Diagnosis of COVID-19 Impact on the Construction Employment: Decline and Recovery

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Abstract

The Coronavirus Disease 2019 (COVID-19) had an unprecedented impact on U.S. construction employment. The assessment of employment declines and recoveries across various construction sectors, workforce demographics, and geographic regions helps develop inclusive long-term plans to overcome the setbacks of natural hazards, such as the COVID-19 pandemic. Existing methods for quantifying the employment decline from sudden shocks do not consider trends and seasonality of construction employment under normal conditions. Hence, it is not clear whether the employment declines are due to the impact of a disaster or associated with trends and seasonal patterns of employment. The objective of this research is to develop an approach based on time series models, i.e., seasonal autoregressive integrated

moving average (SARIMA) models, and cumulative sum (CUSUM) control charts to statistically quantify the impact of the COVID-19 pandemic on construction employment. Seasonal ARIMA models are developed using the pre-pandemic employment data from January 2011 to December 2019, and employment estimates under normal conditions are projected for the period from January 2020 to August 2021. CUSUM control charts are then used to detect employment declines and recovery timeframes for different construction employment. Results show declines in all construction sectors, faster recovery for women and Hispanic workers, and residential building jobs rebounding first. By August 2021, 14 states recovered construction employment, but 36 states lagged. It is anticipated that construction workforce decision-makers can benefit from this study by enhancing their understanding of the employment declines and the recovery status across industry sectors, gender, race, and geographical regions.

Introduction

The COVID-19 pandemic has adversely impacted employment across the United States. Nearly 25 million jobs were lost in the United States between February and April 2020 (Saenz and Sparks 2020). Despite the efforts from the federal and state governments to recover the lost employment, the US employment in February 2021 was 8.5 million less than the employment in February 2020 (Kochhar and Bennett 2021). As the shock wave of COVID-19 rippled through the US economy in early 2020, the construction industry was no exception. Following the overall trend of employment decline in the pandemic, the construction industry lost nearly one million jobs from March to April 2020 (Hilburg 2020). The social distancing, state and territorial COVID-19 stay-at-home order, disruption of supply-chain, project suspension, delays in securing permits, economic deterioration, and high risk of COVID-19 transmission in construction sites led to a halt in construction activities, thereby causing a sharp decline in construction employment (Alsharef et al. 2021; Bou et al. 2021; Jeon et al. 2022). Although construction employment showed some recovery after a sharp decline in March and April of 2020, the number of jobs in construction in 2021 was far from what should have been in normal conditions. The employment in the construction industry was 0.31 million less in February 2021 than the peak employment of nearly 7.6 million in February 2020 (AGC 2021a). The construction employment decline varied by the construction industry, demographics, and geographic regions. The COVID-19 pandemic had a disproportionate impact on Hispanic construction workers, leading to higher job losses compared to their non-Hispanic counterparts (Jan and Clement 2020). Particularly, the construction industry in the Northeast, including states like Vermont, Michigan, and New York, saw a significant decline in employment, with a loss of more than 40 percent from March to April 2020 (Brown et al. 2020). When examining specific construction subsectors, there were notable 12-month employment losses in various construction sectors. Building construction experienced an 11.7% decrease, heavy and civil engineering saw an 8.4% drop, and specialty trade suffered a 13.4% decline from April 2019 to April 2020 (Baral et al. 2022). There was a substantial increase in construction workers missing work due to personal medical reasons, with a 70 percent jump from March to April 2020 (Brown 2020). Before the onset of the COVID-19 pandemic, the construction industry was already facing challenges such as the need to improve project performance, enhance productivity, address labor shortages, introduce standardization, reduce fragmentation, and promote collaboration (Bou et al. 2021). The COVID-19 pandemic exacerbated these issues by causing a significant loss of construction employment. Furthermore, the construction job recovery varied among different sectors of the construction industry, demographics, and geographic regions (Saenz and Sparks, 2020; Baral et al. 2022).

To develop inclusive long-term recovery policies, policymakers should be aware of the pandemic impact on different construction sectors, demographics, and geographic regions along with the current state of employment recovery. Proper understanding of the current recovery status helps policymakers develop intervention measures targeting specific groups that are yet to recover from the setbacks of the COVID-19 pandemic. The impact of COVID-19 on employment and the current recovery state can be understood by studying fluctuations between actual employment and normal condition employment, which would have occurred in the absence of the COVID-19 pandemic. Construction employment in normal conditions has inherent trends and seasonality that should be considered while studying the fluctuation of employment caused during the pandemic. Existing studies quantifying the employment decline from the sudden shock of COVID-19 pandemic do not consider trends and seasonality of construction employment under normal conditions (Kochhar and Bennett 2021; Baral et al. 2022). Hence, it is not clear whether the change in construction employment across various construction sectors, demographics, and geographic regions is due to the impact of COVID-19 or a mere reflection of the inherent cyclic pattern in construction employment.

Efforts have been made to quantify the impact on construction employment during past shock events, including the great recession of 2007-2009 (Taylor et al. 2011; Hadi 2011; Tilley et al. 2013; Aum et al. 2017) and the 1990-1991 recession (Singleton 1993). Taylor et al. (2011) studied the recovery of jobs among men and women workforce from the end of the great recession in June 2009 through May 2011. Two years post the end of the 2007-2009 recession, construction employment was still shedding jobs (Taylor et al. 2011); from June 2009 to May 2011 the women workforce in construction decreased by 11.8 percent compared to 7.8 percent for men. Aum et al. (2017) studied the impact on employment in the construction industry during the 2007-2009 recession and the recovery of jobs post-recession. The construction industry shed more than 2 million jobs in the 2007-2009 great recession; this job loss alone accounted for 30 percent of the total job losses during the 2007-2009 recession. The recovery of jobs post-recession (2007-2009) was sluggish; in 2014, employment in the construction industry was 15 percent below the peak of 2007 employment (Aum et al. 2017). Hadi (2011) studied the impact on residential and nonresidential construction employment during the 2007-2009 recession. Employment during the recession (December 2007-June 2009) fell by 27 percent and 14.8 percent for residential and nonresidential construction, respectively (Hadi 2011). Tilley et al. (2013) revealed that the recovery of construction jobs after the 2007-2009 recession varied among the Federal Reserve's third district, which includes the states of Delaware, New Jersey, and Pennsylvania. The employment decline from December 2007 to December 2012 was highest for Delaware (33 %) followed by New Jersey (26.8 %) and Pennsylvania (16.1%). Singleton (1993) studied the impact on construction jobs during the 1990-1991 recession; the study revealed that employment for special trade contractors fell by 265,000 (9 percent) and by 35,000 (5 percent) for heavy construction between May 1990 and March 1991. All these studies determining the employment declines and recovery during shock events ignored the trends and seasonality in the construction job market which are present in normal conditions. Therefore, it is unclear if the impacts are entirely due to the shock events or are outturn of the ingrained employment trends and seasonality in the construction industry. To accurately assess the impacts and recovery, the actual employment during the shock events should be compared with the employment in normal conditions, which can be projected considering the inherent cyclic behavior of construction employment.

This research uses an approach based on time series models and cumulative sum (CUSUM) control charts to study the fluctuations in construction employment during the COVID-19 pandemic. This is the first attempt to diagnose pandemic-led construction employment variations considering the employment trends and seasonality that would have occurred under normal conditions. In addition to assessing the fluctuations in construction employment, the proposed approach is also used to determine if there is a statistically significant decline in construction employment for different construction sectors, demographics, and geographic regions. The results from the proposed approach will help policymakers to develop an inclusive policy by revealing the sectors, demographics, and geographic regions that are most impacted by the COVID-19 pandemic.

