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Modeling working shifts in construction projects using an agent-based approach to minimize the spread of COVID-19

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ABSTRACT

The spread of COVID-19 has modified how we relate with other people and our built environment, changing from in-person to primarily virtual activities. However, some activities are impossible to be virtually performed, such as construction activities. Consequently, the construction industry has been highly impacted by the pandemic due to COVID-19. In response to the impacts of the pandemic, the construction sector must identify alternatives that can minimize the spread of COVID-19 among workers in construction projects. Given this context, this study explores the alternative of managing the workforce of construction projects using multiple working shifts as multiple shifts may reduce construction workers' density in the field, and with that, reducing the probabilities to spread COVID-19 among workers. This study presents an agent-based modeling approach to assess the impact of using two shifts to reduce the spread of COVID19 among construction workers. The model is supported by data found in the literature to simulate workers' behavior regarding multiple shifts and by international institutions to simulate the pandemic context through multiple scenarios. This study found that the more workers are assigned to a night shift during a project, the higher the average number of workers classified as healthy (i.e., without COVID-19) is going to be. Namely, by assigning approximately half of the workers involved in a project to a night shift, the average number of healthy workers can be increased by 20% on a project. Quantifying the impact of alternatives that may reduce the spread of COVID-19 among construction workers can incentivize the implementation of such alternatives by construction managers. This study contributes to quantifying the benefits of using multiple working shifts to minimize the spread of COVID-19 among construction workers.

1. Introduction

The pandemic, due to COVID-19, has impacted our society in its entirety. It has modified the way people relate with each other (e.g., social distancing) and how people interact with their natural and built environment (e.g., quarantines, virtual activities); thus, creating the need to adapt the existing built environment to the pandemic's unprecedented requirements [1,2], such as quickly building healthcare facilities to combat COVID-19 [3]. The construction industry has been recognized as a key player in shaping the existing built environment [4–9]. Therefore, an essential aspect of how the existing built environment adapts will relate to how the construction industry can continue operating during and after the current pandemic context.

The construction industry has been heavily disrupted due to the spread of COVID-19, for instance, by delaying and halting construction projects under development before the pandemic began [10]. As online activities cannot replace construction activities on the construction sites, construction projects must continue to be developed in construction fields where construction workers are going to interact with each other risking getting COVID-19 [11]. Furthermore, as various cities and countries are starting to re-open from stay-at-home policies [12] and prepare plans for the financial response to boost local economies [13], construction projects appear to be an attractive alternative to do so by local authorities. Consequently, an appropriate response to the adaptation required by the built environment during the pandemic will have to account for how the construction projects can manage the spread of COVID-19 and develop alternatives to minimize the spread of COVID-19 among construction workers.

As the spread of COVID-19 has continued worldwide, research studies have started to report challenges that workers may face while performing their jobs during the pandemic context (e.g., Refs. [14,15]. Of note, a few studies have focused on the challenges that COVID-19 may have on construction workers in the current pandemic context [3,11,16]. For instance Ref. [11], proposed a model to study how the spread of COVID-19 among construction workers may impact the construction workforce's planning during a project. However, limited stud-

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ies have explored potential alternatives to manage and minimize the impacts of COVID-19 among construction workers. As the current pandemic conditions make data collection unfeasible in the construction field, the author explored the existing literature in construction engineering and management to identify potential alternatives to minimize the spread of COVID-19 among construction workers and modeling techniques to study such alternatives. As an alternative to minimize the spread of COVID-19 among construction workers should increase workers' social distancing and avoid densely populated construction sites, one alternative found in the literature that contributes to increase social distancing among construction workers is using multiple labor shifts in construction projects using day and night shifts [17–19].

Given this context, this study aims to model the impact of using multiple shifts during a construction project on the spread of COVID-19 in a construction project using an agent-based modeling approach. Quantifying the influence of using multiple shifts in a construction project regarding the spread of COVID-19 among construction workers may assist project managers to plan the workforce required to develop construction projects minimizing the exposure of workers to COVID-19.

2. Research background

This section discusses existing literature regarding the impact of COVID-19 in construction, and the use of night shifts to manage the construction workforce and identifies this as an alternative to managing construction projects in the current pandemic context. This section then discusses agent-based modeling as a feasible approach to model workers' behaviors in the current pandemic context.

2.1. Construction and COVID-19

As strict safety and sanitation measures must be taken to minimize the spread of COVID-19 around the globe, construction projects have seen a dramatic decrease in the number of workers allowed to be on the construction site. The limited number of workers on the field translates into construction projects slowing down to be completed on time. Given this context for the construction industry and the important role that the construction sector plays in recovering the economy of countries, recent literature has started to report some of the impacts that COVID-19 has had on the construction industry around the globe (e.g., Refs. [20–22].

