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Leveraging Social Media Data to Understand COVID-19 Prevention Measures in Construction: A Machine Learning Approach

Emmanuel B. Boateng [1,*], Daniel Oteng [2], Dan N. O. Bonsu [3] and Vinod Gopaldasani [1]

[1] School of Social Sciences, University of Wollongong, Wollongong, NSW 2500, Australia; vinodkum@uow.edu.au
[2] School of Architecture and Civil Engineering, The University of Adelaide, Adelaide, SA 5005, Australia; daniel.oteng@adelaide.edu.au
[3] Chemistry and Forensic Sciences, Griffith University, Nathan, QLD 4111, Australia; d.bonsu@griffith.edu.au
* Correspondence: eboateng@uow.edu.au

Abstract

The COVID-19 pandemic was a particularly challenging time for the construction industry as it experienced significant disruptions to operations, affecting various stakeholders. With various national and international health agencies promoting preventive measures, the construction industry struggled with the implementation of these measures due to the unique nature of the work involved in construction. This study aimed to highlight the ways in which stakeholders in the construction industry interacted and responded to the prescribed preventive measures through social media analysis. Using model-based clustering and structural topic modelling, this study provided insights into the prevalent discussion topics in social media around prevention measures in construction. In addition, sentiment analysis demonstrated interesting polarisation around the topic areas. Four prevalent topics that encapsulated the entirety of the social media data were identified, with two of the topics showing an upward trend, as expected, while the other two topics showed a contrasting downward trend. These findings offer practical value for construction managers and policymakers by revealing the effectiveness of different communication strategies and identifying areas where prevention measures faced resistance or acceptance. The sentiment polarisation patterns (50% positive, 40% negative) provide actionable insights for developing more targeted engagement approaches, while the topic evolution trends inform the timing and focus of safety communications. Construction organisations can leverage these insights to improve workplace safety protocols and enhance stakeholder buy-in for future health initiatives. This study lays the foundation for future studies to investigate the connections between the prevalent prevention and the interrelated dynamics within the conversation regarding COVID-19 prevention strategies in the construction sector.

Keywords: coronavirus; social media; construction industry; machine learning; topic modelling

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Academic Editor: Antonio Caggiano

Received: 13 May 2025
Revised: 13 June 2025
Accepted: 20 June 2025
Published: 23 June 2025

Citation: Boateng, E.B.; Oteng, D.; Bonsu, D.N.O.; Gopaldasani, V. Leveraging Social Media Data to Understand COVID-19 Prevention Measures in Construction: A Machine Learning Approach. *Buildings* **2025**, *15*, 2191. https://doi.org/10.3390/buildings15132191

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1. Introduction

A public health emergency declaration was issued due to the rapid spread and transmission of the COVID-19 virus between humans on 8 February 2020. There was a reported death of 14,443 among 323,081 confirmed cases in 179 countries as of 23 March 2020 [1].

Consequently, the death toll reached over 5 million on 20 November 2021 [2]. This contributed to several countries introducing strict measures such as quarantine requirements, social distancing protocols, travel restrictions, orders to stay at home, and others, to help curb the transmission of the virus. This resulted in many businesses and industries being disrupted, with several others being forced to halt operations [3,4].

The construction industry, like other workplaces, also experienced hardships and significant disruptions in its operation during this period. For example, a survey conducted in the United States revealed that the pandemic caused projects to be delayed and some halted, which was reported by 28% of the respondents from the results of [5,6]. There were other disruptions around the world, including the shortage of workers owing to strict quarantine rules and the interruption to the construction supply chain [7,8]. Other reported disruptions are attributed to project suspensions [9], delay of payments, [10], delay of projects [9], challenges with health and safety on site [11], and contractual and legal complications [12].

There are related essential activities provided by the construction industry in the fight against COVID-19. Activities such as maintenance, emergency retrofitting to makeshift hospitals using existing buildings, modular components logistics and supply, emergency construction, facilities services and material logistics provided and added value during this period. Moreover, for frontline healthcare workers to improve productivity, efficient infrastructure was provided by construction workers. An example is the retrofitting of temporary buildings into hospitals to cater for the active cases and reinfection of patients in Korea during the 2015 MERS outbreak [13]. To ensure effective delivery, construction workers needed to adhere to strict compliance during operations and revisit occupational health and safety measures to enforce safety measures on COVID-19 and minimise viral infection risks during construction [1].

In the past, we have seen several pandemics and viruses, such as severe acute respiratory syndrome (SARS), Middle East respiratory syndrome coronavirus (MERS-CoV), and Ebola. Accordingly, noticeable efforts have gone into dealing with pandemics by medical doctors and researchers before COVID-19, which is admirable as this was not the first global pandemic [14]. Nonetheless, the contribution of computer technologies and science to decision making in medical situations has proved exponentially beneficial to solving infectious outbreaks and diseases in this current era of technology [15] and artificial intelligence. This is made possible with historical data, some acquired through social media platforms, that aids in generating better decisions and conclusions through sentiment analysis and opinion mining.

Artificial intelligence and machine learning provide incredible opportunities in the fight against infectious outbreaks and diseases. Significantly, these play a remarkable role in analysing public sentiment using social media data. According to Singh et al. [16], considering social media data could have controlled many pandemics and outbreaks. Consequently, it is important to study pandemics such as COVID-19 using sentiment analysis based on the latest outcomes [17]. The purpose of this research is to gather useful data from internet sources to improve our comprehension of the ways in which workers and professionals in the construction industry interacted with COVID-19 prevention strategies.

2. Literature

The management of the COVID-19 pandemic by companies was firmly recommended by public health experts, stating the need to provide health surveillance, care, screening, and training to employees [18], and containment measures that were introduced. The literature explores the construction industry within the pandemic era and the measures that were introduced and adhered to during construction operations.

2.1. COVID-19 and the Construction Industry

The construction industry is one of the economic pillars in many countries and contributes to the development and growth of these countries [19]. It accounts for 7–10% of the total gross domestic product (GDP) and around 1.7 trillion in many worldwide economies [20,21]. This meant that, a disruption in the construction sector would have a detrimental impact on the economy. Because of this, many construction sites resumed activities during the pandemic but had to follow the World Health Organisation [2], which had formulated safety guidelines including the wearing of masks, social distancing, and other hygienic and health guidelines. To address workforce limitations during the pandemic, some studies explored innovative workforce management strategies. Araya [22] used agent-based modelling to demonstrate that employing multiskilled construction workers could reduce workforce deficits by approximately 50% during COVID-19, from 33.4% to 16.7%, providing construction managers with greater flexibility in workforce planning and project continuity.

2.2. COVID-19 Health and Safety Measures

A country's rate of response and containment measures are critical to the survival of its population when it faces periodic diseases (epidemics, pandemics), and the effects are detrimental [23], cause extensive panic [24], and widely affect their emotions [25]. It is therefore imperative to design measures to address these challenges. Some of the approaches used to mitigate these diseases are discussed and addressed in the literature.

According to Wong et al. [26], in the past, governments have often adopted containment measures such as isolation during pandemics, which is evidently not a new strategy or measure for curbing pandemics. An example is the enforcement of school-age people to self-isolate in their homes during the Swine Flu Pandemic back in 2009, which was mostly affecting school-age and young people. Similarly, there was the isolation of suspected MERS patients at hospitals during its outbreak [1].

During COVID-19, health and safety measures were important in areas around the construction site and employers ensured communal areas were safe. Companies also made sure that working at home was also safe for employees through self-assessment forms that were sent to them [27]. Other mitigation measures including health and safety were suggested [28]. A study by Uddin, Albert, Tamanna and Alsharef [4] highlighted the adoption of health and safety measures like educational banners and signage, isolating infected people in tents, thermal camera use, disinfection, and stations for hand sanitation. Again, the implementation of safety performance and guidelines on construction sites was one of the measures that was rated high considering health and safety [29].

Compliance of construction companies with the rules and regulations set out by government went a long way to curb the spread of the virus. An example was the thorough sanitation of all restrooms, changing rooms, rest, and work areas at the site. This in addition to the proper sanitation of all surfaces and workplaces, which was fundamental in averting and controlling the risks and infections through hygienic environments [30]. Moreover, most companies hired compliance officers for COVID-19 to teach and train workers [31].