Methodology

Figure 1 shows the methodology used for assessing the impact of the COVID-19 pandemic on construction employment. First, the data on construction employment is obtained from the Current Population Survey (CPS) and Current Employment Statistics (CES) program, both of which are administered by the Bureau of Labor Statistics (BLS) (Bowler 2006). The CPS provides employment data for different races and Hispanic ethnicity (BLS 2021a). CES provides data on construction employment in different sectors (also sub-sectors) of the construction industry and construction employment for the 50 states in US (BLS 2021b). The construction employment data from January 2011 to August 2021 was obtained from CES and CPS databases for different categories, including construction sectors, race, and states as shown in Table 1. The time series models are fitted using the employment data from January 2011 to December 2019, and the employment forecast is made from January 2020 to August 2021, as a projection of the normal conditions (i.e., absence of pandemic). This period is selected because the first US COVID-19 case was detected in January 2020 (Jorden 2020), and August 2021 was the latest month whose data on construction employment is available by the time of this study. Before fitting the time series models using the pre-pandemic employment data, the Augmented Dickey-Fuller (ADF) test was used to examine the stationary of the time series data (Said and Dickey 1984; Worden et al. 2019). The seasonality of the times series was examined using the autocorrelation function (ACF) plot and partial autocorrelation function (PACF) plot on incremental monthly change in construction employment. To capture the seasonality and trends in the time series data, SARIMA models were fitted to the employment data. Equation 1 shows the SARIMA (p, d, q), (P, D, Q) model for projecting the construction employment (E_c) during normal conditions (Khodahemmati and Shahandashti 2020; Kim et al. 2022).

$$(1-B)^d\,(1-B^s)^D E_c(t) = \mu + \frac{\theta(B)\Theta(B)}{\emptyset(B)\Phi(B)}\, W(t) \qquad \text{Eq. 1}$$

where B is the backshift operator, i.e., $B \bullet E_c(\mathrm{t}) = E_c(\mathrm{t}-1)$; d is the order of differencing; D is the order of seasonal differencing; s is the period of seasonality; μ is the mean for time series $(1-B)^d\,(1-B^s)^D E_c(t)$; $\theta(B)$ is the non-seasonal moving average operator, i.e., $\theta(B) = 1 - \theta_1 B^1 - \theta_2 B^2 - \cdots - \theta_q B^q$; $\emptyset(B)$ is the non-seasonal autoregressive operator, i.e., $\emptyset(B) = 1 - \emptyset_1 B^1 - \emptyset_2 B^2 - \cdots - \emptyset_p B^p$; $\Theta(B)$ is the seasonal moving average operator, i.e., $\Theta(B) = 1 - \Theta_1 B^1 - \Theta_2 B^2 - \cdots - \Theta_Q B^Q$; $\Phi(B)$ is the seasonal autoregressive operator, i.e., $\Phi(B) = 1 - \Phi_1 B^1 - \Phi_2 B^2 - \cdots - \Phi_P B^P$; and W(t) is a white noise time series with mean zero and standard deviation (σ).

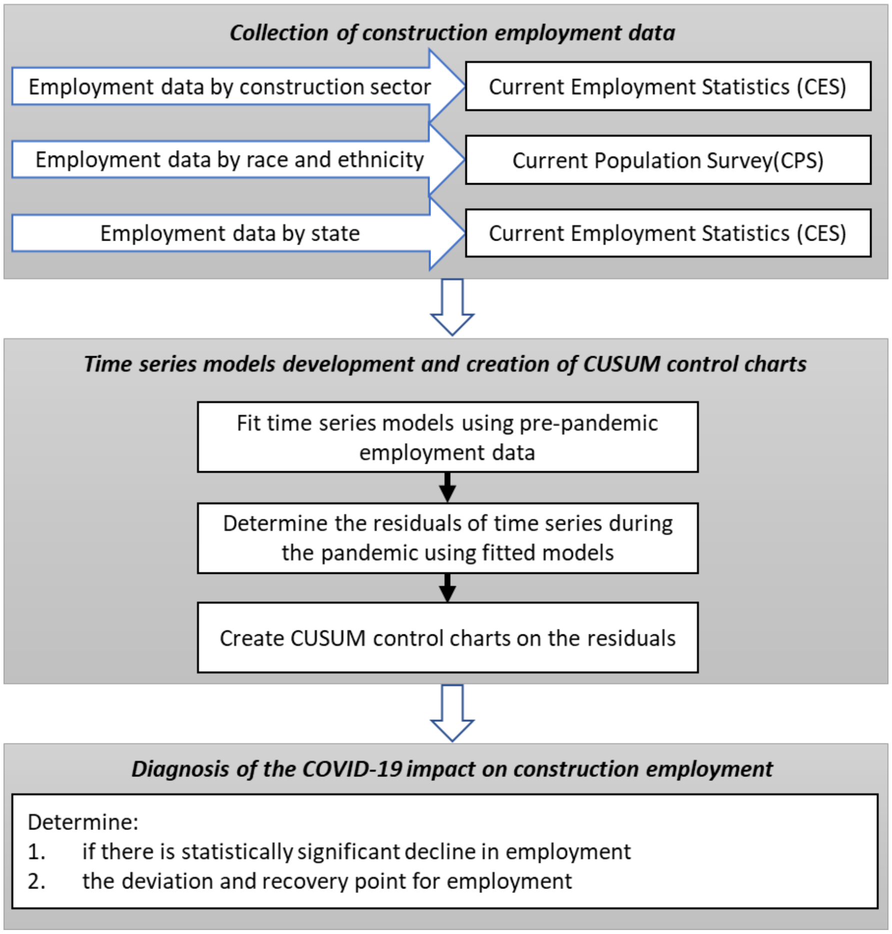

Figure 1. Methodology to analyze the impact of the COVID-19 pandemic on construction employment

Table 1. Categories examined for construction employment analysis

Construction Sector	***Race***	***States***
○ Construction of building ○ Heavy and civil engineering construction ○ Specialty trade contractor *Source: BLS (2021b)*	○ Whites ○ Hispanic and Latino ○ Black or African American ○ Asian *Source: BLS (2021a)*	○ 48 conterminous states, Alaska, and Hawaii *Source: BLS (2021b)*

The order of differencing (d) and the order of seasonal differencing (D) were used in model-fitting to make the data stationary. One differencing, i.e., d=1 and D=1, is commonly sufficient to transform non-stationary data to stationary (Ashuri and Lu 2012). The period of seasonality of the employment data is 12 months, i.e., s=12. The values for parameters p, q, P, and Q in the SARIMA models are selected through the observation of ACF and PACF plots of differenced construction employment data (Watson and Teelusingh 2002). In selecting the parameter values for the time series models, the combination of p, q, P, and Q that yield a lower value of the Akaike information criterion (AIC) was selected over the parameters that led to a higher value of AIC.

After fitting the time series to the employment data, residuals were calculated using Equation 2. The residuals are the difference between actual employment (E_A) during the pandemic and the projected employment (E_P) from the time series models.

$$\hat{Z} = E_A - E_P \qquad \text{Eq. 2}$$

The residuals were used to create CUSUM control charts if the time series models provide a good fit to data and residuals are not serially correlated. The Ljung-Box test was used to check if the residuals are independently distributed (Fisher 2011). If the Ljung-Box test results yield a p-value higher than 0.05, the residuals are independently distributed, and a CUSUM analysis is performed on the residuals. The CUSUM control charts detect if the process is within normal operating conditions (in-control) or has exceeded the normal conditions (out-of-control). The CUSUM accumulates the deviation above the target value in statistics C^+ and the deviation below the target value in statistics C^-. The statistics C^- and C^+ are called one-sided lower CUSUM and upper CUSUM, respectively. The C+ and C^- can be calculated using Equation 3 and Equation 4 (Montgomery 2019).

$$C_i^+ = \max\ [0, x_i - (\mu_0 + K) + C_{i-1}^+] \qquad \text{Eq. (3)}$$

$$C_i^- = \max\ [0, (\mu_0 - K) - x_i + C_{i-1}^+] \qquad \text{Eq. (4)}$$

where C_i^+ is the cumulative deviation of point i above $(\mu_0 + K)$; C_i^- is the cumulative deviation of point i below $(\mu_0 - K)$; μ_0 is the mean employment value.

K is the reference value (or the slack value), which is usually halfway between the target value μ_0 and out of control value μ_1. The process is out-of-control when the cumulative deviation (i.e., either C^+ or C^-)

exceeds the decision interval H. The reasonable value of decision interval (H) is three to five times the process standard deviation (Montgomery 2019; Novoa 2020).

