0.234	0.369
Productivity and Technological Opportunities (O3)	Sustainable architecture	0.421	-0.016	**0.807**	-0.017
	Increased productivity	-0.174	0.106	**0.792**	0.250
	Use of technological tools in an effective manner	0.145	0.520	**0.611**	0.085
Construction Innovation Opportunities (O4)	Modular construction technology	0.081	0.100	0.083	**0.889**
	BIM enabled construction	-0.211	0.114	0.176	**0.859**

Note: Rotation method: Varimax with Kaiser normalization. Bold numbers represent the highest loading values.

V. FINDINGS AND DISCUSSION

A. COVID-19 Challenges

1) Productivity and Organizational Challenges (C1)

This component group explains the highest portion corresponding to 23% of the total variance. Having the highest factor loading, restriction on movement and travel (mean: 4.6; factor loading: 0.7) was determined as the most significant variable of the C1 component group. According to Gamil and Alhagar [23], the restriction of movement is one of the most important challenges of the pandemic. For example, AECOM infrastructure consulting firm restricted non-essential travels during the pandemic [56]. Moreover, Stride et al. [45] mentioned that not being able to meet face to face caused mental health problems. Therefore, this is considered an important challenge of the pandemic, where construction people feel restricted for moving or traveling even for work purposes. Less efficient site work (mean: 3.6; loading: 0.7) was rated as the second most significant variable of C1. Site crews must be on site to get control of processes for higher productivity. However, the lockdown rules implemented during the pandemic greatly affected the way that teams work [27]. Further, social distancing between workers on the construction sites led to a significant decrease in productivity rates [28].

Revisiting existing strategies (mean: 4.1; loading: 0.6) is the third significant variable of C1. As indicated by Stoller [57] "Crises test the adequacy of existing governance structures and also require deployment of new ad hoc roles." The way the construction industry is managed should change to meet the expectations in case of an emergency crisis [23]. The current procedures are not sufficient to handle the COVID-19 outbreak, and long-term plans such as the use of information technologies and knowledge management, and industry 4.0 adoption that is needed for smoothening the impacts of the pandemic [45]. During the lockdown period, managing project teams working from home became challenging [27]. Minnullina et al. [58] suggested that revisiting management decisions plays a critical role in minimizing risks in terms of enhancing employee reliability. The interviewees also mentioned that COVID-19 has already changed many things at the workplaces. One of the interviewees stated that ‘‘COVID-19 has led us to adopt new strategies because we have already witnessed that current procedures are not satisfactory in terms of worker health protection and workplace organization. Our company has already made a critical assessment about the current strategies and is now working towards ways to transform organization into a technology focused one’’.

Work culture change (mean: 4.5; loading: 0.6) was identified as the fourth significant variable of C1. Stride et al. [45] stated that "Companies must create safe remote working culture". In the construction industry, work culture change such as social distancing, teleworking, isolation, and the use of technology is required to overcome COVID-19 challenges [27]. AECOM realized this shift and provided a wellness schedule for their employees [56]. According to Biörck et al. [46], for projects to be successful after COVID-19, it is necessary to create a new work culture and develop new skills to adapt to the new normalization process.

Poor planning and scheduling (mean: 3.4; loading: 0.6) was determined as the last variable of C1. Construction planning and scheduling are significantly affected by crises. Rehman et al. [11] stated that schedule is revised, extension of time is requested, and a new completion date is determined for most construction projects. For this reason, managers must develop backup plans in times of crisis [23]. This is essential to smoothen the effects of the pandemic on work conditions and deal with the productivity challenges.