When it comes to the literature on construction and COVID-19, recent studies have found that COVID-19 has impacted the construction industry at different levels [20,23,24]. These levels can be classified as impacts on the construction field (e.g., safety and health of workers) and impacts outside of the field (e.g., contractual consequences of the pandemic context). Impacts outside of the construction field have been focused on understanding the applicability of the force majeure clause in the current pandemic context (e.g. Refs. [16,25,26]. [26], discussed the impact that COVID-19 has had on the Nigerian construction industry [26]. Suggested that given the highly disruptive events COVID-19 has placed on the Nigerian construction industry (e.g., by slowing down completion of projects due to social distancing practices), force majeure contractual clauses should be reviewed among the parties involved so to minimize the challenges that COVID-19 has placed on construction contracts. Similarly [16], explore the force majeure clause in the context of public-private partnerships (PPP). Casady and Baxter argued that given the important role that infrastructure projects will play in the economic recovery of nations and the stress that COVID-19 is placing on force majeure clauses, it is important that these clauses are reviewed in a comprehensive manner to minimize their impacts on construction projects.

Regarding impacts on the construction field, existing studies emphasize that COVID-19 has disrupted the normal operations of construction projects, placing a high level of attention on the safety and health of construction workers on the field [11,20,27,28]. [11] focused on understanding the spread of COVID-19 among construction workers on the field based on the level of risk from the activities that workers can perform in the field. Of note [29], identified multiple risk factors that place challenges on construction projects due to COVID-19. Wang and colleagues (2020) identified that the main factors were the following: accessibility to the site, availability of workers, shortage of construction materials, and limited equipment for protecting workers against COVID-19. Similarly [21], studied the challenges of safety measures on the construction industry in South Africa to face the COVID-19 pandemic [21]. Found that there are multiple challenges to reduce the spread of COVID-19 among construction workers on the field, for instance, limited supply of personal protective equipment, risk of using public transportation for construction workers in traveling to the project, and following social distancing policies [21].

Furthermore, the same authors also explored measures to minimize the spread of COVID-19 among workers on construction sites (i.e. [27]. [27], found that the majority of construction companies studied have implemented measures to protect the safety and health of workers on the field through social distancing policies, sanitization, screening, and personal protective equipment; however, improvement is needed in implementing measures regarding screening, site access and the delivery of materials on site [27]. Similarly, Stiles and colleagues (2020) also studied the impact of COVID-19 on the construction sector, finding that measures to prevent the spread of COVID-19 among construction projects might be more successful if integrated with pre-existing safety procedures [28].

Additionally, researchers have discussed different alternatives that might help engineers and construction managers to complete construction despite the current pandemic context (e.g. Refs. [3,22,32]. [3], reported the use of product, organization, and process (POP) modeling combined with building information modeling (BIM) for the accelerated construction of two hospitals to fight the COVID-19 pandemic in China. The authors found that the use of BIM facilitated the design, planning, and construction of the hospitals [3]. Similarly [32], reported the use of a modular composite building approach to accelerate the construction of hospitals to manage the pandemic [32]. Reported the use of BIM for the design process of the hospital, combined with high-technology tools, such as drones and artificial intelligence, helped in quickly building an emergency hospital to fight COVID-19. Alternatives to minimize the spread of COVID-19 beyond sanitation practices on the construction field that have been discussed are using offsite construction [33], install physical barriers among workers, and divide the workforce into groups to increase the social distancing among workers [27].

Finding alternatives to minimize the spread of COVID-19 among construction workers is of paramount importance, as understanding such alternatives may assist the construction sector to recover from the economic impacts due to COVID-19 [22]. Existing literature has identified a variety of impacts of COVID-19 on construction projects and has also discussed some alternatives to minimize such impacts. However, there is a gap in quantifying the potential impact of such alternatives in minimizing the spread of COVID-19 in construction projects.

2.2. Using night shifts in construction

Existing studies in literature recognize that workers performing their job during night shifts may see affected their performance depending on the job being performed [34–36]. Specifically, in the context of construction projects, the use of night shifts has been related to negative outcomes when compared with day shifts, such as the higher risk of injuries and accidents [37], lack of sleep from construction workers [38], and loss of productivity [39]. However, other studies have suggested that no alternative should be dismissed when scheduling the workforce during a construction project [18,19] and that multiple shifts may help to reduce workers' fatigue by spreading working hours of the labor force [17]. Namely, it has been reported that project characteristics should be assessed to decide whether night shifts may be a convenient alternative [18], and that the use of more than one labor shift can be optimized to minimize the negative effects of night shifts when construction projects have to accelerate their schedules [19]. More recently has also been suggested that using multiple shifts in construction projects may be beneficial as workers may be more efficient due to a less congested work environment [17]. Interestingly, as examples of construction projects successfully accelerating their schedule using day and night shifts have been reported during the current pandemic context (e.g. Refs. [40,41], this suggests the alternative's validity as a way to move forward with the development of construction projects in a safe manner. This existing gap motivates to quantify the impact of using night shifts in managing the construction workforce in the current pandemic context.

2.3. Modeling the construction workforce

Multiple studies in the field of construction engineering and management have used Agent-Based Modeling (ABM) to study the role of construction workers in construction projects (e.g., Refs. [42–44]; Osman, 2012; [45,46]. For instance Ref. [45], studied the behavior of individuals workers and the interactions among construction crews to model the labor efficiency of a project as emergent behavior. Similarly [46], used ABM to study the influence of the interactions between construction workers and the construction manager regarding workers' safety behaviors.

