Capturing the Impact of COVID-19 on Construction Projects in Developing Countries: A Case Study of Iraq

Abstract

The outbreak of COVID-19 has impacted construction markets worldwide due to supply chain disruptions, workforce restrictions, and legislative changes. However, construction markets in developing countries are perceived to be more vulnerable to the challenges as- sociated with the pandemic. As such, the goal of this paper is to capture the impact of COVID-19 on construction projects in developing countries by considering the case of the Iraqi construction sector. A multistep research methodology was adopted by the authors, including (1) literature analysis and semistructured interviews with 40 industry experts to identify a comprehensive list of construction themes and factors affected by the pandemic; (2) survey data collection from 388 industry professionals to quantify the significance and influence of each identified factor; (3) Cronbach's alpha test to check the reliability of the survey; (4) fuzzy inference system to assess the impact of the pandemic on each construction theme and factor; and (5) Mann-Whitney U-test to examine the perceived impact by the public and private sectors. Results show that the pandemic has impacted a total of 16 construction factors grouped under four construction themes, including contractual implications, construction financial market, and supply chain operations, as well as safety and risk management, where the latter is the most impacted theme. The factors impacted the most by the pandemic are safety management measures, interpretation of the contract language, building materials prices, risk management practices, construction materials, construction labor, and construction subcontractors. Also, the findings of the fuzzy model show significant difference in the captured impact of the pandemic between the public and private sectors. This research contributes to the body of knowledge by providing a foothold foundation for researchers and decision makers to enhance investigating the effect of the pandemic with its deep uncertainties in relation to developing countries.

Introduction

The World Health Organization (WHO) declared on May 11, 2020, the rise of a global pandemic caused by the novel coronavirus disease (COVID-19) (Dryhurst et al. 2020). The pandemic is considered the biggest danger to the global economy since the Great Recession (OECD 2020a, b). In fact, the World Bank estimated a contraction of 4.3% in the global economy as a result of the pan- demic, making it one of the top four global recessions witnessed in the last 150 years (World Bank 2021). Such negative

impact is as- sociated with the enforced governmental measures and regulations to control the spread of the virus such as official travel restrictions, social or physical distancing, and quarantine measures, as well as border control and closures (Ashurst 2020; Porter 2020; Assaad and El-adaway 2021). According to Franzese (2020), the response of the governments and private sectors to the pandemic is expected to greatly impact the operations and performance of various global and national markets and sectors, including construction. Unlike other sectors and industries, the construction industry could not implement telecommuting to mitigate the safety challenges and productivity disruptions associated with the pandemic (Daniels et al. 2020), leading to difficulties in maintaining safety measures while delivering projects on time. In particular, the pan- demic has caused many project delays and challenges due to (1) supply chain disruptions, (2) changes in the laws, (3) financing pressures, (4) health and safety challenges, (5) lack of human re- sources and workforce restrictions, (6) challenges in accessing jobsites, (7) contractual implications and claims, (8) suspension of construction projects, and (9) unavailability of needed materials, tools, and equipment (O'Connor et al. 2020; Assaad and El-adaway 2021). According to price water house coopers (PWC) (2020), these challenges could further deepen depending on the length and se- verity of the crisis across the various construction markets and sec- tors. As such, capturing the impact of COVID-19 is essential to enable construction firms and companies implement proper planning, management, and mitigation strategies to overcome the associated challenges (Goodman 2020). It is evident that the outbreak of COVID-19 has impacted construction markets worldwide. However, the construction markets of developing countries are perceived to be more vulnerable to the challenges associated with the pandemic. In fact, the high number of positive cases identified within the developing countries are expected to significantly impact their construction sector as governments seek to minimize the risk of contamination among their populations (Simmons and Simmons 2020). This aligns with Diop (2020), who found that the reallocation of government budget funds to contain increased COVID-19 cases is one of the causes of disruptions to infrastructure projects in developing countries. Furthermore, travel limitations and disrupted supply chains have significantly impacted infrastructure projects in developing countries due to the lack of foreign skills as well as high reliability on imported materials (Diop 2020). In addition, developing countries suffer from major construction financial challenges that may further escalate the impact of COVID-19, including variations in foreign exchange rates, inflation, changes in interest rates, and fluctuations in material price (Derakhshanalavijeh and Teixeira 2017; Ke et al. 2011). To this end, it is important to examine the

unique and com- plex impact of the pandemic on the construction industry in general and developing countries in particular. Many previous studies have examined the impact of COVID-19 on the various construction and engineering management disciplines (Assaad and El-adaway 2021; Wang et al. 2021; Parr et al. 2020; Harinarain 2020). However, in order to complement this important research stream, the goal of this paper is to capture the impact of COVID-19 on construction projects in developing countries by considering the case of the Iraqi construction sector. The associated objectives are to (1) identify a comprehensive and validated list of construction themes and factors affected by the pandemic in developing countries, (2) quantify the impact of COVID-19 on each construction theme and factor, and (3) investigate the captured impact in private versus public sectors.

Background Information

Iraqi Construction Industry According to United Nations Development Programme (UNDP) (2020), Iraq possesses a Human Development Index of 0.674, positioning the country in a medium development category and at a rank of 123 out of 189 territories and countries. In fact, Iraq shares industry challenges and characteristics similar to other developing countries. The construction industry in Iraq, like in any other developing country, faces persistent and common challenges including (1) poor project management culture, (2) limited use of technology, (3) skills shortages and lack of training, (4) materials supply problems, (5) inadequate supply of skilled, educated, and experienced workforce, (6) absence of investment, (7) lack of ap- propriate procurement methods, (8) poor health and safety systems, (9) variations in foreign exchange rates, (10) inflation, (11) changes in interest rates, and (12) fluctuations in material price (Peckitt et al. 2004; Darvas and Palmer 2014; Boadu et al. 2020; Derakhshanalavijeh and Teixeira 2017; Ke et al. 2011). All of the aforementioned persistent challenges and characteristics may further escalate the impact of the pandemic on the construction industry of developing countries in general and Iraq in particular. Iraq represents one of the developing countries that has witnessed great impact on its construction sector due to the outbreak of COVID-19. In fact, Iraq was particularly hard hit by the COVID- 19 pandemic in 2020 due to an increased number of positive cases (AL-Monitor 2020). The Iraqi government imposed a full curfew in the country from March 2020 until the end of May, excluding security, medical and media personnel, in addition to other essential services. The curfew comprised all construction activities (including essential repairs and maintenance) in the residential, commercial, and public projects. Moreover, and at the beginning of June 2020, the Iraqi governments imposed a partial curfew and reopening (25% capacity) of businesses. However, the reopening was