2) Project and Resource Related Challenges (C2)

The Project and Resource Related Challenges component group explains 13% of the total variance in which workforce shortage (mean: 3.8; loading: 0.8) was found as the most significant variable. As per Gamil and Alhagar [23], workforce shortage and job loss are among the important challenges due to the pandemic. The project and resource challenges vary for construction organizations. For example, project executors have tried to reduce the workforce on site while supporting remote work for certain processes. However, the remote working method causes the personnel to slow down [58]. Jallow et al. [27] indicated that management, communication, health and safety are the most important factors for current workforce protection. One needs to consider these factors to better deal with project and resource challenges. In the semi-structured interviews, one interviewee said ‘‘COVID-19 has taught us a very important thing, which is to put our health first as the priority. In the past, we have mostly considered that work is more important than our mental and physical stress, and fatigue. However, this is not the case now. We are now learning to stop the line when necessary. This way we can also improve productivity and experience less workforce shortage’’. Indeed, this challenge is now becoming a lesson learnt for the most construction organizations in terms of making an effective plan to manage resources and the project, where safety is considered first.

Suspension of projects (mean: 3.7; loading: 0.7) was found as the second most significant variable among C2. Gamil and Alhagar [23] emphasized that the pandemic's most significant impact is the suspension of projects in construction. Uncertainties in the future demand, unwillingness of parties, changes in design led to suspension of projects [28]. In addition, the suspension of projects caused financial effects such as delay of payments and legal problems due to the non-compliance with contract terms [13], [23].

Time and cost overruns (mean: 4.3; loading: 0.6) was found as the third significant variable of C2. Gamil and Alhagar [23] indicated that time and cost overruns are among the serious consequences of the pandemic on the construction industry. Stride et al. [45] reported that all companies participating in their study experienced cash flow problems and project delays. Turner construction company specified that material prices have experienced fluctuations during the pandemic. They reported that some material prices are increasing recently, although there are some signs of levelling according to their cost index [59]. Considering the burden of increased material prices and delayed payments, nearly all construction companies applied cost-cutting measures [11].

Shortage of supplies (mean: 4.4; loading: 0.6) is the fourth significant variable. Due to COVID-19, supply chains are disrupted for many industries [29]. The pandemic has brought risks such as delays in material delivery and shortage of construction materials and supplies [28], [58]. Turner construction reported that supply chain disruptions are at unprecedented levels for the fourth quarter of 2021 [59]. Further, Whiting-Turner contracting company reported supply chain disruption and their effort to find alternative materials and to mitigate this effect [60]. Interviews of Rehman et al. [11] also showed that construction companies tried to find alternative and available local materials and equipment.

Financial and economic impact (mean: 4.0; loading: 0.6) was determined as the last critical variable of C2. Companies have been challenging with suspending or cancelled projects which create income loss [31]. COVID-19 hygiene guidelines have already resulted in a considerable increase in project costs [61]. Stride et al. [45] indicated that a new recession in the construction industry could arise due to COVID-19. This shows the significant financial and economic impact of the pandemic on construction.

3) Change and Uncertainty Related Challenges (C3)

The third component group explains 10% of the total variance. In this component group, the Requirement of COVID-19 Protocols (mean: 4.9; loading: 0.7) is the most significant variable. Construction companies need to regularly monitor policy makers' statements to comply with COVID-19 guidelines such as providing additional personal protective equipment (PPE), social distancing, and disinfecting shared tools and parts [41]. Bohannon [30] reported that most construction companies were implemented new protocols that had not been required before for safety. However, Bsisu's [42] study considered that workers are not expected to keep social distance and sustain the use of basic PPE after lockdown ends. Therefore, it is a significant challenge to foresee how COVID-19 protocols will affect the industry.

Less skilled personnel (mean: 3.0; loading: 0.7) is the second most significant variable of C3. The lack of skilled labor was already one of the common risks for construction companies before the pandemic [30]. Stride et al. [45] stated that basic skills in the construction industry will be lost due to COVID-19, where 75% of the workers were laid off leading to a shortage of skilled personnel. There are concerns related to transition of workforce to other industries [28]. The lack of a qualified workforce on construction sites may bring along customer complaints. Hence, it is critical to address the less skilled personnel challenge to avoid workforce shortages.

Impact on Research and Technology (mean: 2.8; loading: 0.6) was found as the third significant variable of C3. Although the use of technology in the pandemic has provided many benefits, it has also caused problems. The need for use of technology revealed challenges regarding digital infrastructure [28]. The implementation of new technologies may create difficulties in terms of requirement of training, learning and motivation. Further, information leaks can cause serious problems such as a complete shutdown of a company. Another threat is employee misbehavior and hacking which require security systems to deal with such situations.

