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Research Article

Modeling the influence of multiskilled construction workers in the context of the covid-19 pandemic using an agent-based approach

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Abstract: as the COVID-19 pandemic continues, construction projects have struggled to be completed. As such, it is necessary to find alternatives that optimize the limited human resources that can be working on construction sites. One alternative to do so is using multiskilled workers so workers can be reassigned to construction activities minimizing projects' disruption due to workers getting contagion with COVID-19. This study simulates the influence of multiskilled workers in the development of a construction project in the context of the COVID-19 pandemic using an agent-based modeling approach. The aim of the study is to quantify the influence of multiskilled workers in the deficit of construction workers due to COVID-19. The proposed model generates six scenarios to include the uncertainty from limited data from the field due to the pandemic context to quantify the deficit of workers to develop a construction project. This study found that using multiskilled workers reduces the deficit of workers required to perform critical activities in construction projects. More specifically, it can reduce the average deficit of workers roughly in half when compared with the alternative of using only single-skilled workers, from 33.4% to 16.7% of deficit. Consequently, multiskilled workers represents an alternative for construction managers to deal with the disruption from COVID-19 in construction projects from a workforce management standpoint. Understanding alternatives to minimize the impacts of COVID-19 in construction projects may assist engineers and managers in applying strategies to develop construction projects accounting the limitations that COVID-19 places on construction sites.

Keywords: construction, COVID-19, multiskilled workers, construction management, agent-based modeling.

1. Introduction

As the pandemic due to COVID-19 continues around the globe, multiple studies have focused on the consequences of the pandemic on our society (e.g., Aktar et al., 2021; Mofijur et al., 2021). Multiple sectors have been able to transition to virtual environments, for instance, the education sector through online education. However, that is impossible for sectors that are required to perform physical activities on the field, such as the construction sector. The completion of construction projects has been challenged by the implementation of stay-at-home and social distancing policies among workers (ENR, 2020a). As a result of policies to fight COVID-19, the number of construction workers allowed to be on construction sites has drastically decreased, and construction projects have been halted or delayed due to the fight against COVID-19 (ENR, 2020a; ENR,

2020b). Furthermore, the availability of qualified construction workers may be limited as the fear of getting infected with COVID-19 may reduce the number of construction workers willing to participate in construction projects (ENR, 2020c). This context placed a significant challenge for construction engineers and managers as they must optimize the limited construction workforce willing and allowed to be in the construction fields due to the influence of COVID-19.

The interaction between environmental factors of construction projects and construction workers has been studied in the past (e.g., Chan et al., 2012; Chun et al., 2010; Lee et al., 2019; Weiss et al., 2018; Yi et al., 2017). For instance, Chun et al. (2010) studied the sensitivity of chemical exposure among construction workers. Similarly, Chan et al. (2012) explored the impact of workers performing their work in hot and humid environments. Chen et al. (2019) studied the health risks of construction workers due to dust exposure in tunneling projects, and Lee et al. (2019) explored the influence of noise exposure among construction workers. Interesting to note, most of these studies recommend that interventions are required to minimize the influence of environmental factors on construction workers. In response to the spread of COVID-19, multiple intervention methods have been proposed for the population to minimize its spread, such as quarantines, social distancing, and wearing face masks (Zhang et al., 2020).

However, limited intervention methods have been proposed specifically for the development of construction projects. Of note, interventions that may be implemented in construction projects must address the safety of workers but also to allow the successful development of construction projects. As such, by reviewing existing literature in construction engineering and management, an alternative to manage the limited workforce that construction projects may face, is the use of multiskilled workers (Haas et al., 2001; Lobo and Wilkinson, 2008; Nasirian et al., 2019a).

A Multiskilled construction workforce refers to workers that have the skills so they can participate in one or more construction processes outside their primary trade during a project (Carley et a., 2003; Gomar et al., 2002). In recent years, research in multiskilling has experienced an increasing trend regarding the construction engineering and management field (e.g., Nasirian et al., 2019a; Sarihi et al., 2020). The existing literature regarding multiskilled construction workers has been focused on three big areas: repetitive projects, onsite construction, and offsite construction (Nasirian et al., 2019a); finding multiple advantages and disadvantages regarding the use of a multiskilled construction workforce. This review of existing literature aims to focus on aspects of multiskilling that may be relevant for construction managers dealing with the current COVID-19 pandemic context in the construction field.