The CUSUM charts were used to detect any deviation of construction employment from the usual condition during the COVID-19 pandemic. The authors used forward process and reverse processes in the CUSUM control charts to determine the deviation and recovery point of employment. The forward process measures the cumulative deviation from the start point to the endpoint to determine the deviation or out-of-control point. The out-of-control point is the place where the cumulative deviation exceeds the upper or lower control point in the CUSUM charts. The reverse process measures the deviation from the endpoint to the start point to determine the recovery point. At the recovery point, the fluctuation in employment is within the normal variation (Mesnil and Petitgas 2009).

Results

Time series models and CUSUM control charts were developed based on the construction employment data collected from BLS by different construction sectors, demographics, and states. The process of fitting a time series model and creating a CUSUM control chart for residential building construction is outlined here. First, the ACF plot (Figure 2) was developed to detect autocorrelation in employment data. The slow decay of ACF values represents the high serial autocorrelation in the construction employment data.

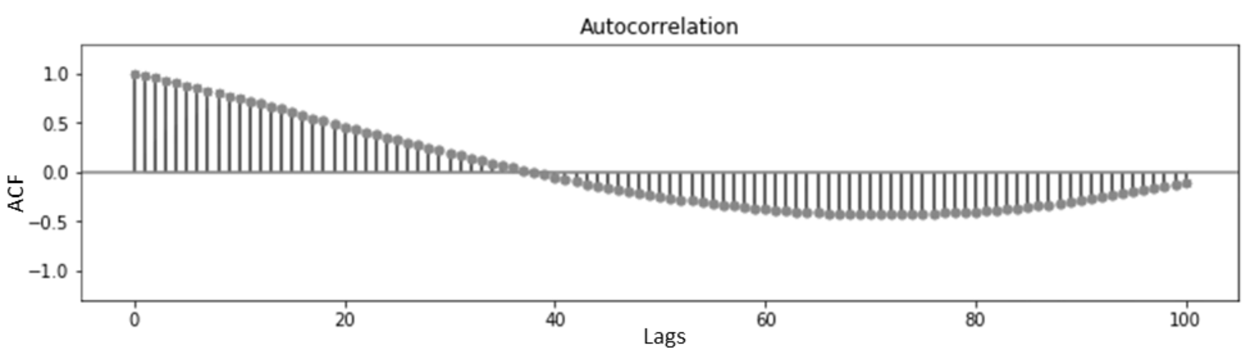

Figure 2. Autocorrelation Function (ACF) plot of employment time series data for the residential building construction sector

The employment data was also checked for stationarity using the ADF test before fitting the appropriate time series model. The ADF result shows that the employment data are non-stationary. Hence, differencing order should be determined before fitting the time series model. Figure 3 and Figure 4 show the residential building construction employment and incremental change in residential building construction employment. From Figures 3 and 4, it is validated that one difference is sufficient to make the data stationary. ACF and PACF plots are developed to determine the seasonality in the time series data. Figure 5 shows ACF and PACF plots for incremental employment data with a significant spike on the 12th lag representing strong seasonality in residential construction employment. Hence, a SARIMA model was fitted to the employment data due to the seasonality and non-stationarity of the time series. The data from January 2011 to December 2019 were used for fitting the time series model. The probable values of p, q, P, and Q were selected based on the ACF and PACF plots (Figure 5). The model with the least AIC value for p, q, P, and Q was used to forecast the projected normal employment from January 2020 to August 2021. A similar approach was used for fitting the time series models for other construction sectors, demographics, and construction employment by state.

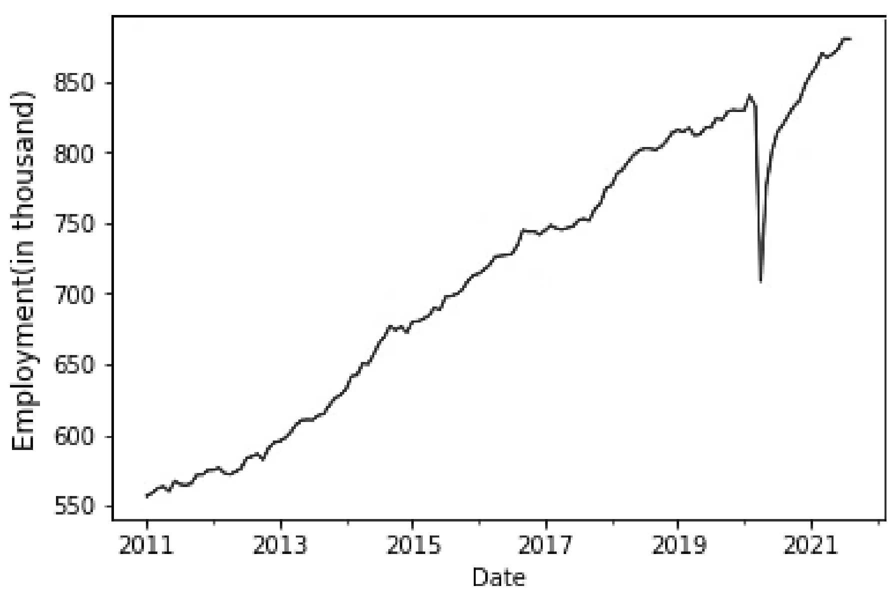

Figure 3. Time series of total employment in residential building construction (Data from Current Employment Statistics (BLS 2021b))

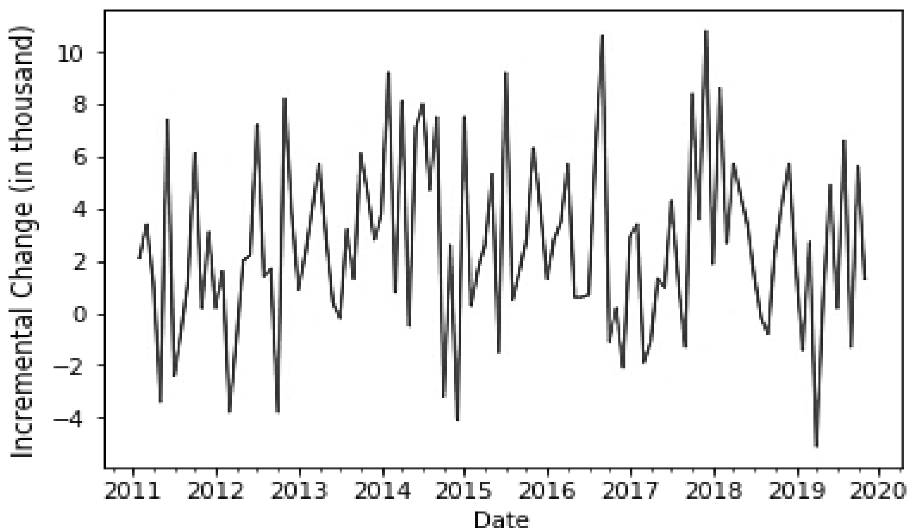

Figure 4. Time series of incremental employment change in residential building construction