Problems with Adopting COVID-19 Precautions (mean: 3.4; loading: 0.5) is the fourth significant variable of C3. Amoah and Simpeh [62] reported the difficulties such as the inadequacy of PPE, use of public transport by workers, and sterilization of construction materials. Bsisu [42] revealed that 24.6% of civil engineers surveyed believe that PPE will be available on site as part of COVID-19 requirements, where 20% believe that social distancing is a proper procedure, and 12.3% implied that workers will adhere to the safety precautions.

4) Socioeconomic Challenges (C4)

This component group explains 9% of the total variance. Among the variables of this component, Socioeconomic Impact (mean: 3.2; loading: 0.9) was found as the most significant variable. Because of financial difficulties due to COVID-19, companies struggle to pay employees properly, and layoffs are common [28], [29]. Stride et al. [45] stated that there is a considerable portion of employees, who lost their jobs due to the pandemic struggling financially. Some socioeconomic problems such as job and income losses, and psychological problems were exacerbated by the pandemic [24], [28]. Work and Life related Uncertainties (mean: 4.0; loading: 0.8) is the second most significant variable of C4. Companies have procedures in place against anticipated major risks. However, these procedures are sometimes not sufficient to deal with unpredictable risks such as the risks brought by COVID-19 [45]. In an uncertain environment, construction companies are advised to adopt an agile approach [40].

5) Regulatory and Legal Challenges (C5)

This component group constitutes 7% of the total variance. In this component group, Additional Safety Equipment Use (mean: 4.5; loading: 0.8) is the most significant variable. Construction companies are advised to provide additional PPE to protect workers' health [41]. Amoah and Simpeh [62] highlighted that the lack of PPE violates COVID-19 safety measures. Moreover, additional PPE use might present a challenge for employees, some of whom are not already comfortable with using the basic PPE. Therefore, construction companies need to develop ways to promote the use of additional PPE, especially on site.

Problems related to Legal Issues (mean: 3.0; loading: 0.7) is the second most significant variable of C5. Sihombing [44] claims that COVID-19 is not a force majeure event and mediation is needed for the force majeure claim. However, delays caused by COVID-19 might be avoided with a section of contracts named as force majeure [40]. Cases such as suspending projects or additional costs due to the COVID-19 pandemic cause non-compliance with contract terms and contractors may face legal problems [23], [40]. Several measures were adopted by construction companies to mitigate disputes. Enhanced collaboration and relations between parties helped to reassess, renegotiate, and agree on contractual terms [63]. Amendments were introduced in many contracts to address the pandemic [11]. In a situation like COVID-19, efforts should be made to protect the parties and reduce the difficulties [33].

B. COVID-19 Opportunities

1) Collaboration and Communication Opportunities (O1)

This component group explains the largest (35%) total variance. Having the highest loading, Academic Collaborations for Greater Success (mean: 1.6; loading: 0.8) is the most significant variable of O1. Academic collaborations may provide future directions for construction practitioners. Further, lessons learned may help develop theory and direct policies. Another aspect of collaboration with universities is to educate potential industry practitioners to prepare them for similar situations. After the pandemic, it is advised to communicate with universities to ensure that the right skills are developed by trades. It is further recommended that crisis management courses shall be added to the construction education curricula [27].

Improved Leadership Programs (mean: 2.2; loading: 0.8) was determined as the second significant variable of O1. Employees struggle with health and safety problems and experience stress. Leadership plays a critical role in motivating employees and supporting them continuously. Besides, leadership is essential to ensure health and safety management in the times of COVID-19 [34]. On the other hand, managing the uncertainties and crises, taking quick and proactive decisions and promoting cultural change can be achieved with good leadership. Stoller [57] specified some important characteristics of leadership in COVID-19 such as proactivity, quick actions, and active communication. Jallow et al. [27] stated that "Effective leadership is one of the most important aspects of managing crisis." For this reason, it is necessary to develop leadership programs that can cope with crises such as pandemics.