accompanied with strict safety and cautious measures to be implemented on site. Besides the strict safety measures and curfews, the vaccination rate in Iraq is still very low, delaying the post pandemic or recovery phase of the overall economy, including the construction sector. Construction firms in Iraq are experiencing huge disruptions and difficulties due to the pandemic. According to OECD (2020a, b), many Iraqi construction firms are witnessing loss of profits and facing challenges due to the impact of COVID-19, which are preventing their sustainable growth and development. Furthermore, preliminary statistics showed that the construction sector in Iraq is experiencing a 52% employment reduction and 68% production reduction (IOM 2020). Ultimately, the case of Iraq reflects the unique and complex impact of the pandemic on construction sector of various developing countries that share similar challenges and characteristics.

Existing Literature and Knowledge Gap

The impact of the COVID-19 pandemic has been extensively explored within various sectors and industries such as the energy, health care, food and agricultural, education, tourism, trade, and business, among others. For instance, Aloui et al. (2020) examined and modeled the impact of COVID-19 on the energy market— particularly on crude oil and natural gas using vector autoregression modeling. Al-Jabir et al. (2020) examined the impact of the pandemic on surgical practice and provided guidelines for more efficient and safe care to patients. Furthermore, Jambor et al. (2020) conducted a literature review to identify the impact of the pandemic on food and agricultural market. The results indicated that the pandemic influenced labor, food safety, supply, demand, and trade, among others. Dawadi et al. (2020) provided a reflection on the challenges and opportunities associated with the pandemic in relation to the technologization of education system in Nepal. Another example includes the work of Batrik et al. (2020), who quantitatively examined the effect of the pandemic on small businesses using data collected from surveys. Although previous studies have examined the effect of the pandemic on the various industries, their findings cannot be generalized on the construction industry due to (1) the unique types of goods being produced and services being offered (Kirchberger 2018), (2) the one-of-a-kind characteristics of its projects (Guerlain et al. 2019), and (3) its overall dynamic nature (Mohamed and Tran 2021). As such, careful and particular consideration and examination of the pandemic's impact on the construction and engineering sector is required. To this end, as indicated in Table 1, many previous research studies have investigated the effect of the pandemic on various construction and engineering management fields and areas using different techniques and methods.

Table 1. Summary of existing studies

Most of the studies have addressed particular consequences or aspects related to the pandemic such as changes in transportation and traffic behavior (Hendrickson and Rilett 2020; Parr et al. 2020), effects of teleworking and lockdown on stakeholders and project participants (Pirzadeh and Lingard 2021; Hansen 2020), emergency megaproject citizenship behavior (EMCB) (Wang et al. 2021), disinfection of construction sites (Kim et al. 2021), and applicability of force majeure clauses (Harinarain 2020). Although some studies have addressed the pandemic in developing countries (Wang et al. 2021; Hansen 2020), they fall short in addressing all the potential impacts of the pandemic that could be witnessed during the execution phase of construction projects. On the other hand, Assaad and El-adaway (2021) provided highly valuable guidelines, impacts, and future research directions as a response to the pandemic in construction projects. However, the results of Assaad and El-adaway (2021) are (1) strictly based on the analysis of existing literature, (2) do not address the unique and complex characteristics of construction industry in developing countries, and (3) do not examine the captured impacts of the pandemic in a quantitative manner. Based on the preceding discussion, the current literature falls short in (1) systematically identifying a comprehensive list of construction themes and factors impacted by the outbreak of COVID-19 using a hybrid approach (i.e., systematic literature review followed by semistructured interviews), (2) quantitatively assessing the im- pact of the pandemic on construction projects of developing countries, and (3) investigating the pandemic's impact on the private versus public sectors. This paper fills this knowledge gap

Methodology

In order to achieve the goals and objectives of this paper, the authors adopted a hybrid approach, which involves qualitative and quantitative methods as shown in Fig. 1.

The upcoming subsections present the detailed steps adopted by the authors.

Step 1: Identification of Construction Themes and Factors Prior to conducting impact assessment, the authors should first identify a list of main construction themes and corresponding factors affected by COVID-19. Several studies have conducted literature review analysis to identify the impact of the pandemic on the construction sector. However, the current literature is still not enough to ensure the comprehensiveness and inclusiveness of all potential construction themes and factors that may be affected by such complex situation. Therefore, the authors in this paper followed a hybrid approach to

collect the primary data by performing a systematic literature review analysis and subsequently validating the findings using semistructured interviews. The latter should ensure that the identified list of construction themes and factors are comprehensive and validated by professionals dealing with the im- pact of the pandemic.

Literature Review Analysis. The authors performed extensive database search to identify the key construction themes and corresponding factors. The detailed steps adopted in the selection procedure of relevant articles are as follows:

- Database search engine and keywords: The database search was conducted using Google Scholar, Scopus, and Clarivate data- bases. The keywords that were used for searching the published work included SARS-CoV-2, coronaviruses, health crisis, novel coronavirus, pandemic virus, COVID-19 impact, construction and COVID, pandemic impact on industries, COVID and construction cost, and COVID and construction time, as well as COVID impact assessment. It is important to note that the used keywords were selected based on previously published research (Bartik et al. 2020; Newell and Dale 2020; Zowalaty et al. 2020; Aloui et al. 2020; Shafi et al. 2020) that conduced literature review analysis on COVID-19 related topics for different industries and sectors.
- Screening and selection criteria: The selection criteria adopted during screening included literature works that (1) are re- search articles, newsletters, and technical reports published by well-recognized and reputed bodies, (2) are strictly related to COVID-19 in the construction sector, and (3) mention, discuss, or list the main construction themes affected by the pandemic during the year of 2020.