In terms of challenges and disadvantages associated with construction multiskilling workers, Carley et al. (2003) studied non-union workers in the United States and found that one of the challenges was that construction workers might be unwilling to train to get extra skills as workers may have concerns about the additional payments due to the extra skills. A disadvantage of multiskilling reported in literature is the negative learning effect it may have on construction workers' primary skills. Wang and colleagues (2009) found that multiskilling may negatively affect the learning curve of construction workers. Similarly, Ho (2016) found that multiskilling, although it was an alternative to face labor shortages in the Hong Kong construction industry, it was perceived as leading to a lack of specialization among construction workers.

Conversely, the literature has identified multiple advantages of using multiskilled workers in construction projects; for instance, Hegazi et al. (2000) found that using multiskilled workers lead to more efficient use of human resources in construction projects thus, saving time and money. Similarly, Lill (2009) found that using multiskilled construction workers, the workforce of a construction project is more stable compared with a workforce only based on single-skilled workers. This stability of using multiskilled workers is captured by having fewer overloads and slack periods for the multiskilled construction workers.

Liu and Wang (2012) explored how to optimize linear project scheduling using multiskilled crews and found that multiskilling can be used to optimize a project duration and improve the flow of work in a construction project (Liu and Wang, 2012). Interestingly, Gomar et al. (2002) studied the optimization of allocating multiskilled workers in a construction project and found that the benefits of using multiskilled construction workers have a limitation. Gomar and colleagues (2002) found that in terms of workforce composition, most of the benefits of multiskilling were marginal when there is roughly 20% of

multiskilled workers in the workforce of a project. Additionally, Gomar et al. (2002) found that the benefits were also marginal for construction workers with skills in two or three crafts.

The use of multiskilled workers has been found to have multiple benefits regarding the management of construction projects, such as savings in construction time (Liu and Wang, 2012), reduced construction cost (Hegazi et al., 2000), and optimize crew composition (Ahmadian Fard Fini et al., 2016). Therefore, based on the existing literature, multiskilled workers may help construction managers minimize challenges placed by the pandemic due to COVID-19 on the successful management of construction projects. Moreover, there is a gap in the literature regarding the influence that multiskilled construction workers may have on construction projects while facing a pandemic context that needs to be further studied.

As the pandemic due to COVID-19 was completely unexpected and spread rapidly around the globe, limited access has existed to investigate the impacts of COVID-19 on construction projects due to the health exposure from researchers and workers, so limited studies exist about COVID-19 and Construction projects (e.g., Alsharef et al., 2021; Araya, 2021b). Araya (2021b) proposed an agent-based model to study the spread of COVID-19 among construction workers based on the level of risk that construction activities may be classified. Of note, Araya (2021b) discussed the existing limitations that the pandemic places on visiting construction sites to study the impacts of COVID-19 on construction projects, and as such, modeling and simulation tools can be of great assistance in studying potential alternatives for construction managers to deal with the impacts of COVID-19 in construction projects.

Given the influence that managers have on the performance of construction projects (Pham and Kim, 2019), construction managers are facing a challenge when it comes to optimizing the composition of the workforce so that construction projects can be developed despite limited workforce availability due to constraints placed by the fight against COVID-19. An approach that may provide more flexibility for construction workforce management is having multiskilled workers. As such, the purpose of this study is to evaluate the influence of multiskilled construction workers in the context of the COVID-19 pandemic using a modeling approach. This study contributes by researching an alternative to facilitate more efficient construction workforce management during a pandemic context.

An overview of the existing literature has been introduced. Then, the section with the methods describes the modeling approach used in this study, the model formulation, implementation, verification and validation, and a hypothetical project with the multiple scenarios to illustrate the proposed model is presented. Finally, the results, the discussion, and the conclusion sections are presented.

2. Methods

In this section, the agent-based modeling technique used in this study is explained, and the formulation and implementation of the proposed model is presented. This method provides a tool to achieve the objective of this study, which is to quantify the influence of multiskilled workers in the deficit of construction workers due to COVID-19.