Improved Communication with Project Employees (mean: 2.3; loading: 0.8) is the third significant variable of O1. During the pandemic, companies had to use digital tools to communicate due to constraints like remote working [27], [41], [45]. Because of this, communication tools are constantly being developed [58]. Like many companies, for instance, AECOM informed and updated their employees regularly via email and videoconferences [56]. Stride et al. [45] reported that a company providing remote working option contacted with 100% of its employees through regular digital meetings every day resulting in a 97% of paper saving and improved communication. Improved in-house Training (mean: 2.5; loading: 0.8) is the fourth significant variable of O1. Improving in-house training in the COVID-19 pandemic will provide essential knowledge on crisis management [27]. Moreover, construction employees can benefit from frequent training provided in-house that reinforce their skills and qualifications. For example, Costain company provided extended reality solution enabling immersive learning for training purposes during the pandemic [64].

Increasing Cross-Sector Collaboration (mean: 2.5; loading: 0.7) is the fifth significant variable of O1. Cross-sectoral collaboration is a must to identify best and worst practices due to COVID-19 impacts on different sectors and companies [27]. Cross-sector cooperation helps companies adopt innovative and technological solutions. Other industries than construction might have already developed solutions to similar challenges. In this respect, cooperation is possible with suppliers, customers, partners, or even competitors, where traditional and creative sectors might work together to cope with the negative impacts of the pandemic [27]. For example, Whiting-Turner company stated their intention to increase their interaction with customers, partners, suppliers and vendors due to pandemic [60].

2) Occupational Safety and Education Opportunities (O2)

This component group explains 18% of the total variance. In this component group, Hygiene Programs (mean: 4.1; loading: 0.8) is the most significant variable. During COVID-19, the health and safety of workers have gained paramount importance [34]. One of the basic rules for developing site-specific health plans in construction projects is hygiene programs. Cleaning programs are strongly encouraged to be included in project schedules [47]. The COVID-19 Guidelines proposed by OSHA are of utmost importance for the hygiene of construction workers [65]. This guide encourages employees to take care of their personal hygiene while helping authorities develop site-specific health plans. This variable has a high mean value indicating that most of the organizations surveyed have been conducting hygiene programs. Similarly, many companies such as Whiting-Turner and Quiring General practiced hygiene programs including cleaning and disinfecting the workplace, providing sanitizer, promoting the importance of handwashing etc. [30], [60]. Hence, there is an opportunity to create safer and cleaner construction sites with the awareness of health, safety, hygiene, and cleanliness that was brought forward owing to COVID-19 [34]. This may also lead to improvement of construction safety standards after the pandemic.

Reduced Waste (mean: 2.8; factor loading: 0.8) is the second most significant variable of O2. Stride et al. [45] reported that the papers to be photocopied were reduced by about 97%. On the other hand, an emergency field hospital was built in a shorter time with the help of advanced technologies such as offsite/modular construction. Thanks to these technologies, it was reported that construction waste has been reduced by approximately 80% [48]. This provides the industry with the opportunity to reduce construction waste in the post-pandemic period. Worker Education (mean: 2.8; loading: 0.7) is the third significant variable of O2. One of the most essential practices for developing site-specific health plans in construction projects is worker training. Informing employees about COVID-19 based on misinformative sources poses major health risks. Therefore, employees should be trained on how to maintain social distance, wear the PPE in a proper way, report the sick workers, and what the symptoms are [23]. Taking one example, Trueback construction company provided all employees with necessary training for COVID-19 prevention [30]. In addition, in-house training needs to be improved to manage a crisis [27].