Ultimately, the database search led to the collection of 46 re- search articles and reports. However, after screening and taking into consideration the adopted selection criteria, the authors included a total of 17 research articles and technical reports in the literature review analysis. Based on the analyzed literature, the authors were able to identify a list of construction themes and factors that were found to be impacted by COVID-19.

Fig. 1. Adopted methodology

Semistructured Interviews

The authors conducted semistructured interviews to further validate the comprehensiveness and applicability of the identified list. This method was used because it (1) enables the authors to gather more in-depth opinions and insights by industry experts about the issue beforehand (Harris and Brown

2010), (2) is an effective method in explaining or exploring complicated phenomena or situations (Galletta and Cross 2013), and (3) has been used extensively by previous studies to identify managerial factors and practices related to construction and engineering management field (Lestari et al. 2019; Liu and Wilkinson 2015; Fellows and Liu 2008; Lu et al. 2013; Javernick-Will 2012). Semistructured interviews are usually performed by preparing open-ended questions prior to the interview (Alsaawi 2014). Thus, the questions were first prepared by the authors based on the construction themes and factors identified from the literature review analysis. Afterward, the questions were pilot-tested with industry experts to maximize benefits and avoid inefficiencies. The pilot test was conducted with five industry experts having more than 15 years of experience in construction. The experts were asked to provide feedback on the questions that need to be modified, clarified, added, or deleted. The authors addressed all the suggestions and comments of the experts until no further modifications were required. The final questions prepared by the authors for the semistructured interviews are shown in the Appendix. Upon pilot testing, the authors conducted a total of 40 semi- structured interviews with experts experienced in the Iraqi construction industry. For the selection of interviewees, the authors adopted a purposive sampling method (i.e., a nonprobability sampling method) where the interviewers/researchers contact potential professionals that are known to be area experts (Creswell and Clark 2011). Understanding the impact of the pandemic on construction is a complex issue, and thus it is crucial that the interviews be conducted with experts from different professional levels and back- ground. To this end, the authors contacted experts working as project managers, main contractors, consultants, senior site engineers, and educators. Another selection criteria is that the interviewed experts exhibit long years of experience in the Iraqi construction industry. The profiles of the interviewees are presented in Table 2.

Table 2. Interviewees' profiles

Step 2: Survey Development and Distribution.

The following subsections provide detailed discussion on the sur- vey development and distribution process.

Survey Development

The authors developed a survey to assess the impact of COVID-19 on the construction themes and

factors identified in Step 1 of the methodology. The survey required the respondents to rate the level of significance (LS) and level of influence (LI) for each factor. Whereas LS reflects the extent of importance of the factor, LI refers to the level of influence of the pandemic on each construction factor in terms of time, cost, and quality collectively. The authors adopted a five-point Likert scale for the assessment of LS and LI of the factors as follows: 1 = very low, 2 = low, 3 = moderate, 4 = high, and 5 = very high. Furthermore, the respondents were asked about their (1) working sector (public or private), (2) construction role, (3) educational qualifications, and (4) years of experience in construction.

Pilot Testing

In addition to the pilot testing conducted for the questions of semi- structured interviews, the authors performed a separate pilot testing dedicated to improving the questions of the survey. Therefore, upon survey development, the authors conducted a pilot test with 12 respondents working as project managers, construction management professors, and consultants. Furthermore, all the respondents participating in the pilot study possessed more than 15 years of experience in construction industry. The respondents of the pilot test study were asked to provide comments and feedback on the survey in terms of questions that need to be added and/or removed; clarity required to ensure consistent understanding by all the respondents; and typos or mistakes available in the survey. Ultimately, the authors revised the comments of all respondents and modified the survey accordingly. The pilot testing process allowed the authors to ensure more response options, add more questions related to sample characteristics, remove redundancies, and ensure the understanding of all respondents who would fill the survey. It is important to note that the data collected during pilot testing were excluded from the final sample to ensure consistent data collection and analysis.

Survey Distribution

The final version of the survey was then distributed to various construction experts working in the public and private construction sectors of Iraq. The authors targeted experts (1) representing various professional bodies, (2) working in the Iraqi construction sec- tor, and (3) who are members of the Iraqi Engineers Association and/or registered contracting companies at the Iraqi Ministry of Trade. To this end, the authors sent the survey to a total of 450 construction experts. A detailed discussion on the respondents' pro- files is provided in the "Results and Analysis" section.

Step 3: Survey Reliability

Upon collecting the survey responses, the authors conducted Cronbach's alpha test to interpret the reliability of the responses collected from the multipoint scales (Santos 1999). A reliable and valid scale shall yield a value of 0.75 and above (Christmann and Van Aelst 2006). For this paper, the authors performed the test to check the reliability of the scales adopted for LS and LI, respectively.

Step 4: Assessment of COVID-19 Impact

In order to assess the impact of COVID-19 on the construction sec- tor, quantitative impact analysis using fuzzy set theory (FST) was performed based on the knowledge of the experts. The benefits of FST stems from its ability to formalize and deal with human knowledge and uncertainties in decision making (Motawa and Al-Mhdawi 2019; Muhammad and Madhav 2016; Roghanian and Mojibian 2015). According to Singh and Tiong (2005), FST is used to handle complex and poorly defined problems due to imprecise and incomplete information that characterizes the real- world situation. Furthermore, Alhumaidi (2015) stated that the use of FST not only deals with incomplete and imprecise data, but also models vagueness and subjectivity associated with linguistic terms. Linguistic variables are different than numerical variables in that their values are sentences or words rather than numbers (Singh and Tiong 2005). When it comes to the scope of this paper, the used scale (very low, low, moderate, high, and very high) consists of linguistic terms associated with subjective and vague nature. Although the experts may possess a wide range of experience in construction industry, the pandemic is a complex situation and phenomena that have not been witnessed before. Therefore, uncertainty in the experts' responses may arise due to ambiguity and imprecise and incomplete information. To capture such uncertainty, the authors selected FST over other conventional approaches for assessing the impact of COVID-19 on the Iraqi construction industry. In particular, the authors used the Mamdani's fuzzy inference system to assess the output variable (i.e., level of impact on each factor) based on if-then rules (Mamdani and Assilian 1975). The detailed adopted steps are presented in Fig. 2 and subsequently discussed in the upcoming subsections.