Awareness was vital in many companies in the fight against the virus. COVID-19 officers were appointed to educate employees through training sessions, toolbox talks and inductions. They also used videos to inform workers, with some having voice-overs captured in several languages to make it easier for them to understand. Some of the information included minimising contact through job re-organisation, personal protective equipment usage, safety practices staff training, regular workplace sanitation, and social

distancing [30,31]. The employees' safety regulations and awareness significantly improved through the education and training.

The advent of COVID-19 vaccination became a solution for many construction companies. Many companies therefore encouraged their workers to get vaccinated so work could continue normally. The vaccine aided in minimising the severity of hospitalisation and infections with a significant reduction in the risk of infections. To promote workplace safety, many employees got vaccinated, which prevented the spread of the virus in most cases [32].

Despite the substantial body of research on COVID-19′s impact on the construction industry, significant knowledge gaps remain that limit our understanding of stakeholder responses to prevention measures. While previous studies have documented the implementation challenges and operational disruptions caused by the pandemic [4,28,29], there is limited research examining how construction stakeholders actually perceived, discussed, and responded to these prevention measures through their own communications. Most of the existing literature relies on surveys, interviews, or case studies that capture structured responses at specific points in time, potentially missing the dynamic, unfiltered perspectives that emerge through social media discourse. Furthermore, few studies have employed advanced machine learning techniques to systematically analyse large-scale textual data from construction industry stakeholders, leaving a gap in understanding the temporal evolution of attitudes toward prevention measures. The lack of comprehensive sentiment analysis and topic modelling approaches in construction health and safety research means that the polarisation of opinions and the underlying reasons for resistance or acceptance of prevention measures remain poorly understood. Additionally, while studies have identified various prevention measures and their implementation challenges, there is insufficient knowledge about which measures generated the most discussion, concern, or support among industry stakeholders over time. These gaps highlight the need for innovative methodological approaches that can capture and analyse authentic stakeholder voices to inform more effective communication strategies and policy development for future health crises in the construction sector.

3. Data and Methodology

This study used a sizeable free text of unstructured data that was compiled of various viewpoints on COVID-19 prevention measures in the building industry from YouTube, Reddit and X. Due to the vast online community features, rapid interaction, and appeal to the workforce, these three large social media sites were acceptable for our study. The idea that social media might play a significant role as a vehicle for dialogue between authorities and individuals is becoming more widespread despite the risks and limitations [33]. Social media sites have been crucial for spreading news about COVID-19 outbreak [34]. And as such, these have been used by health care organisations such as the World Health Organisation and the Centres for Disease Control and Prevention (CDC) to post guidelines and inform the people about mitigative and preventative measures of tackling the coronavirus.

X is widely used for public health debates [35]. Its suitability for analysing occurrences during the influenza pandemic planning operations verified it as a channel for the exchange of news and information about public health events [36]. Moreover, X has established itself as a useful tool for crisis communication [37]. Reddit has also been used to monitor conversations about public health issues. For instance, Low et al. [38] used Reddit data to reveal vulnerable mental health groups and heightened health anxiety during the COVID-19 pandemic. Bunting et al. [39] employed Reddit to analyse how COVID-19 affected social networks and social interactions of opioid users. Lee et al. [40] also assessed how foster families fared in the COVID-19 pandemic using Reddit data.

YouTube is known to be a source of public health education. It is the second most frequently used video search engine and visited website [41]. This could be due to its video-sharing capacity to visually present information such as on hypertension, COVID-19, Ebola and Zika virus outbreaks, awareness, and vaccination developments [42–44]. Particularly, YouTube has been a source of relevant information regarding the COVID-19 pandemic in the building industry [4].

The number of users on X, YouTube, and Reddit who are active every day is 237 million [45], 122 million [46], and 52 million [47], respectively. As a result, this study's findings on the perception of COVID-19 prevention efforts around the world will be insightful. Figure 1 shows the systematic process of conducting this study from data extraction to topic modelling.

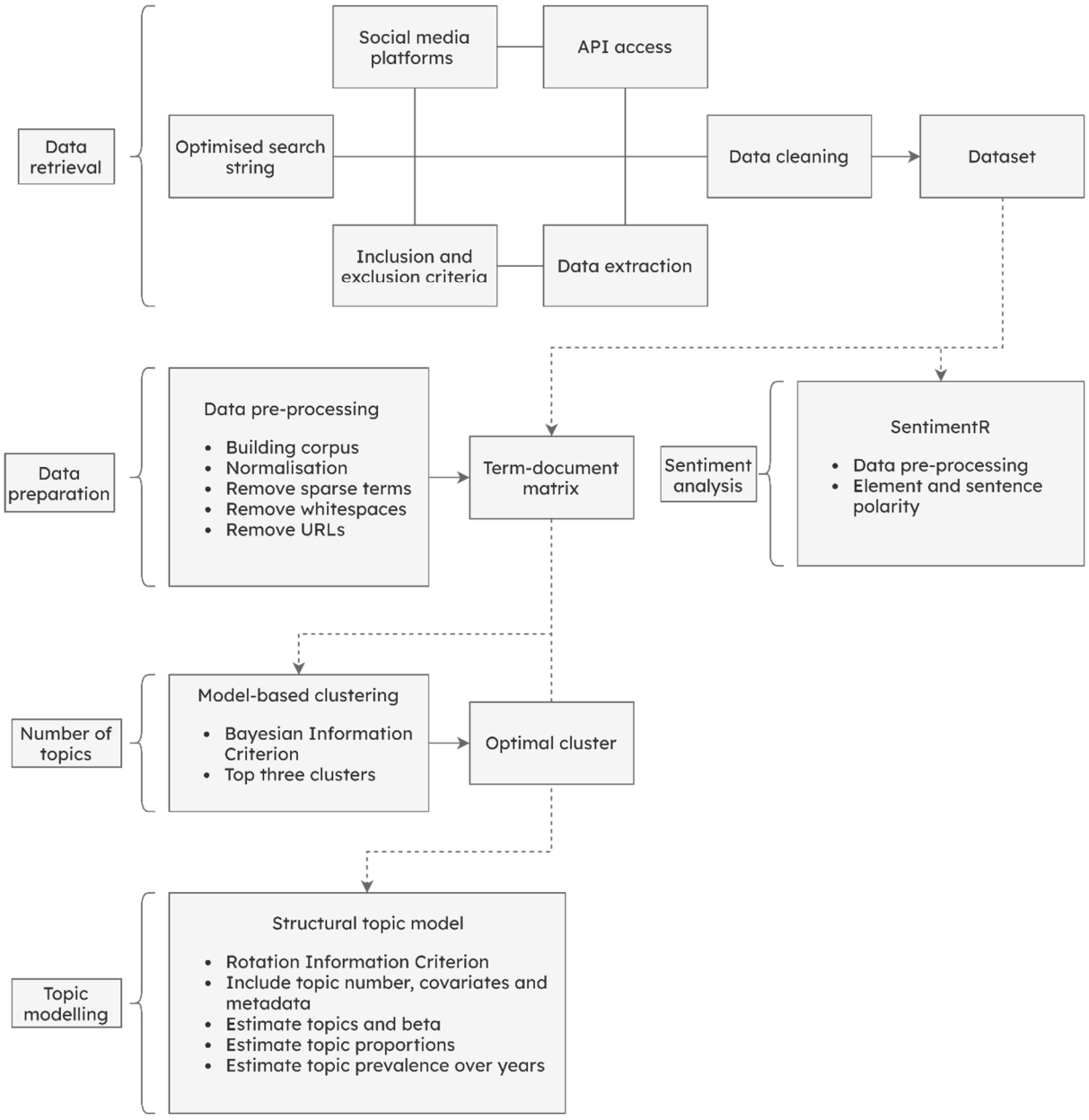


Figure 1. Flow process of methodology.

This research was conducted with approval from an institutional Human Research Ethics Committee (approval number H-2025-041). All procedures performed in this study involving human participants were in accordance with the ethical standards of the institu-

tional research committee and with the National Statement on Ethical Conduct in Human Research 2023.