2.1. *Agent-based modeling*

Agent-based modeling (ABM) is a technique that models complex systems by simulating the behavior of system's individual elements (Bonabeau, 2002). The system's behavior emerges through the interactions among the multiple individuals (i.e., agents) of the system (Macal and North, 2005). The systems' complexity is captured by the heterogeneity of the individual elements and their interaction (Bonabeau, 2002). The capacity to capture the heterogeneity of individual agents and the emergence of complex behaviors from the system are two distinguished attributes from ABM (Macal and North, 2005).

Multiple studies have modeled complex systems using ABM (e.g., Araya, 2021b; Huang et al., 2021; Osman, 2012; Watkins et al., 2009; Zhang et al., 2019). Among the studies that have modeled construction environments, the model's individual elements (i.e., agents) were the construction workers. These studies sought to understand how workers' behaviors influenced multiple aspects of project performance, such as productivity and safety.

For instance, Watkins and colleagues (2009) studied individual workers' behavior and interactions at the crew level to understand labor efficiency in construction project environments. Similarly, Zhang et al. (2019) studied the interactions among workers and construction managers in the context of the safety behaviors of construction workers. More recently, modeling the influence of the pandemic context in construction projects, Araya (2021b) proposed an agent-based model to study the spread of COVID-19 among construction workers based on the level of risk associated with construction activities in the pandemic context. Of note, Araya (2021b) emphasized the need for modeling and simulating tools to understand the impact of COVID-19 in construction projects, as it is still unsafe to visit construction sites for researchers to collect field data due to COVID-19.

Based on the review of the existing literature, it is acknowledged that ABM is a technique that suits very well with the modeling of workers in construction environments. Although efforts have been made to model the spread of COVID-19 among construction workers using ABM, limited studies have addressed the understanding of potential alternatives for construction managers to deal with a limited workforce due to COVID-19.

2.2. *Model Formulation*

Figure 1 shows the abstraction of the model and its components for the analysis. The aim of the model is to simulate the development of a construction project during the COVID-19 pandemic focused on the influence of having single skilled/ multiskilled workers available to develop the project.

There is one type of agent in the model that represents the construction workers in the simulated construction project. Initially, there is an estimated number of construction workers that are required to develop the construction project (i.e., pool of workers required to develop construction project in Figure 1). In real life projects, this estimated number of workers is typically estimated by the construction management team as the required workforce to complete the project. Of note, the construction workforce includes single skilled and multiskilled workers. The proposed model also accounts for the possibility that a percentage of the pool of construction workers participating in the project are multiskilled. The idea behind this is that multiskilled workers may perform a variety of construction activities compared with single skilled workers, and as such, it provides more flexibility to schedule the activities to complete a construction project during the current pandemic context. This is of paramount importance especially given the reduced workforce that construction projects are facing due to the COVID-19 pandemic.

As the proposed model aims to simulate a construction project during the current pandemic context, construction workers might get infected with COVID-19, and as such, these workers must leave the construction site to have a quarantine period, and then return to the project. The proposed model includes the contagion of workers using a contagion rate. Conversely, construction workers that are classified as healthy can continue to participate in the project.

The construction workers that stay healthy are classified as workers required to perform critical or non-critical activities in the project. Critical activities are those that are a part of the critical path of the project and non-critical activities are those that are not part of the critical path. The aim of classifying construction workers required by each type of activity (i.e., critical, non-critical) is to twofold. First, to compute the deficit of workers required to perform the two types of activities. Second, to evaluate the influence of having multiskilled workers in managing the deficit of workers required for critical activities. The deficit of workers is calculated as the difference between the estimated number of workers required to perform critical/non-critical activities in the project with the actual number of workers available to perform critical/non-critical activities. Moreover, it is assumed that multiskilled workers can replace a single skilled worker when there is a deficit of workers to perform critical activities.

As limited information exists regarding alternatives to minimize the impact of the spread of COVID-19 among construction workers, multiple scenarios are simulated to capture the influence of having multiskilled construction workers in the construction project. This is done as multiskilled workers may be assigned to perform multiple construction activities (i.e., in the case of this study, critical and non-critical activities). It is assumed that the flexibility of having multiskilled workers in the

workforce that can be assigned to critical activities when needed may assist in reducing the deficit of workers to perform critical activities in construction projects during the COVID-19 pandemic. As visiting construction sites due to the COVID-19 pandemic is still too risky, the model simulates multiple scenarios with a range of values for the percentage of multiskilled workers available in the construction project to overcome the existing limited information.