Fuzzy Inference System Requirements

Before analyzing the impact of COVID-19 on the identified construction factors using Mamdani's fuzzy inference system, the authors need to define (1) the membership functions of the inputs (i.e., LS and LI) and output (i.e., level of impact), and (2) the relationship between the two inputs and output variable based on if-then rules. Membership Functions. Membership functions are used to define the degree of membership to each linguistic term of the fuzzy set

Fig. 2. Impact assessment process

(Prieto et al. 2017). The most common and popular membership functions include the triangular, trapezoidal, and Gaussian types (Jamshidi et al. 2012; Wulan and Petrovic 2012). In fact, triangular membership functions are known to be (1) effective in capturing subjective and imprecise information, (2) easy in specifying the in- put range, and (3) simple in terms of arithmetic computation (Barua et al. 2014; Nayak et al. 2020). According to Chowdhury and Husain (2006), triangular membership functions are highly used to mitigate uncertainties arising from linguistic terms of industry experts, stake- holders, professionals, and managers. Using another membership functions such as Gaussian or trapezoidal may definitely impact the results of the fuzzy assessment model. However, according to Pedrycz (1994), triangular functions are (1) an effective solution to the optimization of fuzzy modeling, and (2) associated with the half overlap level producing zero value of reconstruction error. Based on the aforementioned points, the authors used triangular membership functions to represent the two input variables (LI and LS) and output variable (level of impact). For this paper, the fuzzy assessment is supported by two inputs (i.e., LS and LI) and the output variable (level of impact). The two inputs are defined with a five-point Likert scale and thus associated with five linguistic terms. Thus, the authors assigned five member- ship functions for each assessment criteria (i.e., LS and LI) as shown in Fig. 3. As for the output variable (i.e., level of impact), it is also associated with five linguistic terms. However, the authors set the scale of the level of impact from 0 to 1. Such scale was used by the authors for easier interpretation and better comparability among the various factors. The membership functions defined for each linguistic term of the output variable are shown in Fig. 4. It is worth noting that adjacent triangular membership functions in Figs. 3 and 4 overlap with crossover points having membership values equal to 0.5. For instance, having a LS or LI equal to 4.38 is associated with 0.5H and 0.5VH.

Establishment of If-Then Rules. As mentioned previously, the authors adopted Mamdani's fuzzy inference system to assess the impact of COVID-19 on the identified factors. Many previous studies have followed the Mamdani's fuzzy inference system to predict or assess various engineering and construction related aspects (Prieto et al. 2017, 2016; Kim et al. 2014, 2016; Nguyen et al. 2020). Such an inference system utilizes if-then rules to map the fuzzy in- puts into the fuzzy output (Prieto et al. 2017). In other words, the fuzzy inference system operates based on knowledge exhibited in terms of if-then rules, which can then be applied to predict the behavior of many undefined systems and data-driven decision- making processes (Ahamed et al. 2016). The relationship between the fuzzy inputs

and output is established by if-then rules in the form of if antecedent then consequent. For instance, an inference system—which has two inputs x1 and x2, and one output y—may have a rule of the form of If x1 is A and x2 is B; then y is C

Fig. 3. Membership functions for the LS and LI.

Fig. 4. Membership functions for the level of impact.

where A, B, and C are linguistic terms and membership functions of x1, x2, and y, respectively. The establishment of the fuzzy if-then rules should be extracted based on experts' judgement and experience. To this end, the rules were set based on interviews conducted with four industry experts. In order to reduce biases during rule formulation process, the authors made sure that (1) the interviewees are experienced in the related area, (2) multiple rounds were conducted, and (3) consensus among the four industry experts was achieved (Mohamed and Tran 2021). In fact, the interviewed industry experts were selected based on their experience in fuzzy set theory and rules formulation on one hand and their knowledge about the conditions of Iraqi construction industry on the other. The interviewed experts included three university professors and one project manager. Ultimately, a total of three rounds was needed to ensure consensus among the interviewed industry experts. At the end, 25 if-then rules have been developed for this model in order to embrace all alternative options of the inputs (i.e., the five linguistic terms for each input variable). The identified 25 rules are provided in Table 3.

Table 3. If-then fuzzy rules generated by industry experts

(TFN) is represented as A = TFN(a, *b,* c) for *a* < *b* < *c,* and its membership value $\mu_{\breve{A}}(x)$ is given by Eq. (1)

$$\mu_{\breve{A}}(x) = \begin{cases} 0, & x < a \\ \dfrac{x-a}{b-a}, & a \le x \le b \\ 1, & x = b \\ \dfrac{c-x}{c-b}, & b \le x \le c \\ 0, & x \ge c \end{cases} \qquad (1)$$

where a, b, and c = lower, modal, and upper values, respectively. Ultimately, the values of LS and LI rated by each respondent were used as inputs for the COVID-19 impact assessment. The LS and LI value from each survey response are fuzzified by obtaining their respective membership values $\mu_{\breve{A}}(x)$ using Eq. (1) and Fig. 3.