3.1. Data Extraction

Using Boolean operators, a search string of synonyms for relevant phrases such as construction, site, COVID-19, coronavirus, health and safety, and safety measures were entered into the advanced search engines of X, Reddit, and YouTube. The initial test search gave some ideas for the best query terms to use to obtain the most data from each platform. X and YouTube were mined for social media data using the "vosonSML" R version 4.5.0 package. The package includes a set of methods used to retrieve social media data and create networks for evaluation [48]. First, after being granted permission for developer access on the sites, applications (APPs) for X and YouTube were developed for this study. These APPs made it possible to create keys and tokens required for authenticating the platforms' application programming interfaces (APIs).

The process yielded 184 recent X comments about COVID-19 prevention measures in the construction industry. Restricted access to the X API led to the few comments. In Figure 2, the 184 comments are shown. There were 98 tweets with 86 replies. In total, 51 of the 184 comments were retweeted. There were 3171 retweets in all. The lowest retweet count was 0, the average was 17, and the highest was 1196. The lowest count of likes on a tweet was 0 and the highest was 54, with a total of 338 likes.

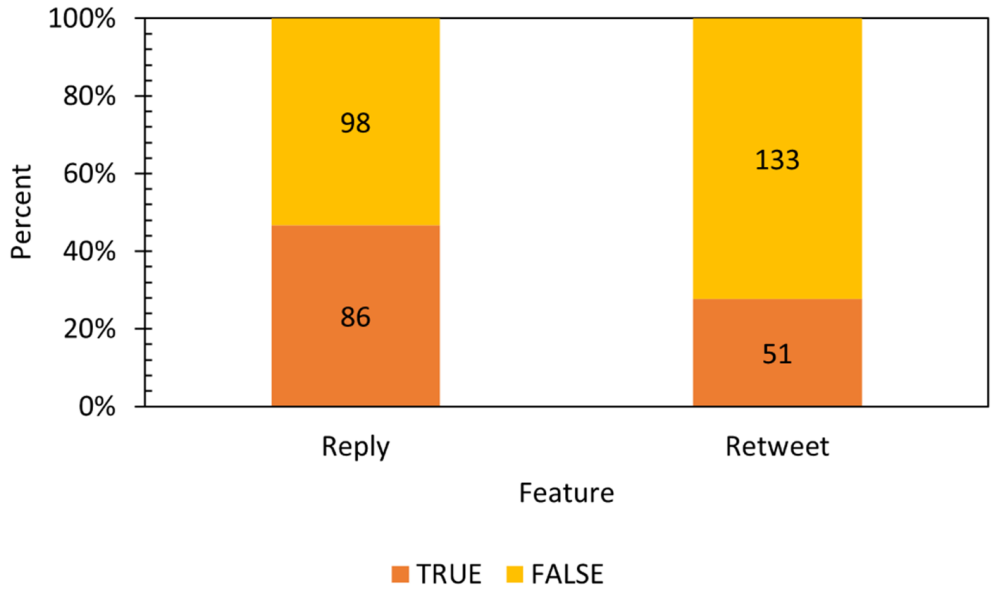


Figure 2. Description of X data on COVID-19 prevention measures on construction sites.

For YouTube, 45 videos that were pertinent to the search terms and the objectives of this study were considered. The videos had one or more comments to guarantee a desired degree of engagement. The universal resource locators (URLs) were used to obtain video identification for each YouTube video. After the YouTube APP was verified, 2548 English comments related to these videos were gathered. A complete breakdown of the 25 videos is shown in Figure 3. The minimum number of comments on a video is one, and the most number is 675. At least 65 people watched each video, with an average of 165,589 and a maximum of 196,538 views, and a total of 745,147 views.

The comments linked to URLs of relevant threads were extracted using the "RedditExtractor" software [49]. Thirty-six Reddit threads that had at least one remark and were relevant to the research goal were chosen. From this, 1961 comments were extracted from these discussions by the extraction technique. Some comments marked as "[deleted]" or

"[removed]" were deleted from the dataset, resulting in 1852 Reddit comments. There were 21,244 scores altogether on the threads, with the lowest score attached to a thread being −47, the average being 11.471, and the highest as 883.

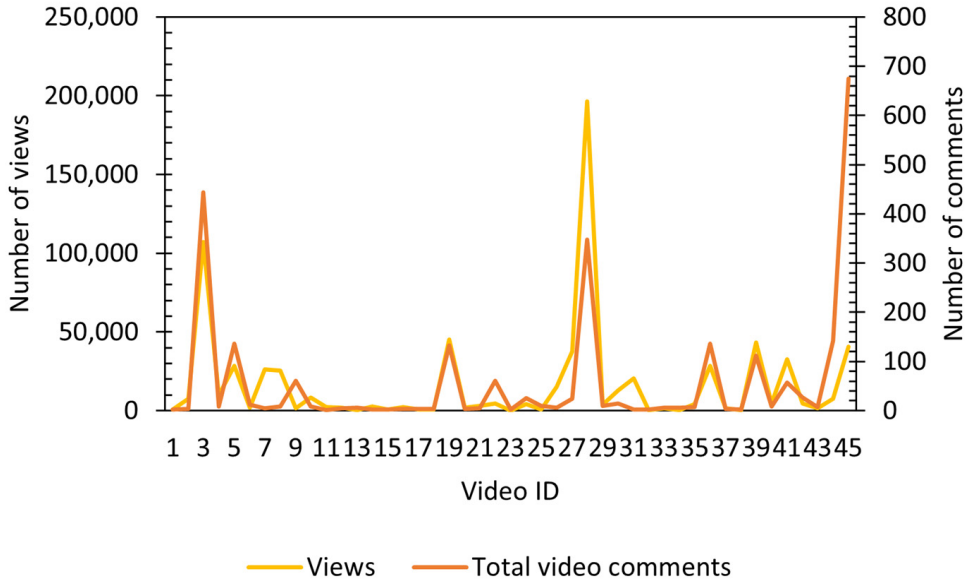


Figure 3. Description of YouTube data on COVID-19 prevention measures on construction sites.

For this study, a total of 4584 comments about COVID-19 prevention measures on construction sites from March 2021 to November 2022 were used. All data from the three social media platforms was retrieved on 5 November 2022.

3.2. Clustering

It can be difficult to determine the number of topics predominately discussed on social media. There is generally no single strategy used to overcome this issue. The best number of topics could be chosen by combining statistical analysis with human judgement [50]. One such technique is clustering. In clustering, unlabelled datapoints are grouped into multiple comparable groups. Considering that the majority of clustering algorithms are rule-based, the "correct" number of clusters must still be specified. This statistical problem of choice can be addressed using a model-based clustering, which has an advantage over the rule-based clustering techniques.

The number of ideal clusters was automatically determined using model-based clustering, which is an application of a finite mixture of models. With this technique, each observation is the result of a finite mixture of G probability distribution, each of which represents a different cluster [51]. The expectation–maximisation (EM) approach is typically used to estimate parameters [52]. The Bayesian Information Criterion (BIC), which is one of many selection techniques, was applied in this regard. BIC has shown consistency in determining the ideal number of clusters [53]. The optimum model is indicated by the highest BIC score [54].

3.3. Topic Modelling

To uncover latent themes in large textual data, topic models have proved to be crucial. This method attempts to handle the individual biases of the researchers' viewpoints, which is a key issue in conventional content analysis [55]. In this light, several studies have employed topic models on social media data. For instance, Melton et al. [56] conducted Latent Dirichlet Allocation (LDA) modelling on textual data from 13 Reddit forums focusing on the COVID-19 vaccination. Corti et al. [57] used the Non-Negative Matrix Factorisation

(NNM) topic model to examine X posts surrounding Autism spectrum disorder (ASD) during the COVID-19 pandemic to compare topics in 2019 and 2020.

This study used the Structural Topic Model (STM) to identify important topics on COVID-19 preventative strategies in the construction industry that were discussed on social media. One distinctive feature of STM in comparison to other topic models is its capacity to add metadata to improve topic estimation [58]. The month and year a comment was posted were included in the model as covariate. The number of clusters suggested by the model-based clustering procedures is then specified as the number of topics in the STM. Spectral initialisation was used to approximately determine the vertices of the convex hull of term concurrences as it has shown to yield best results every time, and is generally reliable [59,60].

Correlations between the topics were also analysed at a 99% confidence interval. As a selection criterion for the neighbourhood selection method, the Rotation Information Criterion (RIC) was employed. The results of empirical research have characterised RIC as unique and extremely effective. In comparison to other approaches, RIC has demonstrated to have the most balanced performance, reaching the optimal balance between sensitivity and false positive rates [61].