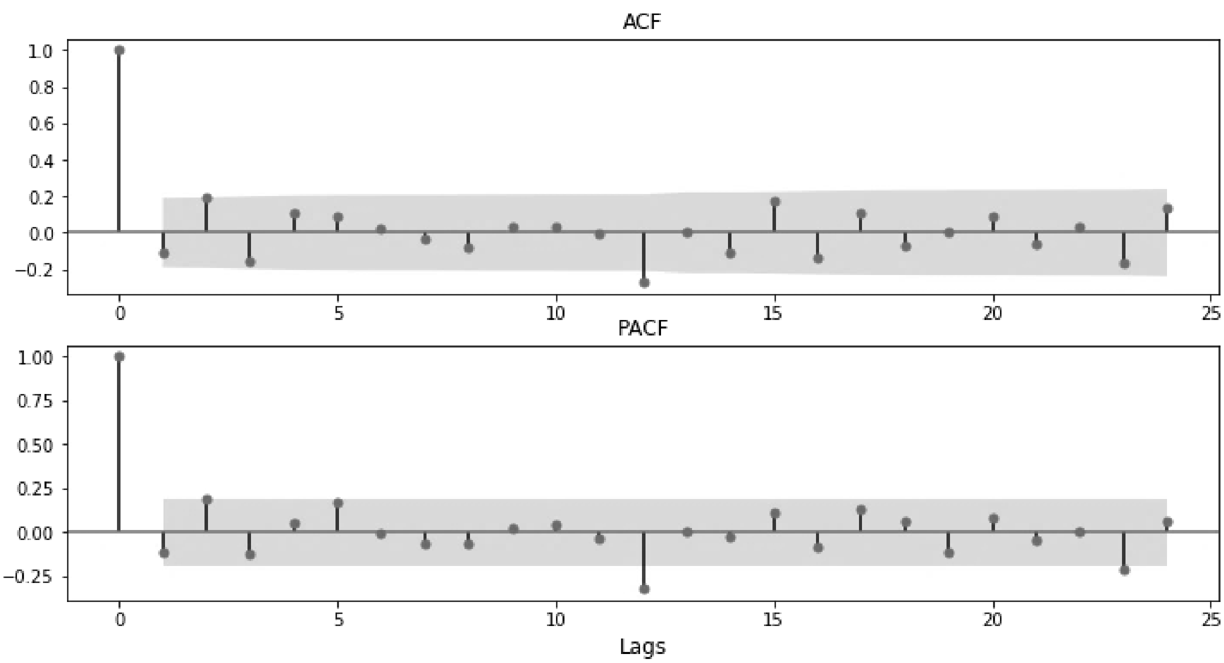

Figure 5. ACF and PACF plots of monthly incremental change in employment of residential building construction

For the forecasted residential building construction employment, the residuals were determined using Equation 2. CUSUM analysis was then performed using the residuals of the time series model. Figures 6 and Figure 7 show the forward process and backward process for determining deviation and recovery points in the employment of residential building construction, respectively. In the forward process, the cumulative deviation from beginning to end is plotted in a CSUSM control chart to determine the deviation point of employment. The out-of-process point in a CUSUM chart is a point where the process deviates from the usual variations. The sectors of construction, the demographic group, and the states that have out-of-control points during the COVID-19 pandemic were identified as having experienced statistically significant declines in employment. Tables 2 to Table 5 show the time series models fitted to the employment data of different construction sectors, demographics, and states. These tables also show the percentage declines in construction employment compared with the projected normal employment in April 2020, when the most job decline occurred at the outset of the COVID-19 pandemic.

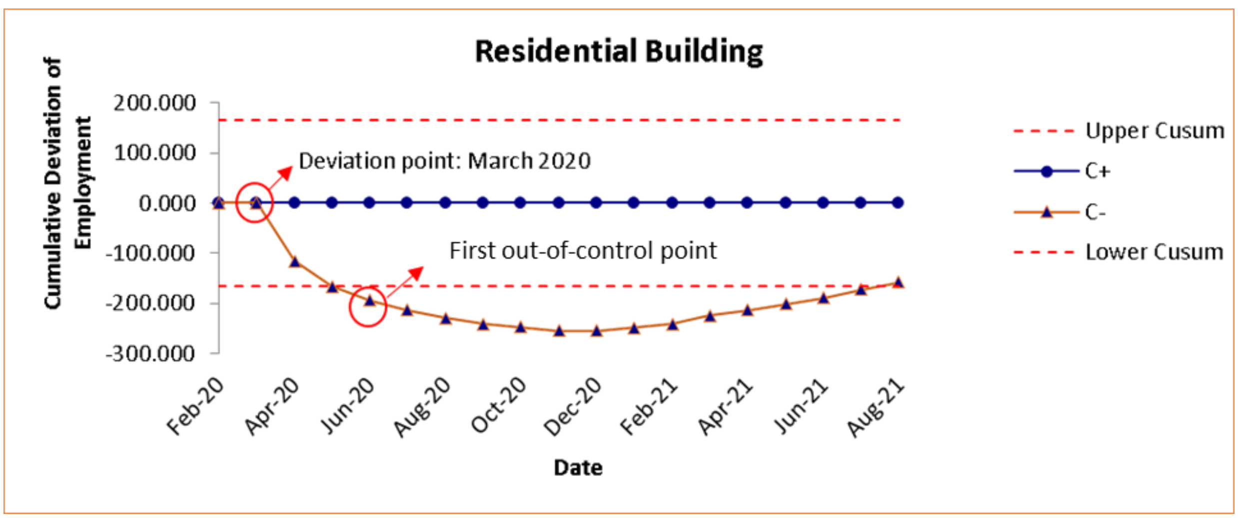

Figure 6. Forward CUSUM process to detect deviation and out-of-control point

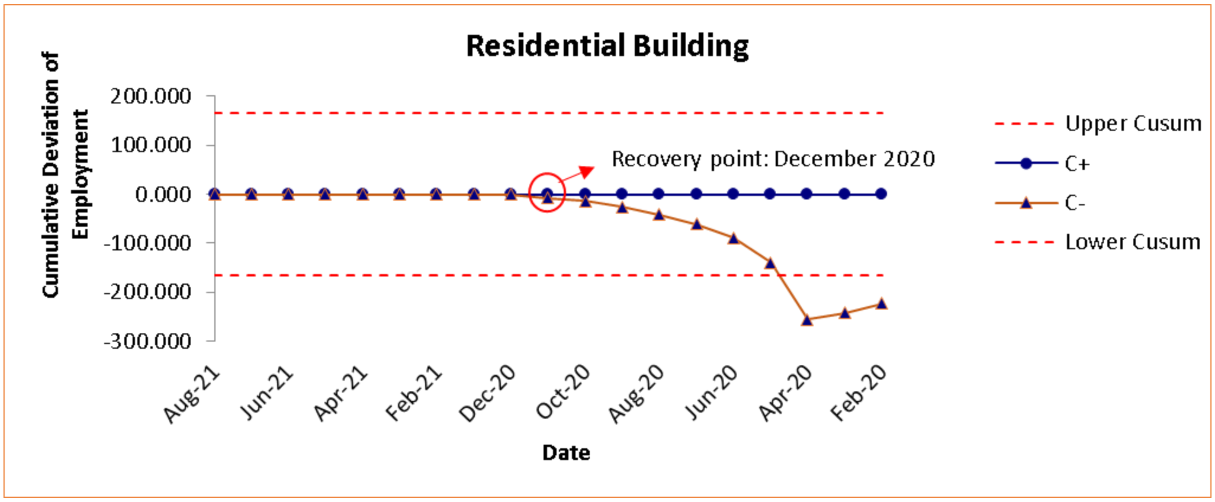

Figure 7. Reverse CUSUM process to detect the recovery point

Table 2 shows the SARIMA models fitted to the employment time series in different construction sectors. The construction industry is divided into three sectors: 1) Construction of buildings, 2) Heavy and civil engineering construction, and 3) Specialty trade contractors. The three construction sectors are further divided into subsectors, as shown in Table 2. CUSUM analysis was performed on the residuals of the time series from January 2020 to August 2021. Construction employment in all the sectors and sub-sectors of the construction industry was out-of-control due to the COVID-19 pandemic. Compared to the projected normal employment, the actual employment was lower by 15 percent in April 2020. Employment in the 'specialty trade contractor' sector had the highest decline (16 percent) in April 2020 followed by the 'construction of buildings' and 'highway and civil engineering construction'. The actual construction employment for different subsectors in April 2020 is also shown in Table 2.