Of note, ABM has been identified as a flexible technique that allows modeling workers' individual behavior and their interactions within construction projects to observe the behavior that emerges from such interactions [43,46]. Additionally, ABM is a simulation tool that allows to test for the implementation of policies and alternatives and simulates the emergent behavior from workers within a construction project. Given these findings in the existing literature, this study uses ABM as a modeling tool to study the influence of multiple working shifts to minimize the spread of COVID-19 among construction workers.

3. Methods

3.1. Agent-based modeling (ABM)

Agent-based modeling (ABM) is a modeling approach to study complex systems based on the notion that by modeling the individual elements of a complex system and how these individual elements interact within the system, the systems' behaviors will emerge [45,47–49]. The individual agents' modeling is through the definition of rules that govern their individual behavior and how they interact with the other agents within the same environment. The definition of agents' rules allows to capture the heterogeneity among agents' behavior and provides flexibility for modeling purposes as these rules can be either deterministic or stochastic. Interesting to note, it is the combination of agents' individual behavior with the interactions among multiple agents that results in the system's behaviors emerging through the modeling process [50]. It is the ability to capture the individual heterogeneity of agents and the modeling of the systems' emergent behavior that allows capturing the system's complexity [49]. Moreover, ABM can be used to simulate multiple scenarios (e.g., what-if scenarios) to evaluate the influence of multiple parameters or strategies included in the model [11,46].

ABM's capacity to focus on the behavior of the individual components of a system, the capacity to include stochasticity of processes, and the capacity to simulate multiple scenarios, make ABM the simulation tool that best fits with the objective of this study, which is to quantify the influence of using multiple shifts in construction projects to minimize the spread of COVID-19.

3.2. Why using ABM in a pandemic context?

Given the current pandemic context, where the spread of COVID-19 is mostly through the interaction among persons, construction workers' role will be of paramount importance for minimizing the spread of COVID-19 on construction projects, so workers can safely perform their jobs. This is important as construction projects will adapt and expand the built environment to the unprecedented needs due to COVID-19 [2]. Additionally, due to the same pandemic context, the data collection process visiting construction fields to observe and record construction workers' behaviors is severely limited, so modeling techniques appear to be the most feasible and safe alternative for now.

ABM presents a tool to understand how COVID-19 may impact construction workers. In this context recently [11], used ABM to study how the COVID-19 may spread among construction workers. However, limited studies exist regarding understanding potential alternatives to minimize the impact of COVID-19 among construction workers.

Therefore, this study proposes using ABM to understand the influence of using multiple labor shifts to minimize the spread of COVID-19 among construction workers. To do so, the model accounts for the health status of workers regarding the spread of COVID-19 and the assignment of workers to either daily or night shifts. Recognizing our limited capacity to visit construction sites to collect actual data regarding the spread of COVID-19 among workers, due to safety concerns, six scenarios are run with the model aiming to overcome the lack of actual data from the spread of workers on construction sites, to account for the uncertainty of parameters and variables used in the model, and to provide a range of model's results that may be representative of a variety of real-life scenarios in the current pandemic context.

3.3. Model formulation

Fig. 1 shows the abstraction of the model and its components for the analysis, while Table 1 provides an explanation of the construction worker agents and the parameters and variables used in the model.

There is one type of agent in the model that represent construction workers within a construction project. The agents transition between being working on the project and leaving the project for the next working day. The simulation starts for each working day, with the manager assigning the construction worker to the corresponding day and night shifts. Once the construction worker agent enters the working shift, the workers' health status is simulated, resulting in two possible outcomes, healthy or sick due to COVID-19. Construction workers classified as sick must go into a quarantine period of two weeks, and once such time has passed, the worker changes to a healthy status and returns to the project the next working day. As COVID-19 is spread through people's interaction, it is assumed that by adding a new shift (i.e., night shift), the distribution of construction workers throughout the construction project decreases as well as the contagion rate among workers, as the same number of workers performing their activities during the project is divided in two shifts instead of only one (i.e., day shift). This assumption is aligned with public policies aiming to minimize COVID-19 using social distancing among persons [2]. Therefore, as the number of construction workers assigned to the night shift increases, the contagion rate of construction workers assigned to the day shift decreases as fewer workers are on the same shift, thus, reducing workers' density on the shift [17].

Regarding the application of multiple shifts, only two shifts were used in the model, as given the current pandemic context, there is evidence in real projects that once a shift ends, the construction company/contractor should go through cleaning and disinfecting procedures to ensure that COVID-19 is not spread among workers from different shifts [41], and as such, leaving limited time to the possibility of having more than two working shifts per day.