Fuzzy Operation and Aggregation. After fuzzifying the inputs (i.e., LS and LI), the if-then rules presented in Table 3 are used to obtain the membership function for the output variable (i.e., level of impact). In this analysis, the antecedent of the established rules have more than one part. Thus, fuzzy operators should be used to get the membership function of the consequence associated with the antecedents in any given rule (Abouhamad and Zayed 2019). For the Mamdani's fuzzy inference system, the min-max composition is used for aggregation and obtaining the output function for each factor (Mamdani and Assilian 1975) as shown in Eq. (2)

$$\mu_s(y) = \max\{\min(\mu_{A_r}(x_1), \mu_{B_r}(x_2))_r\} \quad (2)$$

where $\mu_{\tilde{A}}(y)$ = membership function of output y determined based on Fig. 4; and $\mu_{Ar}(x1)$ and $\mu_{Br}(x2)$ = fuzzified values of inputs x1 and x2 for any given rule r determined based on Fig. 3. Ultimately, the aggregated membership function $\mu(y)$ is obtained for each factor.

Defuzzification. Based the derived membership function of the output, defuzzification process is conducted to come up with crisp (nonfuzzy) value for each factor (Nieto-Morote and Ruz-Vila 2011). There are different defuzzification techniques including centroid method, bisector of area, and middle of maximum, as well as largest of maximum and smallest of maximum methods (Karimpour et al. 2016). In this research, the authors used the most common defuzzification technique, which is the centroid method, due to its proven effectiveness and accuracy (Ozturk et al. 2014; Renduchintala et al. 2018). This technique finds the centroid of the area under the output membership function (Yager 1978) as shown in Eq. (3).

$$y^* = \frac{\int y\mu_S(y)dy}{\int \mu_S(y)dy} \quad (3)$$

where y* = level of impact of COVID-19 on a given construction factor; and $\mu_S(y)$ = output membership function obtained using the min-max composition. Ultimately, the level of impact on each factors is then assessed and ranked by calculating the average impact cross all survey respondents.

Step 5: Comparison between Public and Private Sectors To compare between public sector and private sector in terms of the captured impact of COVID-19, the authors first divided the survey data into two subsets (one for public sector and another for private sector). The authors first performed Shapiro-Wilk

to examine the normality of the data. If the data obtained from each sector were not normally distributed, the nonparametric Mann-Whitney U-test was used. Otherwise, a t-test should be used to examine the mean responses of the two sectors. The conducted hypothesis testing was conducted on the level of impact obtained from each respondent using the developed Mamdani's fuzzy inference system. For the conducted hypothesis testing, the authors adopted a 5% significance level.

Result and Analysis

Identified Construction Themes and Factors

Based on the conducted literature review, the authors were able to identify four construction themes, including (1) contractual implications, (2) construction financial market, (3) supply chain operations, and (4) safety and risk management. The references used in the literature review are presented in Table 4 along with the dis- cussed construction themes. The questions for the semistructured interviews were then constructed based on the construction themes presented in Table 4. Ultimately, a total of 16 factors were determined based on the per- formed literature and semistructured interviews. Table 5 presents the identified constructions themes and factors along with the sup- porting resources.

Profile of Survey Respondents

In Step 2 of the methodology, the authors developed a survey to quantify the level of significance and level of influence for each construction factor presented in Table 5. Out of the 450 distributed surveys, 401 surveys were returned. However, only 388 responses out of the 401 were complete and thus included in the analysis. As such, the response rate for the survey is 86.22%. Such rate is considered high compared with previous construction-related studies (Azhar et al. 2013; Yates 2014; Ling et al. 2008; Chen and Manley 2014; Tabish and Jha 2018; Sadafi et al. 2012). The profile of the respondents and their distribution are presented in Table 6. As indicated in Table 6, 78% of the respondents work in the public sector and 22% in the private sector of Iraqi construction industry. Furthermore, 69.84% of the survey respondents had more than 15 years of experience in the construction industry. Nevertheless, the respondents possess various construction roles in the construction industry including safety engineers (21.65%),

Table 4. Identified construction themes and corresponding references

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386 **Table 5.** Identified construction themes, factors, and supporting resources

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388 **Table 6.** Profiles of survey respondents

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390 subcontractors (14.95%), consultants (14.43%), contractors (15.21%), site engineers (9.53), and
391 project managers (24.23%). As expected, most of the respondents (61%) were holders of a bachelor's
392 degree, and the remaining respondents (39%) were holders of postgraduate degrees. As such, the
393 profile of respondents reflects a wide range of experience with diverse construction roles and
394 educational backgrounds. The latter assures the reliability and validity of the survey responses.

395

396 *Survey Reliability*

397 Upon collecting the responses, the authors performed Cronbach's alpha test to examine the validity
398 and reliability of the survey data and scales. The Cronbach's alpha values calculated for this survey
399 were 0.99 for the LS, and 0.984 for the LI. As mentioned in Step 3 of the methodology, a reliable and
400 valid questionnaire shall yield a Cronbach's alpha value greater than 0.75. To this end, the results show
401 that the distributed survey is reliable and valid.

402

403 *Fuzzy-Based Assessment of COVID-19 Impact*

404 Level of Significance and Level of Influence

405 The authors calculated the mean LS and LI for each factor from the collected survey responses. Table
406 7 presents the mean values of LS and LI. As shown in the table, the top five construction factors in
407 terms of LS include (1) F7: Building material prices, (2) F15: Safety management practices, (3) F2:
408 Interpretation of the contract language, (4) F11: Construction materials, and (5) F1: Live claims and dis-
409 putes. On the other hand, the top five construction factors in term of LI include (1) F15: Safety
410 management measures, (2) F16: Risk management practices, (3) F11: Construction materials, (4) F13:
411 Construction subcontractors, and (5) F12: Construction labors.

412

413 Developed Fuzzy Inference System

In order to develop the fuzzy assessment model, the authors used the fuzzy logic toolbox in MATLAB version 2019b. The member- ship functions for inputs (LS and LI) and output (level of impact) were defined as shown in Figs. 3 and 4, respectively. Furthermore, the if-then rules presented in Table 3 were used in the design of the fuzzy model. Fig. 5 shows the impact surface for the developed fuzzy model. As the shading intensity increases, the level of COVID-19 impact on construction factors decreases. Ultimately, the presented surface reflects the impact level associated with all the potential combinations of LS and LI values.