3.4. Sentiment Analysis

With so much unstructured data available, sentiment analysis is a rapidly expanding topic of study and application [62]. This area of natural language processing (NLP) gathers subjective information from text input and determines the polarity and emotions portrayed in the text [63]. Since it is challenging for the typical human reader to find, extract, and summarise the vast amounts of textual content on social media platforms, sentiment analysis is essential [64].

Research on COVID-19 in the construction industry has employed sentiment analysis in several ways. Palaco and Su [65] used sentiment analysis to examine how social media data influenced the construction industry's image during the pandemic. Zeng et al. [66] also performed sentiment analyses of construction health and safety posts on Instagram. Ghansah et al. [67] also examined the impacts of the pandemic on quality assurance practices of cross-border construction logistics and supply chain. Hence, sentiment analysis was performed in this study to understand the polarity of stakeholder views on COVID-19 prevention measures in the construction industry.

4. Results

4.1. Choosing the Optimal Number of Topics

Model-based clustering was used to determine the ideal number of topics discussed within the social media data on COVID-19 prevention measures. "Mclust", an R package (version 4.5.0) for a model-based clustering algorithm and density estimation, was employed. This software package is a reliable and widely recognised tool that allows for the modelling of data as a Gaussian finite mixture with different covariance structures and varying numbers of mixture components [68]. A seed function was used to ensure consistent and reproducible results whenever the "mclustBIC" function is used on the matrix. This function applies various statistical models with different covariance structures and parameterisations to analyse the data, using the Bayesian Information Criterion (BIC) as a measure of goodness of fit. Figure 4 shows the BIC values obtained for all 14 models applied to the data.

As depicted in Figure 4, the expectation–maximisation (EM) algorithm identifies the top 3 clusters which are best fitted by, first, a model with an ellipsoidal covariance, equal volume, equal shape, and varying orientation (EEV), followed by two models with a

diagonal covariance, equal volume, equal shape, and axis parallel orientation (EEI). The EEV model with two clusters had the highest BIC of 87,232.35, the EEI model with four clusters had a BIC value of 68,903.83, and the EEI model with three clusters had a BIC value of 65,513.11. These suggested numbers of topics served as a guide in a thorough review of COVID-19 prevention measures in the construction literature, in conjunction with a content analysis of 3853 social media comments. After this examination, four topics were considered ideal to account for the statistical variability and philosophical dynamics in the respective literature.

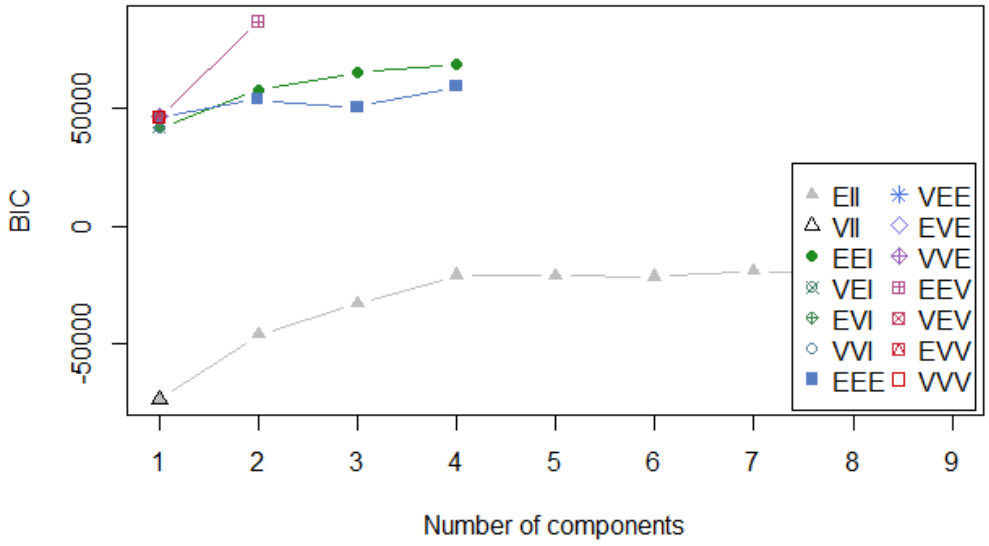


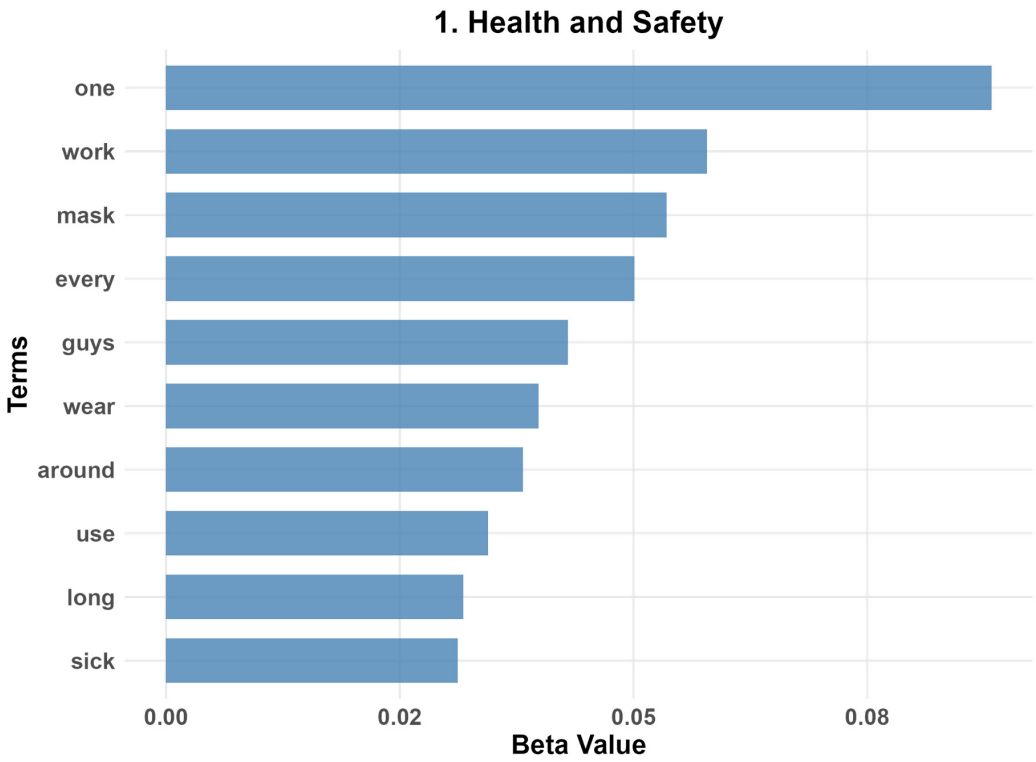
Figure 4. Model-based clustering of social media comments on COVID-19 prevention measures on construction sites.