Table 2. Impact on construction employment due to the COVID-19 pandemic based on the result of the CUSUM control charts (overall construction)

Industry	Seasonal ARIMA (p, d, q), (P, D, Q)	AIC	Statistically Significant Change in Employment	Employment in April 2020 (in thousands)	Percentage Decline in April 2020
Construction	(0, 1, 3), (0, 1, 1)	777.48	Major decline	6556	15.05%
Construction of buildings	(1, 1, 1), (1, 1, 1)	569.28	Major decline	1456.7	14.65%
Residential building	(2, 1, 0), (1, 1, 1)	528.86	Major decline	712.8	16.16%
Nonresidential building	(0, 1, 0), (1, 1, 1)	532.78	Major decline	743.9	12.90%
Heavy and civil engineering construction	(1, 1, 1), (0, 1, 1)	639.11	Major decline	992.9	9.25%
Utility System Construction	(0, 1, 3), (0, 1, 1)	543.73	Major decline	508.3	11.60%
Land Subdivision	(1, 1, 0), (0, 0, 1)	164.95	Major decline	34.8	12.79%
Highway, Street, and Bridge Construction	(0, 1, 2), (0, 1, 1)	534.5	Major decline	331.1	8.75%
Other Heavy and Civil Engineering Construction	(2 1, 1), (0, 1, 0)	434.39	Major decline	112.7	8.33%
Specialty trade contractors	(0, 1, 0), (0, 1, 1)	755.35	Major decline	4106.6	16.27%
Building foundation and exterior contractors	(1, 1, 0), (0, 1, 1)	622	Major decline	786.2	18.05%
Building equipment contractors	(0, 1, 0), (0, 1, 1)	597.45	Major decline	2004.5	14.45%
Building finishing contractors	(1, 1, 0), (1, 1, 1)	560.212	Major decline	691.5	19.36%
Other specialty trade contractors	(0, 1, 0), (1, 1, 1)	563.71	Major decline	618.5	14.01%

Source: Data from Current Employment Statistics (BLS 2021b)
Note: Major decline occurs when the value of cumulative deviation in a CUSUM chart exceeds the lower CUSUM threshold

Table 3 shows the SARIMA models fitted to the women's employment data in different construction sectors. The CUSUM analysis performed on the residual of the time series from January 2020 to August 2021 reveals that women's employment in all construction sectors was out-of-control due to the impact of the COVID-19 pandemic (Table 3). Compared to the projected normal employment, the actual women's employment in construction was lower by 12 percent in April 2020. The actual employment for women construction workers in different subsectors in April 2020 is also shown in Table 3.

Table 3. Impact on construction employment due to the COVID-19 pandemic based on the result of the CUSUM control charts (Women Employment)

Industry	Seasonal ARIMA (p, d, q), (P, D, Q)	AIC	Statistically Significant Change in Employment	Employment in April 2020 (in thousands)	Percentage Decline in April 2020
Construction	(2, 1, 1), (1, 1, 1)	457.07	Major decline	887.0	12.19%
Construction of buildings	(2, 1, 2), (0, 1, 0)	370.51	Major decline	281.8	9.43%
Residential building	(0, 1, 0), (1, 1, 1)	320.92	Major decline	163.3	12.67%
Nonresidential building	(1, 1, 1), (0, 1, 1)	250.08	Major decline	117.6	8.72%
Heavy and civil engineering construction	(0, 1, 1), (1, 1, 1)	260.04	Major decline	104.8	9.19%
Utility System Construction	(0, 1, 1), (1, 1, 1)	184.28	Major decline	49.6	8.55%
Land Subdivision	(3, 1, 0), (1, 1, 1)	101.95	Major decline	12.9	8.06%
Highway, Street, and Bridge Construction	(0, 1, 0), (0, 0, 1)	81.20	Major decline	29.6	9.44%
Other Heavy and Civil Engineering Construction	(1, 1, 0), (0, 1, 1)	88.86	Major decline	13.0	4.82%
Specialty trade contractors	(0, 1, 0), (0, 1, 1)	385.97	Major decline	501.5	12.31%
Building foundation and exterior contractors	(0, 1, 0), (1, 1, 1)	244.82	Major decline	77.6	15.38%
Building equipment contractors	(0, 1, 0), (1, 1, 1)	300.10	Major decline	258.2	10.99%
Building finishing contractors	(1, 1, 1), (1, 0, 0)	290.63	Major decline	94.7	16.13%
Other specialty trade contractors	(1, 1, 1), (1, 0, 1)	227.43	Major decline	70.3	12.68%

Source: Data from Current Employment Statistics (BLS 2021b)
Note: Major decline occurs when the value of cumulative deviation in a CUSUM chart exceeds the lower CUSUM threshold

Table 4 shows the SARIMA models fitted to the construction employment by race and ethnicity. The CUSUM analysis performed on the residual of the employment time series from January 2020 to August 2021 reveals that employment was out-of-control for all races during the pandemic (Table 4). There was a disproportionate impact of the COVID-19 on minority construction workers, especially African Americans and Hispanics, at the outset of the COVID-19. The actual construction employment for Blacks or African Americans construction workers was 24 percent lower than the projected normal employment in April 2021. For Hispanic construction workers, the employment decline was 23.37 percent in April 2020 compared to the projected normal employment.

Table 4. COVID-19 impact on construction employment (Race and Ethnicity)

Race	Seasonal ARIMA (p, d, q), (P, D, Q)	AIC	Statistically Significant Change in Employment	Percentage Employment Decline in April 2020
Whites	(1, 1, 1), (1, 1, 1)	1249.03	Major decline	17.22%
Hispanic And Latino	(4, 1, 0), (0, 1, 1)	1157.31	Major decline	23.37%
Black or African American	(1, 1, 1), (1, 1, 1)	1002.57	Major decline	24.45%
Asian	(1, 1, 1), (1, 1, 1)	891.69	Major decline	14.95%

Source: Data from Current Population Survey (BLS 2021a)
Note: Major decline occurs when the value of cumulative deviation in a CUSUM chart exceeds the lower CUSUM threshold

Table 5 shows the SARIMA models fitted to construction employment for 50 states in the US. The CUSUM analysis performed on the residual of state employment from January 2020 to August 2021 reveals that employment in all states was out-of-control after the occurrence of the COVID-19 pandemic. Table 5 also shows the percentage declines in April 2020 based on the projected normal employment and the actual employment for all the states in the US. South Dakota was the only state to add construction jobs in April 2020, when there was a 15 percent job decline in the US construction industry (Table 2). Nonetheless, construction employment in South Dakota declined as the pandemic progressed (Table 9). The lowest employment decline in April 2020 occurred in Utah (2.49%), followed by Nebraska (2.72%), Montana (3.19%), and Virginia (4.7%). The highest employment decline in April 2020 occurred in Michigan (42.27 %), followed by New York (38.61 %), Pennsylvania (38.11%), and Vermont (37.53%).

Table 5. COVID-19 impact on construction employment (States)

State	Seasonal ARIMA	AIC	Statistically Significant Change in Employment	Percentage Employment Decline in April 2020
Alabama	(1, 1, 0), (1, 0, 1)	191.98	Major decline	5.88%
Alaska	(1, 1, 0), (0, 1, 1)	10.21	Major decline	13.58%
Arizona	(1, 1, 0), (0, 1, 1)	191.73	Major decline	4.38%
Arkansas	(3, 1, 1), (0, 1, 1)	165.68	Major decline	4.12%
California	(1, 1, 0), (1, 1, 1)	598.23	Major decline	18.83%
Colorado	(2, 1, 0), (0, 1, 1)	216.9	Major decline	7.41%
Connecticut	(1, 1, 0), (0, 1, 1)	119.56	Major decline	15.75%
Delaware*	(0, 1, 0), (1, 1, 1)	42.99	Major decline	9.91%
Florida	(1, 1, 0), (0, 1, 1)	556.48	Major decline	7.67%
Georgia	(1, 1, 0), (0, 1, 1)	289.03	Major decline	6.30%
Hawaii*	(2, 1, 2), (0, 1, 0)	63.62	Major decline	9.24%
Idaho	(0, 1, 0), (0, 1, 1)	83.88	Major decline	4.82%
Illinois	(0, 1, 0), (1, 1, 1)	383.64	Major decline	13.27%
Indiana	(0, 1, 0), (0, 1, 1)	259.11	Major decline	10.28%
Iowa	(1, 1, 1), (0, 1, 1)	284.63	Major decline	6.20%
Kansas	(1, 1, 1), (0, 1, 0)	244.85	Major decline	7.95%
Kentucky	(0, 1, 0), (1, 0, 1)	192.98	Major decline	7.78%