Impact Assessment

Upon developing the fuzzy inference system, the authors used the values of LS and LI rated by each respondents as inputs. The values of LS and LI were fuzzified using Eq. (1) such that each fuzzified input has two μ values representing the degree of membership to their corresponding linguistic terms. For instance, the fuzzification of LS with a value of 3.95 indicates that its significance is 16% very high and 84% high. Upon fuzzification, if-then rules presented in Table 3 are then used along with min-max composition of Eq. (2) to map the fuzzified inputs into the output and obtain its membership function. Ultimately, the level of impact rated by each respondent is finally calculated by defuzzifying the output membership function using Eq. (3) presented in the methodology. Ultimately, the captured impact of the pandemic on each factor is then assessed by calculating the average across all respondents. Table 8 presents the average level of impact on each factor and construction theme. As presented in Table 8, the factors that were impacted the most by the pandemic include (1) F1: Safety management measures (0.910), (2) F2: Interpretation of the contract language (0.900), (3) F7: Building materials prices (0.891), (4) F16: Risk management practices (0.885), (5) F11: Construction materials (0.881), (6) F12: Construction labor (0.876), and (7) F13: Construction sub- contractors (0.869). On the other hand, the factors that were impacted the least by the pandemic include (1) F9: Labor wages (0.587), (2) F4: Insurance rates (0.615), (3) F3: Clarity of contractual obligations (0.667), and (4) F6: Currency exchange rates (0.710). Furthermore, and by taking the average impact across all corresponding factors, the impact of COVID-19 pandemic on the various construction themes from the highest to the lowest is as follows: (1) Safety and risk management theme (0.898), (2) Supply chain operations (0.842), (3) Contractual implications (0.800), and (4) Construction financial market (0.744).

444 **Table 7.** Level of significance and level of influence for each construction factor

445

446 **Fig. 5.** Impact surface

447

448 **Table 8.** Level of impact on each construction theme and factor

449

450 **Table 9.** Significant difference in the level of impact on private and public sectors

451

452 Comparison between Public and Private Sectors

453 The authors divided the data into two subsets and subsequently conducted Shaprio-Wilk test. The data
454 were not found to be normally distributed, and thus Mann-Whitney U-test was used to com- pare the
455 impact between the public and private sector. Table 9 presents the mean impact for each factor as
456 perceived by the private and public sectors along with the obtained p-values. The results of the
457 conducted hypothesis testing show that 6 out 16 factors had statistical different impact between public
458 and private sector. These six factors include (1) F2: Interpretation of the contract language, (2) F4:
459 Insurance rates, (3) F8: Construction equipment prices, (4) F12: Construction labor, (5) F13: Construc-
460 tion subcontractors, and (6) F15: Safety management measures. As such, there is 37.5% difference or
461 misalignment in the perceived impact between the public and private sectors. The level of impact
462 perceived by the public sector seems to be higher than that perceived by the private sector as related
463 to most of all factors except for Insurance rates. The differences between both sectors can be attributed
464 to inaccuracy (i.e., overestimation or underestimation) in the assessment of the respondents. Another
465 reason is that decision-making process in the public sector is more complicated than in the private
466 sector and requires a series of steps that amplify disruptions in the project. Thus, any emergency
467 developments such as pandemics would re- quire lengthy legislation and instructions, which may
468 negatively affect the flow of project implementation in public sectors.

469

470 Discussion of the Research Findings

471 The upcoming subsections provide detailed discussion in relation to the research findings.

472

473 Contractual and Legal Implications

Contractual implication was ranked third among the four identified themes in terms of level of impact (0.800). Generally, common contractual-related challenges in construction projects include contradictions and vagueness in contract documents, unclear scope, inefficient negotiation process, and poor contract communication (Ashmawi et al. 2018). Such contractual-related challenges may lead to legal consequences including penalties and lawsuits for not meeting contract terms, invalidation of contracts that do not follow current regulations, and even deterioration of relationship among the various project stakeholders. However, the pandemic has shed the light on such aspects due to the imposed governmental measures and regulatory changes. For instance, the pandemic has given rise to many disruptions and project delays in Iraq due to either full curfews on one hand and strict safety measures and regulations imposed by the government on the other. The following quote describes the impressions from many of the interviewees: Practices to accommodate social distancing in construction sites may be implemented including staggering shifts, daily temperature checks, wearing masks, providing additional hand washing and sanitizing stations and restricted use of shared tools or equipment among construction workforce. Ultimately, the contractual conditions—particularly those related to force majeure—play a significant role in assessing the liability of the parties to the losses and damages associated with such delays and disruptions. For instance, although the Iraqi Civil Code (ICC) clearly discusses the right for construction contract termination due to force majeure events, the definition of force majeure is not explicitly specified (ICC 1951). On the other hand, and according to the Iraqi Contract Conditions for Civil Engineering Works (ICCCEW 1987), contractors are mainly exempted from damages and losses that are strictly associated with military operations, revolutions, rebellion, usurpation of power, civil wars, and radiation hazards from nuclear plants are considered excepted risk. Based on the preceding discussion, the contractual implication theme includes three factors affected by the pandemic including (1) F1: Live claims and disputes, (2) F2: Interpretation of contractual conditions, and (3) F3: Clarity of contractual obligations. Ultimately, the quantitative assessment showed that Interpretation of the contract language is the most impacted factor in this theme (ranked second with a level of impact equal to 0.906). In fact, the quantitative results align with the opinion of one of the interviewees who highlighted the following: The application of a force majeure clause depends on the specified language used in the contract. The legal interpretations of ICC, ICCCEW and contract forms can be a contentious issue between the contract parties (client and contractor). The latter aligns with having the public sector associated with higher level of impact in terms

of the interpretation of the contract language compared with the private sector. Although there may be vague language in the contracts commonly used in the public sector such as ICC and ICCCEW, the private sector can adopt other forms of contract such as ad hoc or international contracts, which may contain clearer language addressing the obligations and responsibilities of the parties during pandemics.