4.2. Results of Major Topics from Social Media Comments on COVID-19 Prevention Measures

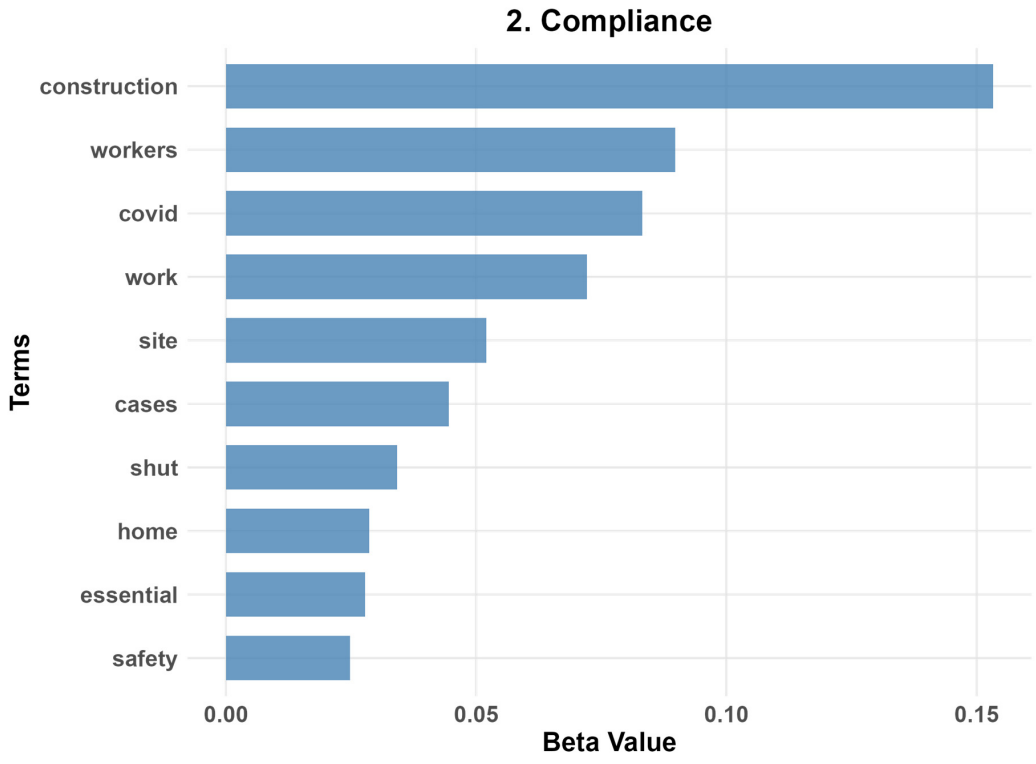
The structural topic model (STM) was used to identify and categorise the main COVID-19 prevention measures discussed in the construction industry on social media. The model was configured to focus on four topics and initiated using spectral initialisation. Metadata such as the year of each comment was considered a covariate in the topic prevalence parameter, and the random number generator was seeded accordingly. Incorporating such metadata alongside estimations can be crucial [69]. The maximum number of EM iterations was set to 75, and the STM model was initialised after defining the necessary parameters. This resulted in a topic model comprising 4 topics, 3853 documents and a 112-word dictionary. Additionally, the model associated the terms in the dictionary with each topic, assigning varying probabilities that reflect the frequency of term–topic associations. These insights were then used to label the topics in conjunction with the outputs obtained from applying the "findThoughts" function, which examined comments strongly related to the four topics. Figure 5a–d shows the top ten beta values in each topic and their corresponding terms.

4.3. Proportions of Topics

This study also quantified how much each topic has been discussed across the documents. Figure 6 summarises the topics ranked by their expected frequency across the corpus. The most discussed topic was "awareness", which constitutes 28.7% of the entire corpus, followed by "vaccination", which accounts for 27.9%, and "compliance", which makes up 23% of the discussions. Lastly, "health and safety" accounted for 20.3% of the whole corpus.

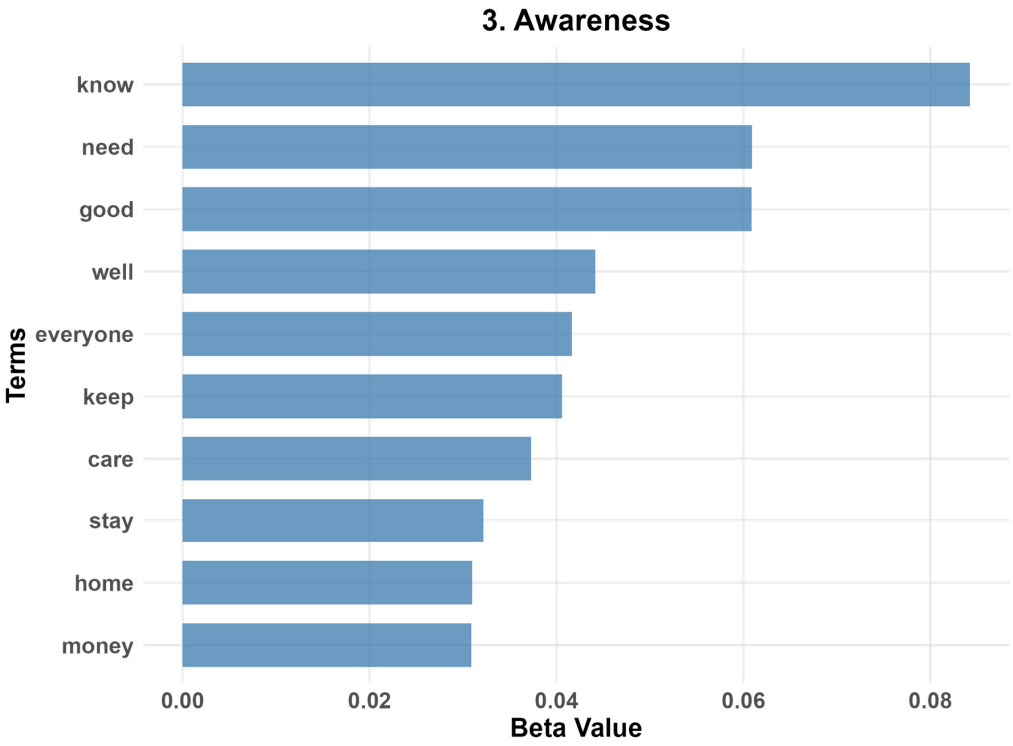


(**a**)

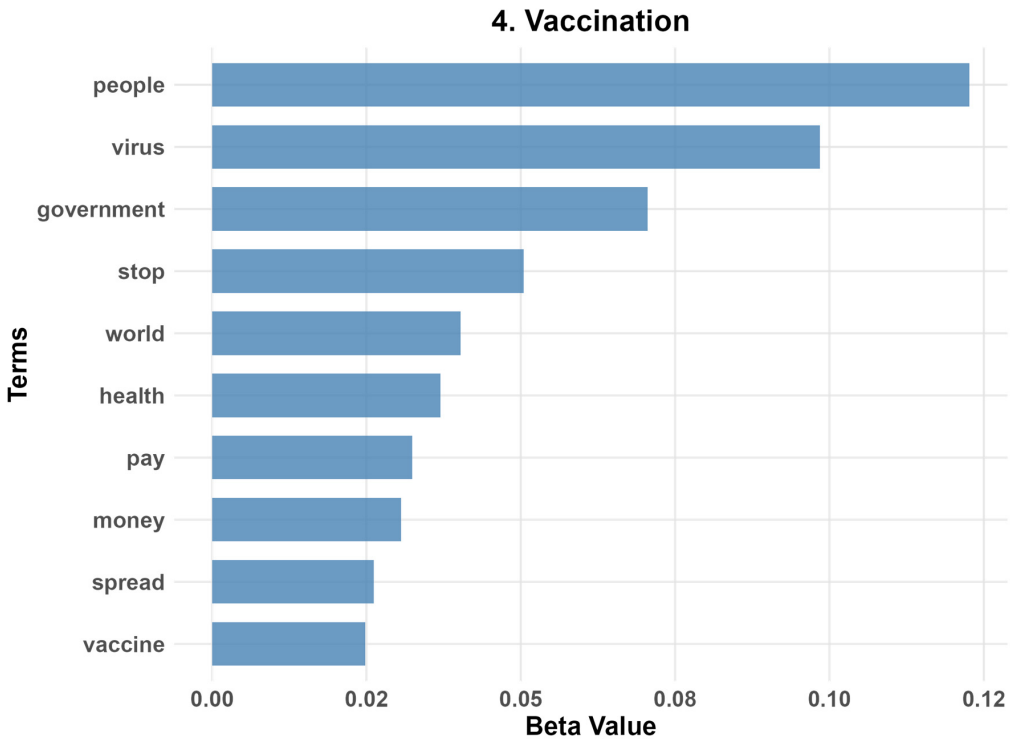


(**b**)

Figure 5. *Cont*.



(**c**)



(**d**)

Figure 5. (**a**) STM plot of topic one from social media comments on COVID-19 prevention measures on construction sites. (**b**) STM plot of topic two from social media comments on COVID-19 prevention measures on construction sites. (**c**) STM plot of topic three from social media comments on COVID-19 prevention measures on construction sites. (**d**) STM plot of topic four from social media comments on COVID-19 prevention measures on construction sites.