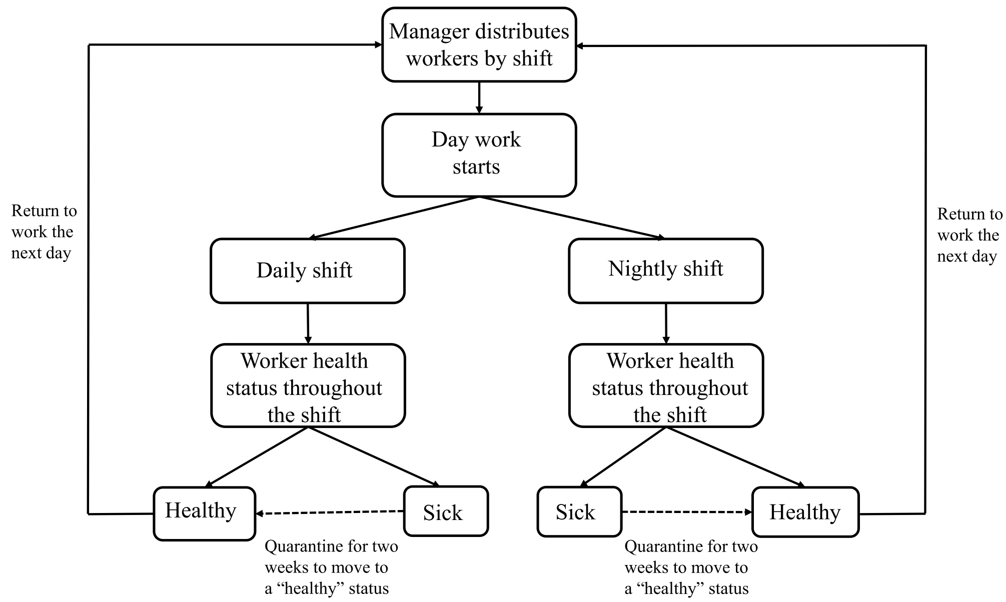

Fig. 1. Abstraction of problem.

Table 1
Object class and associated parameters, variables, and rules.

Object Class	Function	Parameters and Variables	Examples of agents' rules
Construction workers	Simulation of workers' health status during construction project regarding the spread of COVID-19 using multiple shifts.	• Percentage of workers assigned to each shift. • Time when the shift starts and ends. • Percentage of workers classified as healthy. • Contagion rate among construction workers on the same shift.	Contagion rate among workers depends on the number of workers assigned to the shift. Namely, the more workers in a shift the higher the probabilities to get sick with COVID-19.

3.4. Model implementation

The modeling process simulates 100 construction workers' agents involved in one construction project throughout their working days. The model simulates working days, so a month of simulated time is approximately 24 h by 20 working days, which is 480 h. Both shifts (i.e., day and night) are assumed to last for the same number of hours, which is between 8 and 9 working hours from Monday to Friday. The results presented in this study consider a total simulation time of three working months or 1440 h, and the total number of healthy workers assigned to both shifts in the simulated construction project is reported. This assumption was made to provide results that allow identifying trends and emerging behavior from the construction workers regarding the spread of COVID-19 with multiple labor shifts, as revealing the emergent system's behavior is the aim of using an agent-based modeling approach.

The system's behavior is assessed using three key variables, the distribution of workers to each shift (i.e., day and night), the contagion rate among workers on the same shift, and the number of healthy construction workers at the project level. These variables allow the author to observe and understand the impact of using multiple shifts during a construction project on the spread of COVID-19 in a construction project. Acknowledging that the data collection process in real construction projects is severely limited given the current pandemic context, multiple scenarios are presented where the values defined for the key variables vary; this aims to be as representative as possible of the conditions on a real construction project. Six scenarios with different combinations of values for these variables are presented in this study. The results presented in this study were modeled using the object-oriented programming tool AnyLogic [51], which is a simulation software based on the Java environment that supports multiple modeling techniques for complex systems (i.e., system dynamics, discrete event simulation, and agent-based modeling). AnyLogic has been used to simulate complex systems (e.g., Ref. [52]. Notably, it has been used in the existing literature to simulate the spread of epidemics (e.g. Refs. [53,54], and to simulate the role of construction workers on construction projects (e.g., Refs. [23,24,55,56].

3.5. Verification and validation

The model's verification and validation involve an iterative process since the model formulation through the model simulations and the interpretation of the results [57]. Further, verification and validation are fundamental steps for modeling approaches and problems where limited information exists [43], which is the case of the impact of COVID-19 on construction projects and what alternatives can be used to minimize its impacts among construction workers.

These processes were undertaken through discussions with three different subject matter experts (SME). A researcher with more than ten years of experience, a construction worker and a civil engineer, each with approximately 30 years of experience. Notably, these last two SME were familiar with the influence that COVID-19 had on construction projects as both were involved in construction projects under development when the pandemic due to COVID-19 began. The validation of the computerized model was done by applying sensitivity analyses to the model's parameters.

3.6. Case study

The case study aims to illustrate the results that the model can generate. The case study aims to provide as much flexibility as possible, so the model and the results can be transferable and adaptable to different real-life scenarios. This criterion to define the case study structure is used as it is expected that this model can be potentially used in different locations being affected by COVID-19. Table 2 shows the variables and values used in the case study presented in this study.

Data to develop the case study can be classified into two categories, one category relates with the modeling of the spread of COVID-19 among construction workers, and the second category with the conditions that construction workers face when working in multiple shifts. The data for the first category was obtained from the recent literature about COVID-19 (e.g. Ref. [11], and information published by international organizations related to the construction industry (e.g., Ref. [10]. The information about COVID-19 used in this case study is far from being comprehensive of the current pandemic context; however, as discussed by multiple studies about COVID-19, "*much of the information about COVID-19 to feed computer simulations is still unknown and must be estimated or assumed*" [58]. Moreover, multiple studies claim that data collection processes must be adapted to the new pandemic context due to COVID-19 [59–61], and that modeling studies have contributed and will continue to do so in the fight against COVID-19 [58,62].