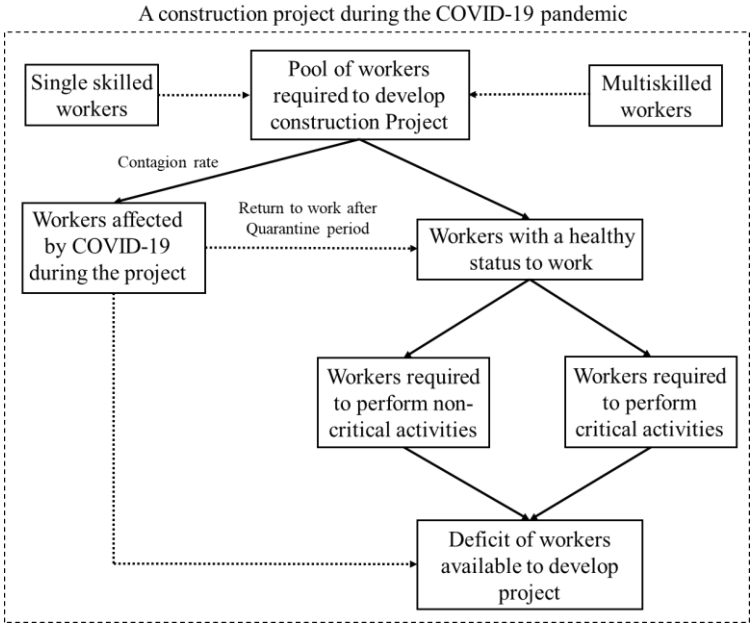

Figure 1. Abstraction of the problem.

2.3. *Model Implementation*

The simulation process starts with the arrival of construction worker agents to work at the project. Once arrived, construction workers are classified as affected by COVID-19 or in a healthy status to perform their work during that day (i.e., simulating a testing process at the beginning of the working day). As limited information is yet available regarding the rate of spreading of COVID-19 among construction workers, the contagion rate is included as a stochastic variable to capture the fact that different construction activities may involve different rates of contagion among construction workers. Of note, the use of stochastic variables to account for the uncertainty related to the spread of COVID-19 among construction workers in simulation settings has been discussed in recent literature (e.g., Araya, 2021b; Currie et al., 2020).

As there is limited information about how multiskilled workers may provide more flexibility to schedule activities in construction projects in the current pandemic context, multiple scenarios are developed using a range of values for the percentage of multiskilled workers between 0% and 20%. This range is used as existing literature suggests that there is a limit to the benefits of using multiskilled workers around the 20% of the workforce composition being multiskilled workers in construction projects (Gomar et al., 2002). Ultimately, construction workers available to work on the simulated construction project are classified into two groups: workers who perform critical activities for the project and workers who perform activities that are not critical for the project. Workers that were classified as multiskilled are capable of performing both, critical and non-critical activities. As such, the presence of multiskilled workers in a project provides more flexibility in terms of workforce availability for construction managers in charge of workforce planning. The modeling process simulates a project with 100 construction workers agents during three months of working days. Three months of working days were selected to have enough simulated results to identify trends and emerging behaviors among the construction workers agents in the model.

The proposed model includes three main variables in the model to respond to the research question of this study. The rate of contagion of COVID-19 among construction workers, the percentage of multiskilled workers in the project, and the percentage of the workforce required to perform critical/non-critical activities. These three variables define how many workers must be out of the project due to the COVID-19 pandemic, how many multiskilled workers are available to distribute throughout the construction project, and what percentage of critical activities can be performed with the workforce available during a project. Presently, as the data collection process in construction fields is very limited due to the COVID-19 pandemic, the influence of the proposed variables is tested by presenting multiple scenarios and performing a sensitivity analysis. Namely, six scenarios are presented in the results section to capture the influence of multiskilled workers in the development of construction projects during the COVID-19 pandemic. Ultimately, the object-oriented programming tool AnyLogic (AnyLogic, 2020) was used to implement the proposed model previously described.