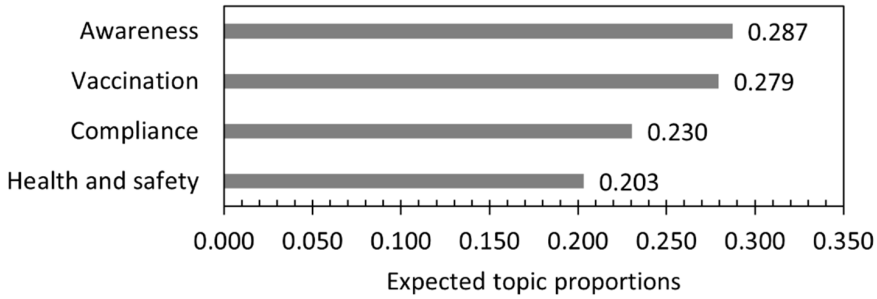


Figure 6. Expected topic proportions across the entire corpus.

4.4. Trend of the Topics over Time

This section provides insights on the annual prevalence of topics from social media on COVID-19 prevention measures on construction sites. As shown in Figure 7, the trend of the identified topics varied within the two COVID-19 years (2020–2022). The topics "Vaccination" and "compliance" showed an upward trend, whereas the "awareness" and "health and safety" topics showed a downward trend. Table 1 provides further explanation of Figure 7. The regression estimates that discussions on health and safety measures and awareness strategies are projected to decrease significantly with time, whereas discussions on compliance and vaccination prevention measures are likely to increase over time.

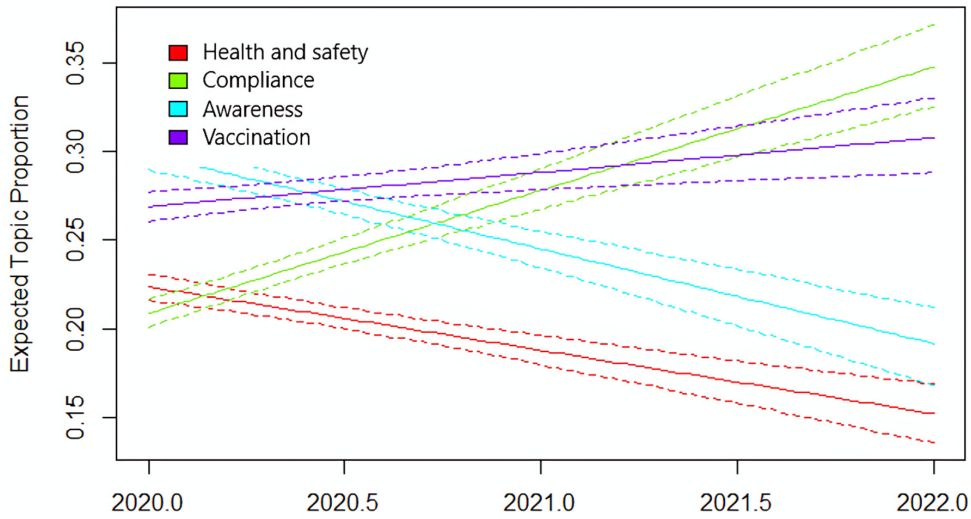


Figure 7. Annual prevalence of topics from social media on COVID-19 prevention measures on construction sites.

Table 1. Regression estimates of the effect of time on topic proportions.

Variable *	Estimate	Std. Error	t Value	Pr (>|t|) +
1. Health and safety				
(Intercept)	73.053	10.516	6.947	0.000
year	−0.036	0.005	−6.927	0.000
2. Compliance				
(Intercept)	−140.694	13.897	−10.124	0.000
year	0.070	0.007	10.141	0.000
3. Awareness				
(Intercept)	108.383	12.858	8.429	0.000
year	−0.054	0.006	−8.407	0.000
4. Vaccination				
(Intercept)	−39.690	13.170	−3.014	0.003
year	0.020	0.007	3.035	0.002

* Topic is the dependent variable; year is the independent. + $p < 0.01$.

4.5. Results of Sentiment Analysis

Sentiments on COVID-19 prevention measures in construction discussed on social media were categorised into three polarity groups. The majority of the comments about the prevention measures were positive (50%), 40.4% were negative, and the remaining 9.6% were neutral. Figure 8 provides further details.

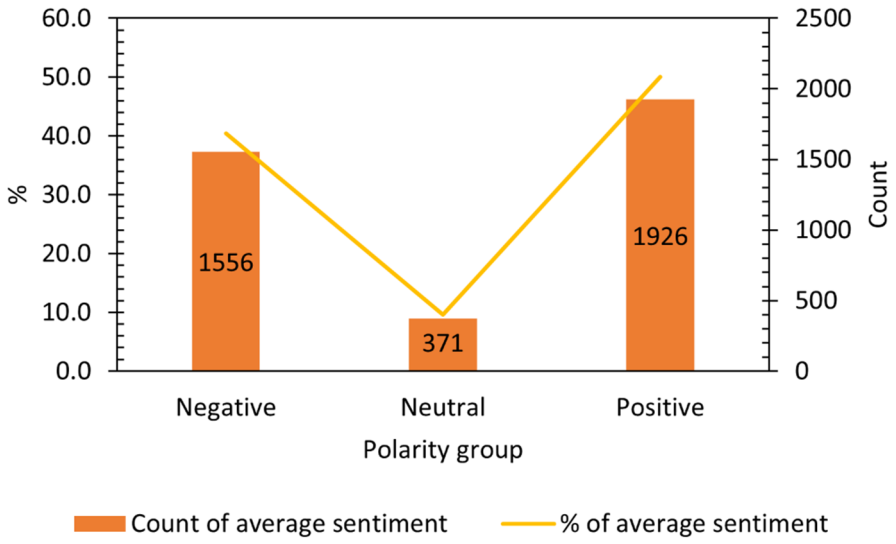


Figure 8. Polarity groups of social media comments on COVID-19 prevention measures on construction sites.

5. Discussion

This study assessed the social media discussions on COVID-19 prevention measures within the construction industry. By identifying important topics and exploring their prevalence and trends over time utilising model-based clustering and structural topic modelling (STM), the data provides valuable insight into the multifaceted nature of the perception of COVID-19 prevention efforts around the world in the construction sector.

5.1. Major Topics from Social Media Comments on COVID-19 Prevention Measures

Based on the STM, the associated terms were clustered into four main topics: (1) health and safety, (2) compliance, (3) awareness, and (4) vaccination. The individual topics along with the corresponding terms are chronologically illustrated in Figure 5a–d. Whereas some terms were unique, others (e.g., work, home) contributed to multiple topics; however, each term was strongly linked with one of the major topics identified as per the beta values (Figure 5). These results align with the existing literature on discussions on COVID-19 health responses around the world for the period examined, corroborating the recurrent themes in prior research [70,71]. To ensure clarity and accurately represent the commenters' perspective, examples from the data are included without edits, even if the remarks inadvertently contain errors.

5.1.1. Health and Safety

Under this topic, construction workers' opinions appear to reflect a mixture of frustration, concern, and practical (logistical) challenges. Many workers expressed dismay at the lack of adherence to safety protocols among their colleagues, and inadequate sanitation facilities exacerbating safety risks. Wearing of masks was one of the most mandatory, visible and widely promoted safety measures during the pandemic [72], and for construction sites where workers often work closely together, concerns about the use of mask were not unexpected. This was highlighted in stances of mask non-compliance as lamented by one

worker: "Group of 7 drywallers at a job last week. Not one of them even feigned wearing a mask. Needless to say I busted out one of my few N95s. . .." A palpable sense of urgency and anxiety about the potential health risks posed by working in "super close quarters" without adequate protection was also echoed when workers described a situation where "Nobody wears [their] masks." Concern about the lack of basic sanitation amenities and social distancing potentially contributing to the heightened risk of COVID-19 transmission in the workplace was also prevalent in social media discussion. For example, "We have 6 toilets to share between 150+ workers with no running water. . .." and "We are supposed to stay 6 feet apart, but we have 2 guys per vehicle so this is impossible".

The heightened concern about health and safety protocols among construction workers may be linked to changes in safety awareness during the pandemic. Namian et al. [73] found that construction workers who experienced COVID-19 demonstrated significantly higher safety risk perception, suggesting that the pandemic experience served as a form of reinforced learning that enhanced workers' situational awareness and safety decision-making.