The second category of data was obtained from the existing literature in the construction engineering and management field, so the conditions presented in the case study are more likely to be representative of what construction workers face in construction projects.

Six scenarios are developed using the proposed model in this study; Table 3 shows the parameters' values for the six different scenarios. These six scenarios aim to represent a range of potential situations regarding the application of day and night shifts in construction projects in the current pandemic context. Scenario 1 represents the situation where all construction workers must work on the same shift (i.e., day shift), which due to the potential high density of workers on the field, is coupled with a high contagion rate of COVID-19 (see Table 3). Scenarios 2 through 6 aim to represent what-if scenarios where construction workers are gradually divided into two shifts (i.e., day and night) in increments of 10% of workers, thus, reducing the density of construction workers on each shift (i.e., day and night) and, with that, decreasing the contagion rate of COVID-19 among workers. Table 3 shows the distribution of workers by shifts involved in the construction project and the contagion rate of COVID-19 among construction workers used for each scenario for the day and night shifts. Table 3 shows the distribution of workers by shifts involved in the construction project and the contagion rate of COVID-19 among construction workers used for each scenario, for the day and night shifts.

Table 2
Parameters and Variables used in the case study with their corresponding justification.

Parameter/Variables	Value Range	Justification
Population of workers used in the model	100	• Commonly used to study construction workers behaviors within construction projects (Ahn et al., 2013 [11];
Distribution of construction workers among multiple shifts	0–100%	• Range varies depending on specific needs of the construction project [18,19]
Rate of infection on workers of each shift	0–10%	• As limited information exists about the contagion rates among construction workers a range of values is used [60] • It is assumed that the more workers are assigned to a shift, the higher the probabilities are going to be for workers to get infected as the workers' density increases. • The contagion rate percentages are lower than in previous studies [11] as it is assumed that as cities and countries are re-opening, the spread of the virus is more controlled
Time of shifts	8–9 h	• The length of the shift is based on the traditional extension of labor shifts in construction projects [19]
Quarantine extension	Two weeks	• Duration of the quarantine for sick workers [30]

Table 3
Parameters' values for the six scenarios.

	Distribution of workers		Contagion rate among workers	
	Day shift	Night shift	Day shift	Night shift
Scenario 1	100%	0%	10%	N/A
Scenario 2	90%	10%	9%	1%
Scenario 3	80%	20%	8%	2%
Scenario 4	70%	30%	7%	3%
Scenario 5	60%	40%	6%	4%
Scenario 6	50%	50%	5%	5%

N/A: not applicable for this case.

3.7. Limitations

It is acknowledged as a limitation of this study that the agent-based modeling approach used may have oversimplified the real-life conditions faced by construction workers on construction projects. Namely, the use of night shifts to accelerate construction projects may negatively affect construction workers, which are not included in the workers' distribution on multiple shifts. However, it must be recognized that the use of multiple shifts may provide considerable benefits regarding the risk reduction of COVID-19 spread among construction workers. Additionally, multiple scenarios are included to account for a wide range of possible cases in the model to minimize the impact of limited real-life data availability due to the pandemic.

Another limitation of this study is the lack of data from a real project regarding the contagion rate of COVID-19 among construction workers to simulate workers' behavior within the model. Nonetheless, as the current pandemic context makes visiting construction projects unsafe and risky for researchers, a computational model can provide valuable insights for construction managers who need to accelerate a construction project but using alternatives that can minimize the spread of COVID-19 among construction workers.

4. Results

Figs. 2–7 show the results for the six scenarios developed using the proposed model. Additionally, Table 4 shows the average percentage of healthy workers on the project and the lowest percentage of healthy workers on the project for each scenario. These results illustrate the influence that using different combinations to accommodate construction workers using multiple shifts may have on the spread of COVID-19 among construction workers.

5. Discussion

The proposed agent-based model simulates the impact of including two shifts to minimize the spread of COVID-19 in a construction project using six scenarios (see Table 4). The results show that for scenario 1, where all workers are assigned to one shift, on average less than half of the construction workers involved in a project remain healthy (i.e., without COVID-19), and the lowest number of healthy construction workers during the duration of the project was 31%. Thus, it is possible that due to the spread of COVID-19, construction projects might have to be developed with approximately one-third of the construction workforce.

Scenario 1 captures the most common way in which construction workers are organized to perform their work, using one shift per working day (i.e., pre-pandemic). If the construction workforce of a project is managed in the same way before the COVID-19 pandemic, the spread