Construction Financial Market

Construction financial market theme is the least impacted by the pandemic (ranked fourth, with an average level of impact equal to 0.744). The construction sector is usually vulnerable to economic changes—especially during recessions—due to high capital outlays, cost flexibility, and high competition (Purnus and Bodea 2015). In fact, these changes depend also on internal and external factors (such as political instability and crises), which can lead to increased financial risks. For instance, and in the context of Iraq, one of the interviewees highlighted the following:

"Iraq is suffering from economic challenges due to protests (started in October 2019 till March 2020 and consisted of demonstrations, marches, sit-ins and civil disobedience), COVID-19 curfew, falling oil prices, Security deteriorates which, in turn, significantly impacted the construction market".

Despite the unique and complex crises in Iraq, the government has not issued subsidies or financial support for employers, con- tractors, or other parties involved. To this end, the interviewees indicated that the construction industry is facing a reduction in the wages of skilled and unskilled workers, and particularly in the private sector. As for construction loans, the interviewees confirmed that the pandemic impacted the ability of the borrowers (contractors and subcontractors) to make their monthly construction loan payments. Therefore, lenders might be hesitant to finance construction projects due to the uncertainties associated with the pandemic. To this effect and based on the conducted literature analysis and semistructured interviews, the construction financial market theme comprises of seven factors that could be affected by the pandemic, including (1) F4: Insurance rates, (2) F5: Tax rates, (3) F6: Currency exchange rates, (4) F7: Building materials prices, (5) F8: Construction equipment prices, (6) F9: Labor wages, and (7) F10: Financial obligations for construction. The quantitative analysis showed that F7: Building materials prices and F8: Construction equipment prices were the most affected factors with a level of im- pact equal to 0.891 and 0.858, respectively. The results align with most of the interviewees, who high- lighted the significant escalation of construction raw materials and equipment

prices due to supply chain disruptions. Another highly impacted factor is F10: Financial obligations for construction, with a level of impact equal to 0.807. In fact, and during the semistructured interviews, many interviewees stated that the pandemic impacted the ability of the borrowers (contractors and subcontractors) to meet their obligations for loan payments.

Supply Chain Operations

Supply chain operations theme was ranked second among the four identified themes with an average level of impact equal to 0.842. Supply chain operations include the processes, systems, and structures used to plan the flow of services and goods within an organization. The supply chain in construction comprises of mainly two components including the demand chain or the number of clients as well as the supply chain of the main contractor who responds to different types of clients (Langford and Male 2008). Construction supply chains can be complicated, especially in large projects, ow- ing to the variety of materials used and involvement of many parties (suppliers and subcontractors) required in the construction phase (Al-Werikat 2017). In the context of Iraq, China is one of the largest suppliers of construction items such as iron and steel, as well as construction equipment and machineries. The interviewees stated that construction projects in Iraq are experiencing disruptions due to shortage of equipment and raw materials, which is, in turn, attributed to the severe impact of the pandemic on the Chinese manufacturing industry. Many interviewees expressed the same concern reflected in the following statement: "*The pandemic most immediate impacts on the Iraqi construction industry is felt by the subcontractors, particularly in the private sector."*

To this end and based on the literature analysis and semistructured interviews, the supply chain operations theme comprises of four factors that could be affected by the pandemic, including (1) F11: Construction materials, (2) F12: Construction labor, (3) F13: Construction subcontractors, and (4) F14: Construction equipment. The quantitative analysis showed that F11: Construction materials, F12: Construction labor, and F13: Construction sub- contractors were highly impacted by the pandemic with a level of impact equal to 0.881, 0.876, and 0.869, respectively. In fact, all interviewees highlighted that contractors and subcon- tractors should perform a thorough review of construction machineries, equipment, and construction materials that have not yet arrived at the construction projects. This review should recognize the manufacturing companies, suppliers involved, and the source of materials to identify the risks involved in the supply chain processes. On the other hand, most of the interviewees pinpointed the disruption or delays in construction processes resulting from short- age of government

565 staff and laborers to carry out the office and field- work, respectively, including issuance of required
566 certificates, work permits, change orders, inspections for accomplished work activities, and construction
567 materials testing labs. Interviewees attributed these delays to the partial curfew policy (i.e., the 25% of
568 workers availability at workplaces). Nevertheless, the pandemic most immediate impacts on the Iraqi
569 construction industry is felt by the sub- contractors because, according to the interviewees, they are
570 more vulnerable to bankruptcy due to the huge disruptions in supply chain.
571
572 *Safety and Risk Management*
573 Safety and risk management (ranked first) is the most impacted construction theme by the pandemic,
574 with an average level of im- pact equal to 0.898. Furthermore, the two factors F15 (Safety management
575 measures) and F16 (Risk management practices) were found to be highly impacted by the pandemic,
576 with a level of im- pact equal to 0.910 and 0.885, respectively. Effective safety management in
577 construction projects is of utmost significance in all organizations because it promotes sustainable and
578 healthy working environment (Othman et al. 2017) and minimizes associated delays and disruptions
579 (Abdul Nabi et al. 2020). In Iraq, the interviewees mentioned that the commitment of construction
580 companies in Iraq to safety laws and regulations is very weak, even before the start of the pandemic.
581 However, an interviewee who is a local consultant with overseas experience in health and safety
582 management stated the following regarding site safety and COVID-19 pandemic in Iraq:
583 *"The safety measures imposed by the Iraqi government in line with the recommendations of the World*
584 *Health Organization have contributed to activating the role of safety management, particularly in the*
585 *construction sector. Now there is a need to establish onsite safety management units specialized for*
586 *COVID-19 testing, impose social distancing, besides their construction duties in ensuring the proper*
587 *application for construction safety measures".*
588 As such, the pandemic is actually promoting safety and making it a priority for Iraqi construction
589 companies to avoid site closure and disruptions. Although there is no evidence on whether such
590 improvement would last in the future and during post pandemic phases, many of the interviewees have
591 emphasized the need to in- corporate comprehensive safety management plans into the Iraqi
592 construction industry similar to those adopted by developed countries in the region and around the
593 globe. As for risk management practices, the interviewees mentioned that the construction industry in
594 Iraq has no formal role of risk man- ager in their projects. Instead, risk manager duties are distributed

among project managers, consultants, and contractors. Despite the extensive field and managerial experiences of the interviewees, they mentioned that they do not apply a formal approach for managing risks. Also, they were not aware of the standard processes and tools and techniques used to identify, analyze, and respond to risks. An interviewee who is a senior project manager at the Ministry of Construction and Housing and Municipalities in Iraq stated the following:

"The current practice of risk management in Iraq is to take actions when the risk occurs; detailed planning and mitigation of risks involved in the design and construction phases are still limited".