State	Seasonal ARIMA	AIC	Statistically Significant Change in Employment	Percentage Employment Decline in April 2020
Louisiana	(1, 1, 0), (0, 1, 1)	362.72	Major decline	18.33%
Maine	(0, 1, 0), (0, 1, 1)	5.19	Major decline	7.05%
Maryland*	(1, 1, 1), (1, 0, 1)	222.07	Major decline	10.03%
Massachusetts	(0, 1, 1), (0, 0, 1)	277.13	Major decline	30.06%
Michigan	(1, 1, 1), (1, 1, 1)	369.07	Major decline	40.28%
Minnesota	(1, 1, 0), (0, 1, 1)	387.07	Major decline	9.15%
Mississippi	(1, 1, 0), (0, 0, 1)	140.89	Major decline	8.22%
Missouri	(0, 1, 1), (1, 1, 1)	281.51	Major decline	7.06%
Montana	(0, 1, 0), (2, 1, 0)	89.87	Major decline	3.19%
Nebraska*	(1, 1, 1), (0, 1, 1)	143.39	Major decline	2.72%
Nevada	(2, 1, 1), (0, 1, 1)	206.97	Major decline	8.26%
New Hampshire	(2, 1, 0), (1, 1, 1)	-21.18	Major decline	9.90%
New Jersey	(0, 1, 0), (0, 1, 1)	329.12	Major decline	18.80%
New Mexico	(1, 1, 0), (1, 1, 1)	145.22	Major decline	6.90%
New York	(0, 1, 0), (0, 1, 1)	434.47	Major decline	38.61%
North Carolina	(1, 1, 0), (0, 1, 1)	306.71	Major decline	6.01%
North Dakota	(1, 1, 0), (1, 0, 1)	210.49	Major decline	11.16%
Ohio	(0, 1, 1), (0, 1, 1)	375.33	Major decline	15.90%
Oklahoma	(0, 1, 2), (0, 1, 1)	214.85	Major decline	5.56%
Oregon	(0, 1, 0), (0, 1, 1)	209.07	Major decline	11.40%
Pennsylvania	(0, 1, 0), (0, 1, 1)	402.29	Major decline	38.11%
Rhode Island	(0, 1, 1), (0, 1, 1)	-26.52	Major decline	20.40%
South Carolina	(1, 1, 1), (0, 1, 0)	255.39	Major decline	6.03%
South Dakota*	(1, 1, 1), (1, 1, 0)	100.69	Major decline	-0.66%
Tennessee*	(0, 1, 0), (1, 1, 1)	242.10	Major decline	4.98%
Texas	(0, 1, 0), (1, 1,1)	483.68	Major decline	8.57%
Utah	(1, 1, 1), (1, 1,0)	164.74	Major decline	2.49%
Vermont	(1, 1, 1), (1, 1,0)	-3.31	Major decline	37.53%
Virginia	(0, 1, 0), (1, 1,1)	273.40	Major decline	4.72%
Washington	(1, 1, 1), (0, 1,1)	356.46	Major decline	18.06%
West Virginia	(2, 1, 2), (1, 1,1)	218.85	Major decline	22.05%
Wisconsin	(0, 1, 1), (0, 1,1)	277.69	Major decline	7.69%
Wyoming	(0, 1, 1), (0, 1,1)	124.10	Major decline	9.94%

Source: Data from Current Employment Statistics (BLS 2021b)
Note: Major decline occurs when the value of cumulative deviation in a CUSUM chart exceeds the lower CUSUM threshold
*Employment number is for combined mining, logging, and construction industry

The forward process and the reverse process in CUSUM were used to detect the deviation and recovery points of the construction employment. From the forward CUSUM process, it was observed that deviation for all the sectors and subsectors of the construction industry occurred in March 2020 (Table 6). The reverse CUSUM process reveals two subsectors, i.e., 'residential building' and 'other heavy and civil engineering construction', recovered lost jobs in December and October 2020, respectively. The 'residential building' subsector includes builders, general contractors, construction management firms, and design firms involved in residential housing construction (Industrius CFO, 2021). The 'Other and heavy civil engineering construction' subsector includes projects associated with open space improvement (e.g., trails and parks), water resources (e.g., drainage and dredging), and the development of marine facilities (Industrius CFO, 2021). All other subsectors of construction have not recovered employment by August 2021.

Table 6. Calculation of recovery period (overall construction)

Industry	Deviation point for construction employment	Recovery point for construction employment	Recovery period (Months)
Construction	March 2020	Not Recovered by August 2021	_
Construction of buildings	March 2020	Not Recovered by August 2021	_
Residential building	March 2020	December 2020	9
Nonresidential building	March 2020	Not Recovered by August 2021	_
Heavy and civil engineering construction	March 2020	Not Recovered by August 2021	_
Utility System Construction	March 2020	Not Recovered by August 2021	_
Land Subdivision	March 2020	Not Recovered by August 2021	_
Highway, Street, and Bridge Construction	March 2020	Not Recovered by August 2021	_
Other Heavy and Civil Engineering Construction	March 2020	November 2020	7
Specialty trade contractors	March 2020	Not Recovered by August 2021	_
Building foundation and exterior contractors	March 2020	Not Recovered by August 2021	_
Building equipment contractors	March 2020	Not Recovered by August 2021	_
Building finishing contractors	March 2020	Not Recovered by August 2021	_
Other specialty trade contractors	March 2020	Not Recovered by August 2021	_

Table 7 shows the results of the forward and reverse CUSUM processes on women's construction employment. Women's employment in the construction industry is recovering quickly compared to overall construction employment in the US. The deviation from normal construction employment for women workers took place in March 2020. Two sectors of construction, ‘construction of building’ and ‘specialty trade contractors’, have recovered women's construction employment by March 2021 and December 2020, respectively. However, the total women's employment in construction has not been fully recovered by August 2021.

Table 7. Calculation of recovery period (Women employment)

Industry	Deviation point for construction employment	Recovery point for construction employment	Recovery period (Months)
Construction	March 2020	Not recovered by August 2021	
Construction of buildings	March 2020	March 2021	13
Residential building	March 2020	March 2021	13
Nonresidential building	March 2020	Not recovered by August 2021	_
Heavy and civil engineering construction	March 2020	Not recovered by August 2021	_
Utility System Construction	March 2020	Not recovered by August 2021	_
Land Subdivision	March 2020	April 2021	14
Highway, Street, and Bridge Construction	March 2020	November 2020	8
Other Heavy and Civil Engineering Construction	March 2020	Not recovered by August 2021	
Specialty trade contractors	March 2020	December 2020	9
Building foundation and exterior contractors	March 2020	June 2021	17
Building equipment contractors	March 2020	October 2020	7
Building finishing contractors	March 2020	December 2020	9
Other specialty trade contractors	March 2020	June 2020	3

Table 8 shows the results of the forward and reverse CUSUM processes on construction employment by race and ethnicity. The employment deviation from normal conditions occurred in March 2020 for Whites, Hispanics, and Asians. For Blacks or African Americans, the deviation point is February 2020, a month earlier than the construction workers of other races. Hispanics and Asians have recovered lost jobs by October 2020, whereas employment for Whites and Blacks (or African Americans) has not recovered by August 2021.

Table 8. Calculation of recovery period (Race and Ethnicity)

Industry	Deviation point for construction employment	Recovery point for construction employment	Recovery period (Months)
Whites	March 2020	Not recovered by August 2021	_
Hispanic And Latino	March 2020	October 2020	7
Black or African American	February 2020	Not recovered by August 2021	_
Asian	March 2020	October 2020	7

Table 9 shows the results of the forward and reverse CUSUM processes on construction employment for 50 states in the US. The employment deviation from normal conditions occurred in March 2020 for all the states but Hawaii, Montana, South Dakota, and Utah. Employment deviation from normal process occurred in February 2020 in Hawaii and Utah, in August 2020 in South Dakota, and in April 2021 in Montana. Fourteen states have recovered the construction jobs that declined due to the sudden impact of the COVID-19 (Figure 8). These states are Alaska, Delaware, Hawaii, Idaho, Kansas, Kentucky, Massachusetts, Michigan, Mississippi, Rodhe Island, South Carolina, South Dakota, Utah, and Vermont. These findings are consistent with the recent study by AGC (2020b) that suggests the 14 states added jobs in construction from the pre-pandemic level in February 2020. Table 9 also shows the recovery periods for construction employment for the US states that have recovered the lost employment.