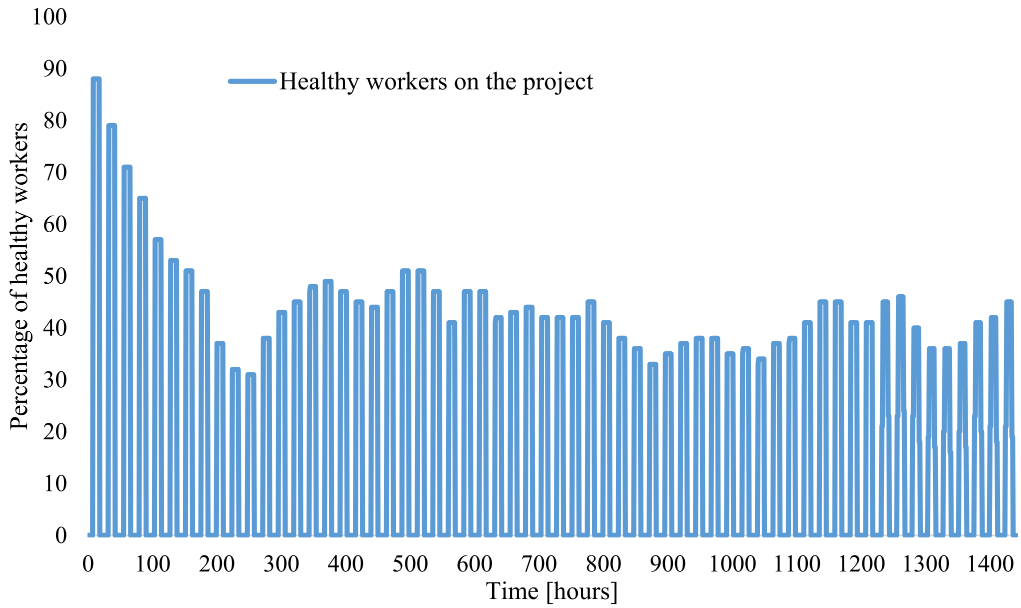

Fig. 2. Model's results for scenario 1.

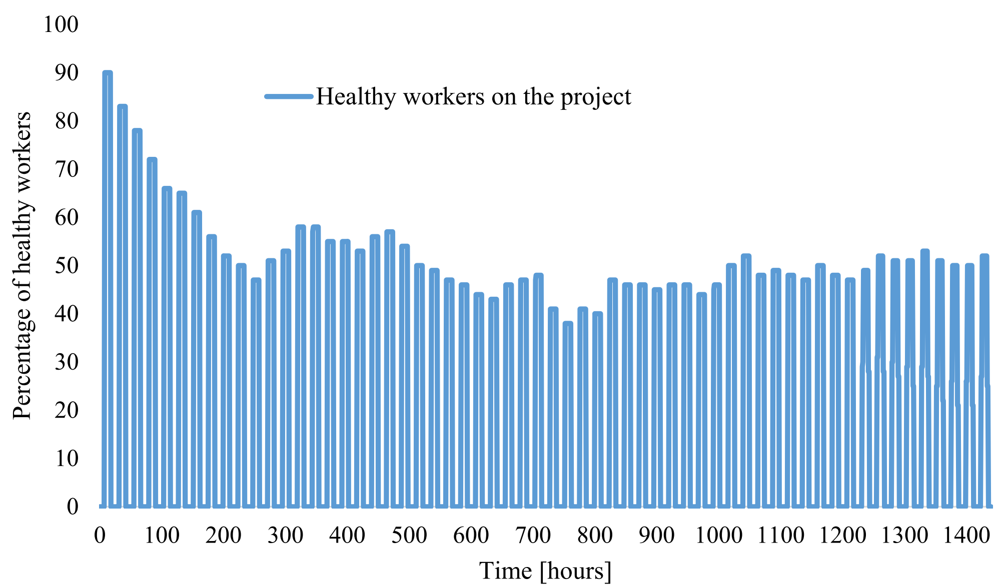

Fig. 3. Model's results for scenario 2.

of COVID-19 among workers may reduce the workforce's availability in a project by more than half (Table 4). This result emphasizes considerable challenges for construction managers, as construction projects that keep business as usual may suffer delays and cost overruns if managers cannot keep their workforce healthy.

Scenarios 2 through 6 show the impact of gradually distributing construction workers into two shifts (i.e., day and night). In scenario 2 (Fig. 3), it can be observed that the low peak of the percentage of healthy workers is a bit higher than for scenario 1 and that the average number of healthy workers throughout the project is also higher compared with scenario 1 (Table 4). When looking at scenarios 3–6 (Figs. 4–7), it can be observed that as the percentage of construction workers assigned to the night shift increases, both the average percentage of healthy workers and the lowest percentage of healthy workers on the project improve (Table 4). Moreover, this trend can also be observed in Figs. 2–6. Specifically, the best results from a workers' health standpoint were scenarios 5 and 6 (Figs. 6 and 7), where the percentage of workers assigned to the night shift was 40% and 50%, respectively. In these two scenarios, the average percentage of healthy workers and the lowest percentage of healthy workers were roughly 20% higher than in scenario 1 (Table 4). These results show that by distributing workers on multiple shifts may reduce the spread of COVID-19 on construction projects. Therefore, making the use of multiple shifts a feasible alternative for construction managers to fight the spread of COVID-19 among construction workers.