Managing COVID-19 required individuals to isolate (stay at home) if they felt unwell and be tested before returning to work [74]. However, financial pressures and logistical constraints contributed to the dilemma faced by construction workers who felt compelled to continue working despite health concerns. Some workers cited financial constraints, including fear of eviction, while others noted challenges accessing COVID-19 testing due to cost or availability, as conveyed in the comment ". . ..I'm pretty sure I've had it/have it, but i can't afford to miss work because I'd be evicted. Testing around here either costs $200 for a rapid test or it takes 2 weeks to get results back. I still haven't gotten my 14 weeks of unemployment from earlier in the year."

5.1.2. Compliance

Adhering to guidelines and measures instituted by the government and public health authorities to mitigate the spread of the virus typically include actions such as wearing face masks, practicing social distancing, washing hands frequently, avoiding large gatherings, staying home when feeling unwell, and following quarantine or isolation guidelines if exposed to or infected with the virus. Globally, governments employed various strategies to promote compliance, including, through law enforcement agencies (police patrols and arrests in extreme cases), issuing fines or penalties for non-compliance and violations of COVID-19 protocols [75]. To avert the scrutiny of authorities, some companies also hired compliance officers [31].

Social media expressions on construction sites as relates to compliance were multifaceted, with discussions often related to shut down due to violations of lockdown rules or inadequate enforcement of safety protocols by authorities. For instance, it is well known that, together with wearing of masks, social distancing was a safety measure implemented to mitigate hospital system overload and prevent pathogen exposure [76,77]. Notwithstanding the effective implementation of this mandate in other sectors, the practicality in construction sites was often in question as workers described the challenges of maintaining social distancing in cramped workspaces, such as small rooms where multiple people were required to be simultaneously present and the impossibility of staying 1.5 m apart due to the nature of their work environment.

Some workers seemed to believe shutting down the construction for non-compliance did not necessary culminate into safety due to the increased incidence of COVID-19 cases upon reopening these sites, as captured by the following comment: "When my county started our lockdown in Mid-March they initially allowed construction to continue with social distancing rules. The cops were spending lots of time warning construction sites that

were breaking the rule so the county shut them down. Now that construction has reopened we have had a noticeable uptick in Covid cases with roughly half at construction sites."

Apart from labour shortages, the dependence on migrant workers in the construction industry occasioned by the pandemic was also mentioned. Additionally, there were discussions about vaccine distribution disparities, with questions on why construction workers were not being prioritised for vaccination as essential workers: "Construction seems pretty essential to me. The real question is why aren't we offering them (and other essential workers) the AstraZeneca vaccines that are sitting in freezers because the over 55 crowd wants to wait for Pfizer and Moderna?"

5.1.3. Awareness

Social media played a crucial role, particularly in the initial phases of the pandemic, facilitating information sharing and fostering community awareness. This was particularly significant as the pandemic was an unprecedented event in recent human history [78,79]. The wide range of perspectives on pandemic awareness in the digital space investigated reflected scepticism about misinformation, commendation for information sharing efforts, discussions on political ideologies, and personal expressions of gratitude. For example, the scepticism towards mainstream media and accusations of spreading fake news were evident in the comment: "Why do you keep propagating fake news? Because they have to. It doesn't make sense for them to let certain nations be humanised and shown to be on average similar to everyone else. Their mind goes directly to "fake news" whenever news comes out of a non-NATO country." As observed in Table 1, there were broader societal commentaries intertwined with awareness discussions. But amidst these varied perspectives, a positive note on the quality of industry-relevant information shared was included: "This was actually better than a lot of the non-construction related information that's gone around to do with this virus."

5.1.4. Vaccination

The increasing focus on vaccination as a prominent topic in social media discussions reflects the rapid global efforts to develop, distribute and administer vaccines [80], including concerns with jurisdictional enforcements. There appeared to be vaccine hesitancy among construction workers. For instance, concerns expressed, such as "People who had the virus and survived the virus have an immunity of it."; "You say take the vaccine but it doesn't stop you getting it, you say you can get it more than once, you want vaccine passports" and "Natural immunity is 13× stronger than any vaccine facts.", highlighted the broader societal implications of vaccination efforts with expression of frustration with perceived inconsistencies about vaccine safety, efficacy, access and the interplay of politics and health. It further emphasises the dangers of misinformation and conspiracy theories on social media, emphasising the need for effective communication and fact-checking regarding vaccines and vaccination.

5.2. Proportions and Trend of Topics over Time

Throughout the period under scrutiny, the prevailing themes in social media discussions were health and safety (20%), compliance (23%), awareness (28.7%), and vaccination (27.9%), as shown in Figure 5a–d. These proportions strongly indicate that awareness and vaccination were the focal points of the discussions, drawing considerably more attention and sparking significant conversations in contrast to health and safety and compliance. Furthermore, over the two-year period examined, discussions about compliance and vaccination saw an upward trend, while 'Health and Safety' and 'Awareness' showed a contrasting decline (Figure 7). The rise in compliance discussions can be attributed to the more rigorous enforcement of COVID-19 protocols and the inadequacy of uniform regulations

that often fail to consider site-specific needs and/or assess the feasibility and effectiveness of these measures. This is particularly evident in workplaces such as construction sites, where shared labour is essential [81]. Similarly, the surge in vaccination discussions may have been driven by COVID-19 vaccine development, distribution, and mandates, which sparked debates on public health versus individual rights and concerns about personal choice, medical freedom, and side effects among construction workers and society [82]. To address workforce limitations during the pandemic, some studies explored innovative workforce management strategies. Araya [22] used agent-based modelling to demonstrate that employing multiskilled construction workers could reduce workforce deficits by approximately 50% during COVID-19, from 33.4% to 16.7%, providing construction managers with greater flexibility in workforce planning and project continuity.

Construction, already considered a high-risk industry with increased safety and health hazards [80], was compounded by the added risk of COVID-19, significantly compromising the well-being and safety of workers. For example, in an earlier study investigating YouTube as an information source for the construction industry during emergencies, such as the early stages of the COVID-19 pandemic, the videos promoted a range of safety measures, including worksite access limitations, health screenings, social distancing, hygiene practices, remote work, and safety solution adoption in various construction settings [4]. Notwithstanding, a declining trend was interestingly observed regarding social media discussions on health and safety and awareness topics (Figure 7). This may have been occasioned by the normalisation of safety precautions. As the pandemic persisted, those in the construction industry may have become accustomed to these safety measures, leading to a reduced need to discuss them explicitly. Additionally, as vaccination efforts advanced and the focus shifted towards immunisation campaigns, the public's attention and discourse shifted towards the topic of vaccination. Consequently, the broader awareness of general COVID-19 measures may have gradually diminished, indicating the complex interplay of social factors influencing public discussions during the pandemic.

These temporal patterns have significant implications for understanding the evolution of safety culture in construction. The declining trend in health and safety discussions suggests that as crises become normalised, proactive safety dialogue may diminish, potentially creating vulnerabilities for future emergencies. This pattern indicates a need for sustained engagement strategies that maintain safety awareness beyond immediate crisis periods. The upward trend in compliance discussions reflects an increasingly regulated approach to workplace safety, which, while necessary, may indicate a shift from voluntary safety engagement to mandated adherence. This evolution has important implications for current construction management practices, suggesting that effective safety programs must balance regulatory compliance with intrinsic motivation to maintain long-term safety culture. The rise in vaccination-related discussions, even as awareness declined, demonstrates how specific interventions can dominate discourse while broader safety education fades. This pattern informs current strategies for introducing new safety technologies or protocols in construction, highlighting the importance of sustained, multi-faceted communication approaches rather than single-issue campaigns.

5.3. Polarity of Stakeholders' Perspectives

Sentiment analysis was conducted to ascertain stakeholders' perspectives on COVID-19 prevention measures in the construction industry, examining the levels of positive, negative, and neutral sentiments expressed through social media comments. While sentiments mostly fell into distinct positive, negative, or neutral categories, some overlap occurred due to key topics. As illustrated in Figure 8, positive sentiments constituted half of social media comments, while negative expressions comprised at least 40%. Less than one-tenth (9.6%)

of comments were indifferent about prevention measures on construction sites, providing valuable insights into industry challenges and attitudes during the pandemic.