3) Productivity and Technological Opportunities (O3)

This component group explains 12% of the total variance in which Sustainable Architecture (mean: 2.2; loading: 0.8) is the most significant variable. Disruptions caused by the pandemic may provide the opportunity to implement new methodologies in the construction industry, which is generally resistant to change. The COVID-19 pandemic has been affecting the living environment, especially indoor spaces. In this process, sustainable architecture, accessible green spaces, and the flexibility of living spaces have gained importance for creating a healthy and safe living space [46], [49]. In the semi-structured interviewees, one interviewee implied ‘‘COVID-19 has led us to use time more effectively due to space and mobility restrictions. This in turn fostered the way that we approach work related problems and develop means to be more productive leading to less waste and more value’’.

Increased Productivity (mean: 2.5; loading: 0.8) is the second most significant variable of O3. The pandemic was advantageous for those who got the chance of working from home leading to increase office work productivity despite the low productivity on site construction. Interviews of Ogunnusi et al. [17] implied that flexible and remote working helped to improve productivity. Bsisu [42] reported that a productivity increase was observed for 21.2% of the respondents who participated in the study, where there was no change for the 47.1%. Stride et al. [45] stated that prefabrication can increase the productivity during the pandemic period.

Use of Technological Tools in an Effective Manner (mean: 3.5; loading: 0.6) is the third significant variable of O3. Like many other industries, the construction industry is moving towards Industry 4.0, focusing on digitalization. 3D models and digital communication tools have also been used in the industry (such as infrastructure) to prevent cost and time losses due to the lockdown [27]. The digitalization in the industry will accelerate post-pandemic breaking the resistance to change. Some large construction companies in North America have used field access modes and other smart technologies to maintain distance between workers entering and leaving the site during peak business hours. At Costain company, digital technologies were offered to create a safe work environment. They used wearable technology to ensure social distancing, camera tracking to identify violation of wearing masks and thermal cameras to detect possible infected workers. They further utilized extended reality solution as a response to challenges of working from home [64]. Construction companies should be encouraged to use these innovative approaches for better productivity and less waste [41]. COVID-19 has opened the path for a quicker transformation into Construction 4.0, which motivates the organizations to use technology for facilitating the digital transformation and automation.

4) Construction Innovation Opportunities (O4)

This component group constitutes 9% of the total variance. Modular Construction Technology (mean: 2.9) and Building Information Modelling (BIM) Enabled Construction (mean: 3.5) are the most significant variables in this component group with loadings of 0.9. Even though there have been some attempts towards the use of new technology in construction, the industry has shown a reluctant approach towards adopting innovative technologies [11]. However, the pandemic required innovative and technological solutions to deal with the problems brought by the change and uncertainty. For example, Zhou et al. [48] reported that an emergency field hospital was built only 10 days after the COVID-19 outbreak. During this construction, they used advanced technologies like BIM and modular construction. Thanks to the modular technology, the construction time was reduced by 40% and waste was eliminated by 80% compared to the traditional method. With the help of BIM, the pre-construction plan was improved, the overlapping processes and waste of resources were prevented, as a result, the construction time was reduced, and the standard of the building was improved [48]. Modular and offsite construction is recommended for the industry for a quick, efficient and less costly response to needs [29], [36]. McKinsey Engineering, Construction and Building Materials Practice group specified that digital collaboration tools such as BIM have been more broadly utilized. They also emphasized that they expect increased off-site construction since it helps to decrease worker interaction along with benefits in quality and speed [46].

C. Recommendations

Infectious diseases are likely to appear and spread as new pathogens emerge, human lifestyle changes where cities become denser, and globalization increases where the borders become less significant. Pandemics mostly have a short and sharp nature starting and finishing within a year [8]. Verikios [8] identifies three characteristics of outbreaks that create instability. First one is the threat of spread and fatality of the disease before identification of the agents causing the disease. Second one is the time required to develop drug or vaccine and to get approval for them. Thirdly, the disease may adapt and evolve over time, and variants may develop. COVID-19 pandemic has these characteristics as well. Accordingly, impact of COVID-19 can be inspected under pre-pandemic, peak-pandemic and recovery periods as previously provided in Fig. 1. In that sense, COVID-19 impact on the construction industry may help to generalize relevant findings in case of similar future outbreaks. Some recommendations are provided in Table 8 based on findings of the study and several sources [17], [27], [28], [40], [46], [60].