In fact, many interviewees highlighted the lack of any systematic methodology or risk management framework in the Iraqi construction industry that can help practitioners deal with COVID-19-related risks such as disruptions in the supply chain, labor shortage, unanticipated project delays, and site security risks. Ultimately, many problems related to risk management were high- lighted including (1) the lack of required knowledge, (2) the absence of formal approach of managing risks and unawareness of the standard processes and tools and techniques used to identify, analyze, and respond to risks, and (3) relying on subjective judgement when managing risks. These challenges are found to be the main barriers toward applying effective risk management approach, especially during the pandemic.

Contributions and Limitations

This paper contributes to the body of knowledge by providing a comprehensive pool of construction factors affected by the pan- demic. The authors of this paper validated the comprehensiveness and applicability of the identified list through semistructured interviews with professionals experienced in the Iraqi construction industry. Thus, the provided list of construction themes and factors constitutes a solid foundation for construction practitioners and scholars aiming to examine the impact of COVID-19 or any potential pandemic in the future. Furthermore, the authors quantified the impact of the pandemic on the various project themes and factors in general and as related to public and private sectors. Following the adopted quantitative assessment, the authors further prioritized the construction themes and risk factors based on their corresponding overall level of impact. Furthermore, the paper pinpointed differences in the captured impact between the private and public sectors that should be taken into consideration when establishing appropriate response plans. According to Markogiannaki (2019), quantification of risk fac- tors is crucial for practitioners and project stakeholders to ensure justified

625 decision making. It is imperative to note that practitioners should deal with all factors impacted by the
626 pandemics. However, because construction projects are usually complex and entails various
627 constraints, established mitigating strategies must be limited to the risk factors that have the highest
628 consequences on the project success (Wageman 2004). Therefore, the prioritization provided in this
629 paper shall help practitioners identify the construction factors that require careful attention and
630 consideration by project stake- holders to alleviate the consequences of pandemics on their project
631 performance in both the public and private sectors. Ultimately, this research contributes to the body of
632 knowledge related to studying the impact of COVID-19 on various construction and engineering
633 management disciplines by helping the associated construction practitioners address the impact of the
634 pandemic during the life cycle of construction projects and providing a foothold foundation for
635 researchers and decision makers to enhance investigating the effect of the pandemic with its deep
636 uncertainties. In this paper, the authors have analyzed the impact of the pan- demic on the identified
637 construction themes and factors in terms of cost, time, and quality collectively. Therefore, the analysis
638 does not consider any variability of the impact in terms of cost, time, and quality individually. However,
639 many previous studies have pro- vided exceptional addition to the body of knowledge by using the
640 same rating approach (i.e., considering the level of influence on time, cost, and quality simultaneously)
641 to evaluate risk factors using a fuzzy approach (Abdelgawad and Fayek 2010, 2012; Abad et al. 2019).
642 Another limitation is related to the semistructured interviews, where the authors have not taken into
643 consideration the effect of the local context (i.e., number of cases and vaccination rates) on the
644 responses of the interviewees to some of the questions. However, the semistructured interviews were
645 conducted prior to start of vaccination rollouts in Iraq and aimed strictly to identify the construction
646 factors that were impacted during the peak of the pandemic. Therefore, the local context did not
647 significantly affect the results or responses of the interviewees.
648
649 **Conclusion and Future Work**
650 This paper captured the impact of COVID-19 on construction projects in developing countries by
651 considering the case of Iraqi construction sectors. First, the authors conducted literature review analysis
652 followed by semistructured interviews with 40 industry experts to identify a comprehensive and validated
653 list of construction themes and factors. Second, survey responses were collected from 388
654 professionals experienced in the Iraqi construction industry to quantify the significance and influence of

655 the pandemic on each factor. Third, Cronbach's alpha test was conducted to check the reliability and
656 validity of the survey. Fourth, a fuzzy inference system was established to assess the impact of COVID-
657 19 on the various identified construction themes and factors. Finally, hypothesis testing was conducted
658 to examine differences in the captured impact between the public and private sector. Based on the
659 adopted research methodology, the authors identified a total of 16 construction factors grouped under
660 four construction themes, including contractual implications, construction financial market, supply chain
661 operations, and safety and risk management. The most impacted construction theme by the pandemic
662 is safety and risk management, and the least is construction financial market. Furthermore, the results
663 showed that the factors that were impacted the most by the pandemic include (1) F1: Safety
664 management measures, (2) F2: Interpretation of the contract language, (3) F7: Building materials
665 prices, (4) F16: Risk management practices, (5) F11: Construction materials, (6) F12: Construction
666 labor, and (7) F13: Construction subcontractors. Also, the findings showed significant difference in the
667 captured impact of the pandemic between the public and private sectors. The pandemic had relatively
668 higher impact on the public sector com- pared with the private sector. Ultimately, this study contributes
669 to the body of knowledge by providing the foundation for industry practitioners to alleviate the
670 consequences of pandemics on their project performance. For future work, the findings of this paper
671 can be used by re- search scholars to (1) develop guidelines and strategies to mitigate the challenges
672 associated with the pandemic on the construction sector of developing countries; (2) establish a rating
673 score or an index that quantifies the impact of pandemics on any given project; (3) investigate
674 the impact of COVID-19 on developing versus developed countries; and (4) study differences in the
675 pandemic's im- pact on the identified construction themes and factors in terms of quality, time, and cost
676 separately.
677
678 **Appendix.** Semistructured Interviews Questions
679
680 **References**
681
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