From a construction manager standpoint, having a more stable level of healthy and available workforce to develop a construction project can facilitate the management tasks and also increase the chances that a construction project can be completed on time, on budget, and minimizing the health risks that the spread of COVID-19 places on construction workers. The results of this study are aligned with previous studies that have identified the use of night shifts to manage the construction

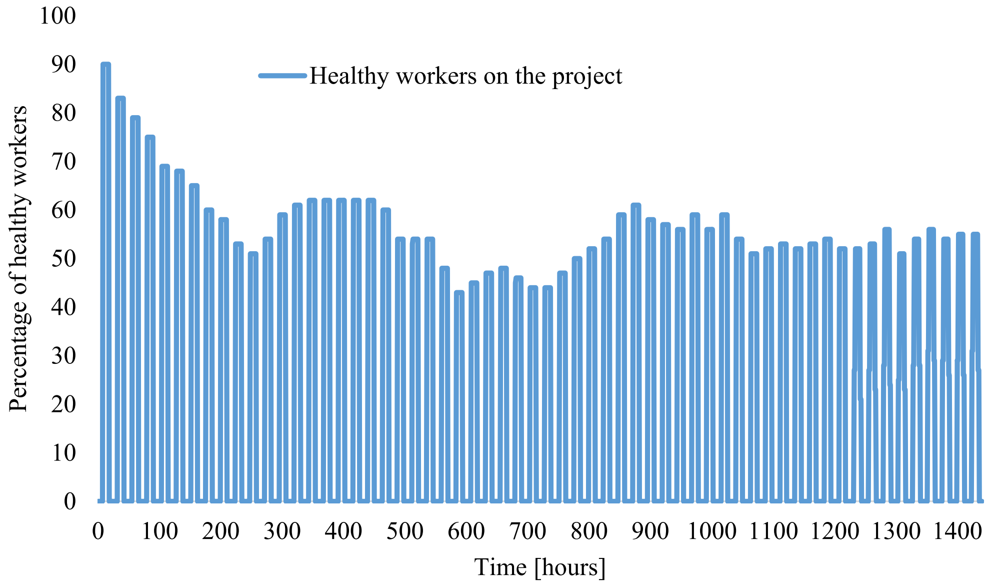

Fig. 4. Model's results for scenario 3.

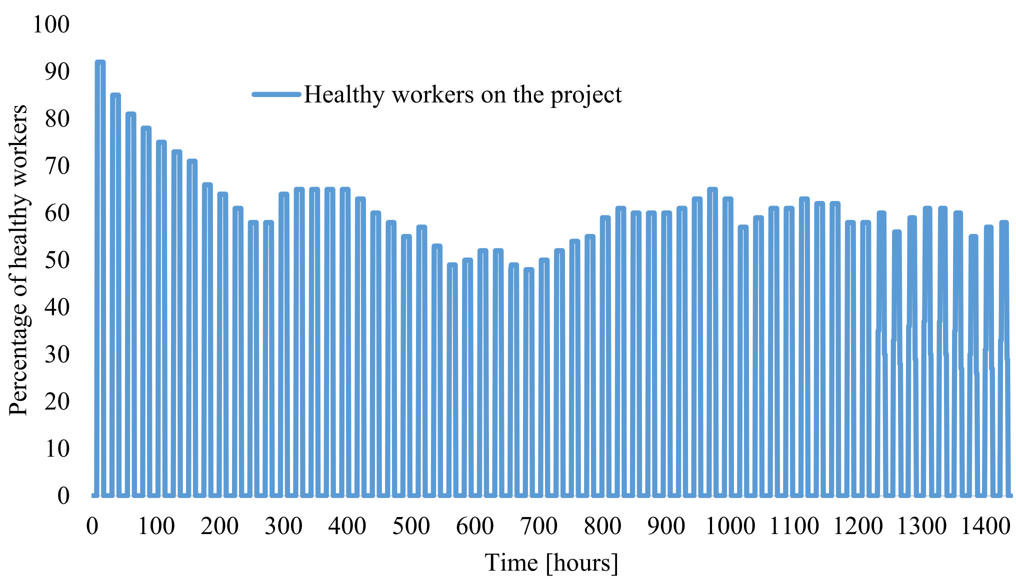

Fig. 5. Model's results for scenario 4.

workforce a feasible alternative based on the context in which a construction project needs to be developed [17–19].

5.1. Study contribution

This study contributes to the body of knowledge by quantifying and showing through simulations that using multiple shifts can be a feasible alternative for construction managers to reduce the spread of COVID-19 among construction workers. This contribution is supported by the results obtained in the simulation of the six scenarios that simulated how COVID-19 spreads among construction workers when using a combination of different distributions to accommodate construction workers using day and night shifts in construction projects. This contribution is aligned with studies adopting modeling approaches to better understand how we can be better prepared to manage the impacts of the COVID-19 pandemic in different contexts of our society (e.g., Refs. [58,62].

In practicality, this study shows that by using night shifts, the average number of healthy workers during a construction project can be increased by roughly 20% compared with the case in which only one shift is used to develop a construction project. Hopefully, this study will spark the discussion regarding potential alternatives to minimize the spread of COVID-19 among construction workers. As important as the reopening of the economic recovery that cities and countries are facing—of which the construction industry plays a key role—it is that we keep construction workers as safe as possible of COVID-19.