Construction workers generally engaged in positive social media interactions regarding efforts to prioritise health and safety, expressing appreciation for safety protocols such as the availability of hand sanitisers and temperature checks on construction sites. Sentiments towards vaccination efforts were also positive, with expressions of hope for immunisation. Negative sentiments included frustrations, concerns, and criticisms. For instance, workers expressed dismay at colleagues' lack of adherence to safety protocols, complained about inadequate sanitation facilities increasing safety risks, and highlighted challenges accessing COVID-19 testing due to financial constraints or logistical issues. Negative concerns about vaccine hesitancy and misinformation, including perceived inconsistencies about vaccine safety and efficacy, persisted. Only a smaller proportion of social media comments exhibited neutral sentiments towards COVID-19 prevention measures in construction, potentially indicating a lack of strong opinion or emotional investment in the major topics.

The relatively large positive perception (50%) is consistent with the previously reported ~51% positive social media sentiments of construction job seekers [65] and surpasses the ~33% positive discourse on the impact of the COVID-19 pandemic on quality assurance practices at construction sites [67]. In contrast, the negative sentiments recorded in this study accounted for an overwhelming 40%, doubling the rate reported by both Palaco and Su [65] and Ghansah, Lu and Ababio [67], which stood at approximately 19%. This disparity is particularly significant given that prevention measures were crucial for human well-being, compounded by the fact that from 2019 to 2022 (the period covered by this study), construction workers were at least five times more likely to contract COVID-19 than the general public [83,84].

The persistent high level of negative sentiment reveals fundamental challenges in construction industry communication and stakeholder engagement that extend beyond the pandemic period. This polarisation suggests that nearly half of construction stakeholders remained sceptical or frustrated with prevention measures, indicating systematic issues in how safety information is communicated, implemented, and received within the industry. The polarised sentiments observed in our study may also reflect changes in workers' safety awareness. Research by Namian et al. [73] indicates that COVID-19 experiences enhanced construction workers' safety risk perception, which could contribute to more critical evaluation of prevention measures and explain some of the negative sentiments expressed in social media discussions. These patterns have lasting implications for current safety initiatives, suggesting that traditional top–down communication approaches may be insufficient for achieving broad stakeholder buy-in. Understanding these sentiment patterns is crucial for developing more effective engagement strategies for ongoing safety challenges, including the adoption of new technologies, climate adaptation measures, and evolving regulatory requirements in the post-pandemic construction landscape.

5.4. Contemporary Relevance and Long-Term Implications

While this study examines data from the COVID-19 pandemic period (2020–2022), its findings hold significant contemporary relevance five years post-pandemic for several critical reasons. First, the construction industry's response patterns identified through our analysis reveal persistent structural challenges in crisis communication and safety protocol implementation that extend beyond COVID-19. The polarised sentiments we observed (50% positive vs. 40% negative) indicate fundamental gaps in stakeholder alignment that continue to affect how the industry responds to ongoing challenges such as climate-related disruptions, supply chain crises, and emerging safety regulations.

The declining trend in "awareness" discussions, coupled with the rising focus on "compliance," suggests a shift from proactive education to reactive enforcement, a pattern that has profound implications for current workplace safety culture. This trend indicates that as immediate crisis awareness fades, the industry may become increasingly reliant on regulatory compliance rather than intrinsic safety motivation, potentially leaving workers vulnerable to future emergencies.

Moreover, the methodological framework developed in this study, combining model-based clustering with structural topic modelling for construction industry social media analysis, provides a replicable approach for monitoring industry responses to current and future crises. As the construction sector faces ongoing challenges including labour shortages, technological disruption, and climate adaptation, understanding how stakeholders communicate and respond through social media channels remains crucial for developing effective intervention strategies.

The vaccination hesitancy and misinformation patterns we identified also offer valuable insights for addressing current health communication challenges in construction, where worker demographics and workplace cultures continue to influence receptivity to public health guidance. These findings inform ongoing efforts to build trust and improve communication effectiveness in an industry where worker safety remains a persistent challenge.

5.5. Limitations and Future Research Directions

This study acknowledges several key limitations. First, our data does not represent a statistically representative sample of the construction industry, as not all construction workers and stakeholders participate in social media platforms. This creates potential sampling bias toward more digitally engaged participants and may not capture perspectives of workers with limited internet access or social media usage. The data collection period (March 2021 to November 2022) captured a specific pandemic phase, and the restricted access to platform APIs, particularly Twitter, limited our dataset size.

The machine learning methodology developed here offers a framework for real-time monitoring of construction industry responses to ongoing challenges. Future research could apply this approach to analyse current industry discussions around automation, climate resilience, and safety technologies while incorporating additional metadata such as geographic location and company size. Studies combining social media analysis with traditional survey methods could address representativeness concerns and provide more comprehensive stakeholder insights. The sentiment polarisation patterns identified warrant investigation into their underlying causes and potential mitigation strategies, examining how different communication approaches influence sentiment patterns and safety outcomes in construction environments.

From an international perspective, this study's relevance extends beyond the specific context of COVID-19 to provide a methodological framework applicable to construction industries globally. The machine learning approach combining model-based clustering and structural topic modelling can be adapted to analyse construction industry responses across different cultural, regulatory, and economic contexts. The four themes identified, health and safety, compliance, awareness, and vaccination, represent universal challenges that construction industries worldwide face during health crises, making our findings transferable to international settings. Additionally, the sentiment analysis patterns and topic evolution trends provide benchmarks for comparative studies across different countries and regulatory environments.

6. Conclusions

This study provides critical insights into construction industry stakeholder responses to COVID-19 prevention measures through comprehensive social media analysis, revealing patterns that have significant implications for ongoing industry practices and future crisis preparedness. By applying machine learning methods including model-based clustering and structural topic modelling, we identified four dominant themes, health and safety, compliance, awareness, and vaccination, that collectively shaped industry discourse during a critical period.

The temporal evolution of these topics, particularly the declining focus on awareness and health safety discussions, alongside rising emphasis on compliance and vaccination, reveals important shifts in industry priorities that continue to influence current safety culture. The substantial sentiment polarisation we observed (50% positive, 40% negative) indicates persistent challenges in stakeholder alignment that extend beyond the pandemic period, suggesting fundamental issues in how the construction industry communicates about and implements safety measures.

Five years post-pandemic, these findings remain highly relevant as the construction industry continues to face complex challenges requiring coordinated stakeholder responses. The methodological framework developed in this study offers a replicable approach for monitoring industry responses to current and future disruptions, from climate adaptation requirements to technological transformations. The patterns of communication, sentiment, and topic evolution we identified provide valuable guidance for developing more effective engagement strategies that can bridge the gap between regulatory requirements and stakeholder acceptance.

Our findings suggest that effective crisis communication in construction requires sustained, multi-faceted approaches that maintain awareness and education alongside compliance enforcement. The tendency for proactive safety discussions to decline as crises normalise highlights the need for systematic approaches to maintaining safety culture beyond immediate emergency periods. Furthermore, the persistent negative sentiment among a substantial portion of stakeholders indicates that traditional communication approaches may be insufficient for achieving broad industry buy-in on safety initiatives.

For policymakers and regulatory agencies, these results emphasise the importance of understanding stakeholder perspectives and sentiment patterns when developing and implementing safety regulations. For construction organisations, the findings highlight the need for comprehensive communication strategies that address diverse stakeholder concerns and maintain engagement across different phases of crisis response and recovery.

The machine learning approach demonstrated in this study establishes a foundation for ongoing monitoring of construction industry discourse, enabling more responsive and evidence-based approaches to safety communication and policy development. As the industry continues to evolve in response to technological, environmental, and social changes, understanding stakeholder perspectives through social media analysis will remain crucial for building resilient and adaptive safety cultures.

Future research should investigate the long-term persistence of the patterns identified in this study and explore how the lessons learned from pandemic response can inform approaches to current industry challenges. The framework developed here provides a valuable tool for continued monitoring and analysis of construction industry stakeholder engagement in an increasingly complex and rapidly changing environment.

Author Contributions: Conceptualisation, E.B.B. and D.O.; methodology, E.B.B.; software, E.B.B.; validation, E.B.B. and D.O.; formal analysis, E.B.B.; data curation, E.B.B. and D.O.; writing—original

draft preparation, E.B.B., D.O., D.N.O.B. and V.G.; writing—review and editing, E.B.B., D.O., D.N.O.B. and V.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data is publicly available.

Conflicts of Interest: The authors declare no conflicts of interest.

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