Table 9. Calculation of recovery period (State Construction employment)

Industry	Deviation point for construction employment	Recovery point for construction employment	Months to recovery
Alabama	March 2020	Not Recovered by August 2021	-
Alaska	March 2020	November 2020	8
Arizona	March 2020	Not Recovered by August 2021	-
Arkansas	March 2020	Not Recovered by August 2021	-
California	March 2020	Not Recovered by August 2021	-
Colorado	March 2020	Not Recovered by August 2021	-
Connecticut	March 2020	Not Recovered by August 2021	-
Delaware*	March 2020	March 2021	12
Florida	March 2020	Not Recovered by August 2021	-
Georgia	March 2020	Not Recovered by August 2021	-
Hawaii*	February 2020	May 2021	15
Idaho	March 2020	December 2021	9
Illinois	March 2020	Not Recovered by August 2021	-
Indiana	March 2020	Not Recovered by August 2021	-
Iowa	March 2020	Not Recovered by August 2021	-
Kansas	March 2020	March 2021	12
Kentucky	March 2020	April 2021	13

Industry	Deviation point for construction employment	Recovery point for construction employment	Months to recovery
Louisiana	March 2020	Not Recovered by August 2021	-
Maine	March 2020	Not Recovered by August 2021	-
Maryland*	March 2020	Not Recovered by August 2021	-
Massachusetts	March 2020	November 2020	8
Michigan	March 2020	August 2020	5
Minnesota	March 2020	Not Recovered by August 2021	-
Mississippi	March 2020	October 2020	7
Missouri	March 2020	Not Recovered by August 2021	-
Montana	April 2021	Not Recovered by August 2021	-
Nebraska*	March 2020	Not Recovered by August 2021	-
Nevada	March 2020	Not Recovered by August 2021	-
New Hampshire	March 2020	Not Recovered by August 2021	-
New Jersey	March 2020	Not Recovered by August 2021	-
New Mexico	March 2020	Not Recovered by August 2021	-
New York	March 2020	Not Recovered by August 2021	-
North Carolina	March 2020	Not Recovered by August 2021	-
North Dakota	March 2020	Not Recovered by August 2021	-
Ohio	March 2020	Not Recovered by August 2021	-
Oklahoma	March 2020	Not Recovered by August 2021	-
Oregon	March 2020	Not Recovered by August 2021	-
Pennsylvania	March 2020	Not Recovered by August 2021	-
Rhode Island	March 2020	February 2021	11
South Carolina	March 2020	March 2021	12
South Dakota*	August 2020	March 2021	7
Tennessee*	March 2020	Not Recovered by August 2021	-
Texas	March 2020	Not Recovered by August 2021	-
Utah	February 2020	November 2020	9
Vermont	March 2020	December 2020	9
Virginia	March 2020	Not Recovered by August 2021	-
Washington	March 2020	Not Recovered by August 2021	-
West Virginia	March 2020	Not Recovered by August 2021	-
Wisconsin	March 2020	Not Recovered by August 2021	-
Wyoming	March 2020	Not Recovered by August 2021	-

*Employment number is for combined mining, logging, and construction industry

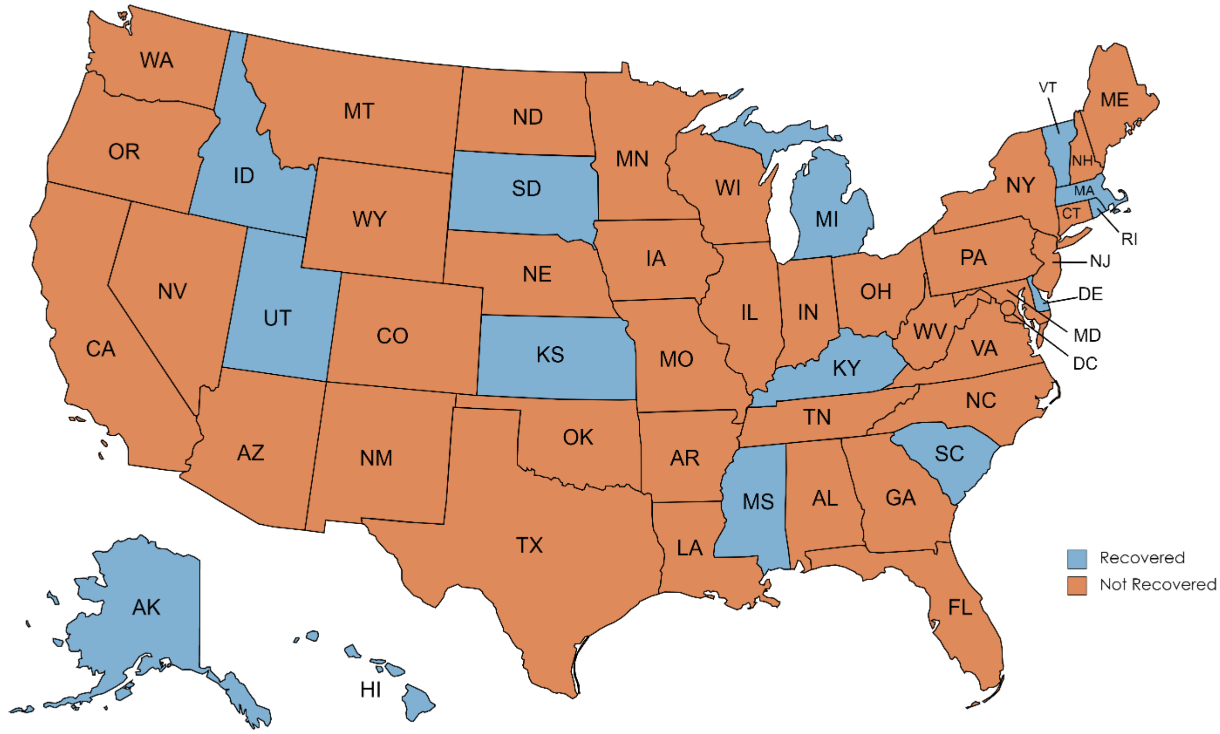

Figure 8. Status of construction employment recovery by state as of August 2021

Discussion

The COVID-19 pandemic generated a sudden and severe impact on construction employment in April 2020. Interventions from the federal government in the form of the Paycheck Protection Program (PPP) (CARES Act, 2021) helped the construction industries to immediately add jobs after a sudden loss of one million jobs during the initial stage of the COVID-19 pandemic (Hilburg 2020). Despite federal and state support, all three construction sectors (construction of buildings, heavy and civil engineering construction, and specialty trade contractors) in the United States suffered statistically significant declines in employment during the COVID-19 pandemic (Table 2). The residential building, a subsector of building construction, has recovered the jobs that were lost at the outset of the pandemic. The residential building subsector had a nearly 15 percent decline in employment in April 2020 compared to March 2020 (Brown, 2020). The employment recovery in residential building construction is due to a strong surge in housing demand in 2021 (Bhaney 2021; Sorrentino 2021). However, nonresidential construction has yet to recover the lost construction jobs. In April 2020, employment in nonresidential construction was 3 points lower than the residential building construction (Table 2). The nonresidential construction sector is affected due to decreasing demand for projects related to public infrastructures (Buckshon 2021). The rising cost of key materials and disruption in the supply chain is further slowing the employment gains for the nonresidential construction sector. The 'specialty trade contractors' sector, which experienced a decline of 706,000 jobs in April 2020 compared to March 2020 (Brown 2020), has yet to recover the lost construction jobs. Although the construction jobs will take years to recover in normal conditions, the recent Infrastructure Investment and Jobs Act (2021), with the commitment to spend more than $1 trillion on roads, bridges, water infrastructure, power grids, and other infrastructures, is expected to significantly increase the construction jobs, helping to overcome the setbacks of the COVID-19 pandemic.