6. Conclusions

This study proposes an agent-based modeling (ABM) framework to simulate the influence of managing the construction workforce using two shifts (i.e., day and night) on the spread of COVID-19 among workers in construction projects. As limited information from the field is available to develop the model due to the pandemic context, multiple scenarios were developed to account for a wide range of cases that

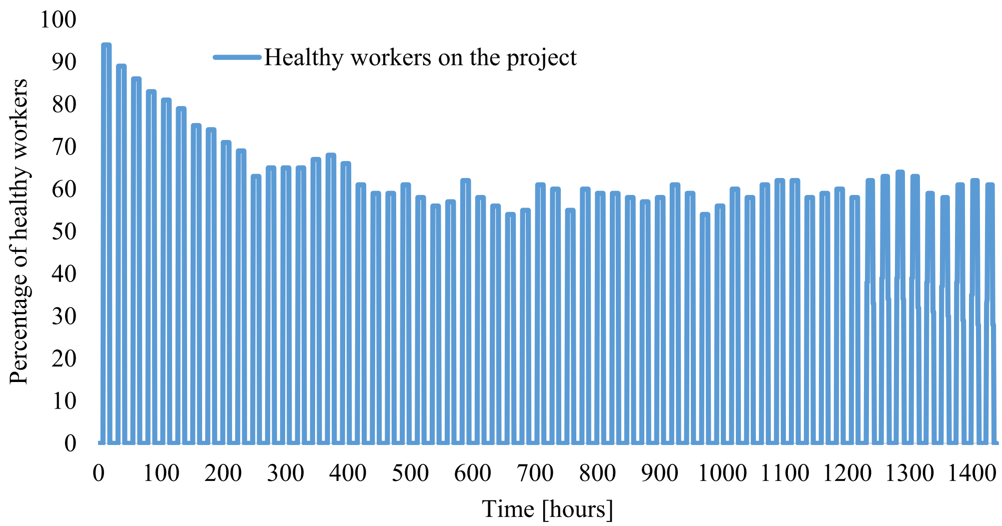

Fig. 6. Model's results for scenario 5.

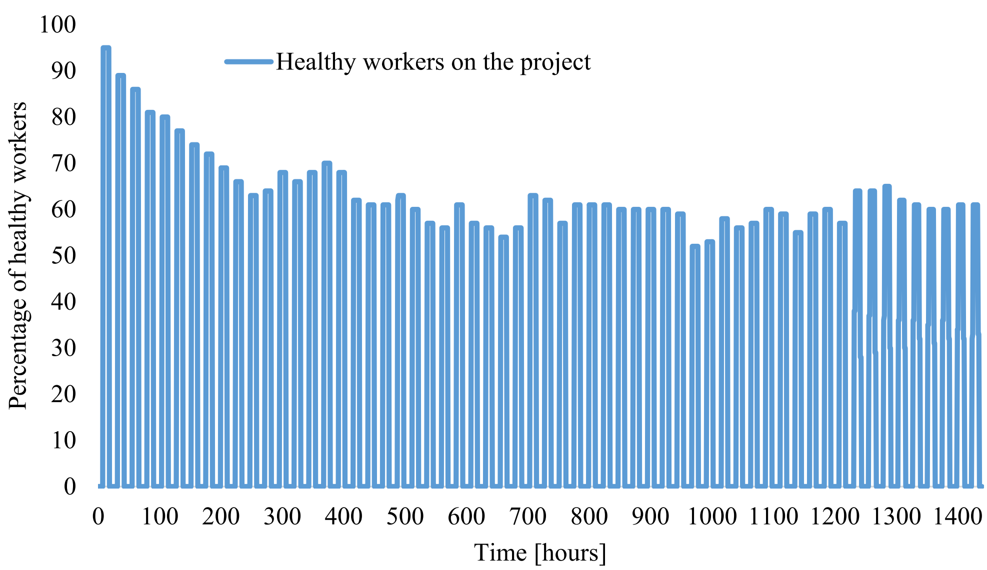

Fig. 7. Model's results for scenario 6.

Table 4
Healthy workers on the project for each scenario.

	Lowest percentage of healthy workers on the project	Average percentage of healthy workers on the project
Scenario 1	31%	43%
Scenario 2	38%	50%
Scenario 3	43%	55%
Scenario 4	48%	59%
Scenario 5	54%	62%
Scenario 6	52%	62%

might occur in real-life projects. This study found that assigning construction workers to multiple shifts increases the average percentage of workers classified as healthy regarding the spread of COVID-19. Managing 100% of the construction workforce using only one shift resulted in an average of 43% of workers classified as healthy, while assigning approximately half of construction workers to each shift (i.e., day and night) resulted in an average of 62% of workers being healthy (i.e., without COVID-19) during a construction project. This study emphasizes that using multiple shifts is a feasible alternative to developing construction projects while minimizing the risk of spreading COVID-19 among construction workers. Moreover, this study reinforces the value of studies using modeling approaches to understand potential alternatives to manage COVID-19 in the construction sector. Future studies can explore workers' perceived safety of working on night shifts to assess if construction workers are willing to work on multiple shifts to minimize their chances of getting COVID-19. Additionally, the author of this study is currently exploring other alternatives to reduce the impacts of COVID-19 on construction projects, namely modeling the use of multi-skilled workers, so the project disruptions due to the reduction of the workforce may be minimized. Ultimately, another avenue for future studies is to assess how countries' laws may support night shifts for construction projects. For instance, some countries have defined initiatives to fight COVID-19 that limit working hours during nights, such as lockdowns or curfews.

Author statement

Felipe Araya: Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Data Curation, Writing – Orignial Draft, Visualization, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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