TABLE VIII
Recommendations for Construction Companies in case of Outbreaks

Pre-pandemic period	Peak-pandemic period	Recovery period
- Observing the environmental changes - Reaching the right information - Conducting risk analysis - Developing contingency plans - Taking necessary precautions - Improving crisis and risk management - Improving digital infrastructure - Adoption of technological tools - Training and education - Arranging contractual agreements accordingly - Forming reliable supply chain partnerships	- Reaching reliable information sources - Following guidelines provided by government agencies - Providing a safe working environment and necessary PPE to employees - Flexible working conditions to decrease spread of the disease - Communicating effectively with all project stakeholders - Training and education - Supporting employees - Promoting agility and resilience	- Providing employees better working conditions - Creating new working culture - Enhancing organizational learning with the help of lessons learnt - Understanding stakeholders' needs

VI. Conclusions

This study evaluated the impact of COVID-19 on the U.S. construction industry. Literature review and semi-structured interviews were conducted come up with a comprehensive list of challenges and opportunities. Accordingly, a questionnaire was administered to construction companies. The results indicated that hygiene programs, use of technological tools in an effective manner and BIM-enabled construction are the biggest opportunities; and requirement of COVID-19 protocols, restriction on movement and travel, and additional safety equipment use are the most significant challenges. Based on literature review, semi-structured interviews and analysis results, recommendations for the construction industry were provided in case of future outbreaks, considering pre-pandemic, peak-pandemic, and recovery periods.

Analyzing the results, one can make future predictions about the construction industry based on lessons learnt. Construction companies should be aware of changes in the environment by following reliable sources. To have the ability of responding to changes, they are advised to adopt agile approach. Based on risk analysis, they should develop contingency plans. Considering the issues may arise due to an unexpected event, they should examine their contracts and make necessary arrangements. Further, considering supply chain disruptions, companies should manage their relations with suppliers and create alternative plans.

The organizations are now strengthening their infrastructure for technology, where the big shift has already started with efforts for digital transformation and automation. Some organizations have started constructing their own information mechanisms not to experience delays and interruptions in communication. COVID has already taught many companies to sustain their business thanks to well-developed communication chain and information technologies. Skilled workforce shortage is another issue that organizations should address by creating a work culture considering employees' needs. Since the pandemic has already affected numerous countries dramatically, construction organizations are now more alert towards developing strict safety and hygiene procedures in order not to experience workforce and time losses. They are now more aware of the safety risks and are working towards developing better safety procedures, which will help them avoid work related hazards and accidents for the future occurrences for such unexpected events. Training and education of employees is significant in terms of applying safety measures. This way, companies might use time more effectively and increase productivity, and more importantly might enhance value for stakeholders.

The results of this study are expected to guide construction practitioners to revise and revisit their strategies and actions in accordance with the change brought by the pandemic. Moreover, for construction companies experiencing similar problems due to COVID-19, the results of this study can be generalized and their views on this issue can provide a roadmap for the wider society. On the other hand, the study had some limitations such that the projects that have already been active before COVID-19 might propose COVID-19 as the potential excuse of project delays, overrunning budgets and schedules, and economic impact of COVID as gospel truth. Moreover, the results might change in other countries due to governmental policies, which might have affected the way respondents viewed and responded to the questionnaire. Finally, the sample size for the questionnaire might reflect the perceptions of a relatively small group, where results might change with a larger group. As a future study, the results of this study shape industrial strategies to evaluate the impact of COVID-19 on the construction industry in other countries or regions. Since COVID-19 is a global pandemic, the results can be compared and better practices to tackle the negative effects may be suggested.

Data Availability Statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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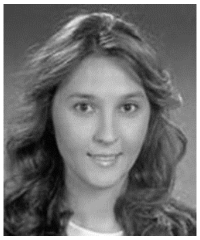

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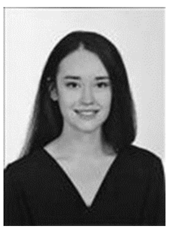

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