Nearly 12 percent of the women workforce lost jobs in April 2020 compared to 15 percent for the overall construction workforce (Table 2 and Table 3). Women's employment in the construction industry is recovering quickly compared to the overall US construction employment (Table 6 and Table 7). The women workforce in two construction sectors, 'construction of buildings' and 'specialty trade contractors', have recovered the construction jobs by March 2021 and December 2020, respectively. Although women represent only 10 percent of the workforce in the construction industry, the recovery of women's jobs in the construction industry is greater than in any other industry (Zhavoronkova and Khattar, 2021). Moreover, the shortage of skilled labor and the high demand for construction workers to rebuild the crumbling US infrastructure (Yurkevich 2021) can provide women with an unparalleled opportunity to increase their proportion in the construction industry (Shrestha et al. 2020; Smith 2021).

The Hispanic construction workers and Asian construction workers recovered construction jobs sooner than White construction workers (Table 8). Hispanics had a 19.8 percent decline in construction employment from April 2020 compared to March 2020, while employment decline was 14.1 percent for White construction workers (Brown 2020). Nevertheless, Hispanic construction workers have recovered the jobs lost by August 2021, but White construction workers and Black or African construction workers have yet to recover from the job decline during the COVID-19 pandemic. The Black or African Americans might be lagging in employment recovery due to the low rate of employment recovery in low-paying jobs (Bateman and Ross 2021), which enroll most minorities construction workers (Baral et al. 2022). Policy-level interventions are essential to support the recovery of construction employment among the Black or African American workers, who only represented 6 percent of the construction workforce before the COVID-19 pandemic (Adolphus 2020). It is worth noting that despite Hispanics also occupying a sizeable portion of low-paying jobs, the negative effects on workforce recovery have been more than offset by the huge increase of new Hispanic workers. According to Dubina (2021), Hispanics are projected to account for 78% of net new workers between 2020 and 2030, based on the data from the U.S. Department of Labor. The diversity and inclusion goals, which have been long desired in the construction industry, are likely to be hurt if policy-level interventions are not directed to promote minority construction workers who are significantly impacted by the pandemic.

Construction jobs have recovered in fourteen states (Table 9). These states are Alaska, Delaware, Hawaii, Idaho, Kansas, Kentucky, Massachusetts, Michigan, Mississippi, Rhode Island, South Carolina, South Dakota, Utah, and Vermont (Figure 8). The most significant percentage gain in construction employment from February 2020 to August 2021 was observed in South Dakota (7.1%), Idaho (6.7%), and Utah (6.5%) (USGNN, 2021). Thirty-six states have not recovered jobs that were lost due to the sudden impact of the COVID-19 (Figure 8). Texas shed the most construction jobs between February 2020 to August 2021. Texas had 48,000 less construction employment in August 2021 compared to February 2020 (USGNN, 2021). New York and California shed 47,300 and 32,600 construction jobs during the same period (USGNN, 2021). Certain states, including New York, New Jersey, and Pennsylvania, implemented widespread closures of construction projects, with limited exceptions for emergency repairs and construction related to healthcare facilities (Berenato et al. 2020; Dunn 2023). These abrupt shutdowns resulted in a significant wave of layoffs in the construction industry during the early stages of the pandemic. The reopening of construction activities in these states took place gradually, with strict operational restrictions in place. This cautious approach contributed to a slow recovery in construction employment (Dunn, 2023). The decline of employment can be attributed to various factors, including material price and supply shortages, suspension of ongoing projects, permit and inspection delays, cost escalation, varying state policies regarding the essentiality of construction operations, anticipated rise in dispute and litigation, safety concerns among workers (McLoud 2021; Bou et al. 2021; Liang et al. 2022). These multifaceted challenges have collectively contributed to the downturn in employment across different construction sectors. The recovery of construction jobs in states will most likely depend on the state's population growth, housing affordability, housing demand, the state's resiliency, and the capacity of state transportation agencies to fund transportation projects (Pain et al. 2020; Black 2020). For instance, South Dakota had the fourth-highest influx of people moving into the state of all 50 states in 2020, which contributed to a very high demand for housing and further led to a notable rebound in the construction sector (Chinander 2021). The $10 billion aid approved by Congress to the state DOTs as a year-end legislative package in December 2020 will enhance the DOTs' capacity to fund the construction project in the upcoming years (Franks 2020). The recently approved Infrastructure Investment and Jobs Act (2021) can further increase the construction activities in states, significantly increasing the number of jobs in individual states' construction industry.

The findings from this research hold significant implications in various facets. Specifically, the research underscores the need for customized strategies in response to sectoral variations within the construction industry, encompassing residential, commercial, and infrastructure sectors, in order to optimize employment recovery efforts. Additionally, it underscores the necessity of regional economic planning, especially in areas impacted by the pandemic, to foster fair economic growth and alleviate regional disparities. Furthermore, the study unveils a notably greater impact of COVID-19 on construction workers of Black and African American heritage, emphasizing the pressing requirement for prioritized and tailored approaches to expedite the recovery of lost construction jobs within this demographic group. In summary, these insights make substantial contributions to the broader discourse on pandemic-induced effects on construction employment and advocate for adaptable solutions to address the complex challenges confronting the construction sector.

This study enhances the theoretical framework by introducing a methodological approach that measures the impact of unforeseen disruptions, such as the COVID-19 pandemic, on employment by fusion of time series models with control charts. The study also addresses a theoretical gap by acknowledging that existing methods often fail to differentiate between employment declines caused by disasters and those associated with normal trends and seasonal patterns. By using the integration of time series analysis and a control chart, the study seeks to provide a more accurate understanding of the pandemic's impact on construction employment. The research contributes to practical applications by offering insights that can guide decision-makers in the construction industry. By analyzing employment declines and recovery timelines across various construction sectors, demographics, and geographic regions, this study provides valuable information for formulating more inclusive, equitable, and informed long-term plans. This study aids in identifying vulnerable groups within the construction industry, allowing for tailored recovery strategies to be devised not only for the current pandemic but also for future unforeseen crises.

Conclusion

This paper explores the impacts of the COVID-19 pandemic on construction employment in terms of decline and recovery with consideration of different construction sectors, demographics, and geographic regions. An approach based on SARIMA and CUSUM analysis was used to determine if there was a significant deviation in construction employment from the projected normal conditions. Forward and reverse processes in CUSUM were used to detect the deviation and recovery points of the construction employment. There was a statistically significant decline in construction employment due to the COVID-19 in all sectors of the construction industry. The residential building subsector has recovered quickly compared to other construction subsectors, such as nonresidential, highway, and utility constructions. Employment recovery among women construction workers is more rapid compared to the overall construction workforce. As of August 2021, women's employment has recovered in two sectors: a) construction of buildings and b) specialty trade contractors. Hispanic construction workers who experienced a decline of 23 percent in April 2020 have recovered employment by October 2020. Black or African American construction workers and White construction workers have yet to recoup from the employment decline prompted by the COVID-19 pandemic. Fourteen US states have recovered the lost construction jobs by August 2021, while 36 states have yet to recover the declined employment. This paper contributes to the state of practice by proposing an objective and quantitative method to identify the time points of employment decline and the time points of recovery. The policy-level intervention focused on different construction sectors, demographics, and geographic regions should be considered by policymakers to facilitate the recovery among the groups that are experiencing disproportionate impacts of the COVID-19 pandemic.

This study primarily focuses on the immediate and short-term effects of COVID-19 on construction employment and its recovery. Future research opportunities lie in examining the long-term consequences of the pandemic and evaluating the effectiveness of policy interventions in expediting the industry's recuperation from its impact. The Seasonal ARIMA models and CUSUM control charts used in this study to analyze construction employment assume certain characteristics of the data and stability in trends of construction employment. Future studies should investigate alternative modeling techniques that are less reliant on these assumptions to improve the accuracy of analyses related to construction employment trends.

Data Availability Statement

All data, models, or codes used during the study are available from the author upon reasonable request.

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