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

Object class	Function	Parameters/variables	Examples of agents' rules
Construction workers	Simulation of workers' health status during construction project regarding the spread of COVID-19	Percentage of workers classified as sick due to COVID-19, and contagion rate among construction workers	Contagion rate among workers is stochastic and varies between a range due to the limited information that exists and to capture that the probabilities that workers get sick with COVID-19 will vary among construction activities
	Simulation of workers availability to perform activities that are critical and non-critical for the development of the construction project	Percentage of the workers classified as multiskilled. Deficit of construction workers needed to perform critical and non-critical activities for the development of the construction project.	Multiple scenarios are presented where the percentage of multiskilled workers varies. The deficit of workers is calculated by comparing the workers that are available to develop the construction project with the number of workers that was initially estimated to develop the project

2.4. *Verification and validation*

Model's verification and validation was an iterative and continuous process beginning with the model formulation through the simulation and analysis of the results obtained (Sargent, 2004; Sargent, 2013). Model's verification and validation are fundamental steps in proposing a modeling framework in contexts where limited information exists to compare the proposed model with real-life results, which is the case with the current impact of COVID-19 among construction projects.

Model's verification and validation were done through interviews with two subject matter experts (SMEs), a construction worker with roughly 30 years of experience working in projects, and a civil engineer with more than 30 years of experience managing construction projects. Both experts reported being familiar with the impact of COVID-19 on construction projects as both were working in projects when the COVID-19 pandemic began and have continued to do so.

Of note, this model aims to provide a framework that can be used by decision-makers and construction managers to minimize the influence of COVID-19 on construction projects using multiskilled workers; thus, model flexibility and adaptability to multiple scenarios was sought over a deeper specificity regarding the specific behavior of construction workers. Moreover, at the time this study is being developed, no information is available regarding construction workers' behaviors in the pandemic context to validate values for the variables proposed in the model. Ultimately, sensitivity analyses to the model's parameters were used to validate the computational model.

2.5. *Simulated construction project as a case study*

The COVID-19 pandemic has impacted construction projects worldwide, and as the aim of the proposed model is to remain as flexible and applicable as possible, no specific location was selected for the project simulated and used as the case study to

illustrate the capabilities and implementation of the model. In this way, the values used in this case study and their corresponding results may be applicable to multiple contexts, and as such, improving the applicability of the proposed model. In terms of the number of agents, the model includes 100 construction workers agents. This number of agents has been suggested as adequate to simulate the role of construction workers in construction environments (e.g., Ahn et al., 2013). Table 2 shows the range of values for the parameters and variables used in the case study.

Table 2. Model's parameters and variables.

Parameter/variables	Value range	Justification
Population of workers used in the model	100	• Previously used to study construction workers behaviors within construction projects (Ahn et al., 2013).
Distribution of construction workers classified as multiskilled	0-20%	• Benefits of multiskilled construction workforce have been found to be when having between 0% and 20% of workers with multiple skills (Gomar et al., 2002).
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 (Varotsos and Krapivin, 2020). • 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 (Araya, 2021b) as it is assumed that as cities and countries are vaccinating and re-opening, the spread of the virus is better controlled.
Percentage of workers required to perform critical activities	10%-60%	• The percentage of human resources required to perform the project critical activities will depend on the planning and type of project being developed (AACE, 2017; Hendrickson et al., 1989).
Quarantine extension	Two weeks	• Duration of the quarantine for COVID-19 infected workers (ENR, 2020d).

Six scenarios are presented to illustrate the capabilities of the proposed model, Table 3 shows the values of the parameters that varies for the proposed scenarios. The idea of these scenarios is to illustrate the influence that the availability of multiskilled workers to perform critical activities may have on the development of construction projects during the COVID-19 pandemic. Therefore, scenarios vary the percentage of workers required to perform critical activities and the percentage of multiskilled workers available during the project.

Table 3. Values of parameters for scenarios reported

Scenarios	Percentage of workers required to perform critical activities	Percentage of multiskilled workers		
Scenario 1	10%	0%	10%	20%
Scenario 2	20%	0%	10%	20%
Scenario 3	30%	0%	10%	20%
Scenario 4	40%	0%	10%	20%
Scenario 5	50%	0%	10%	20%
Scenario 6	60%	0%	10%	20%

2.6. *Limitations*

This study suffers from limitations that need to be acknowledged. To use an agent-based modeling approach is necessary to simplify real-life conditions by making assumptions about agents' behavior. In doing so, real-life conditions may be over-simplified, such as the process of contagion among workers. Another limitation of this study relates with the lack of specificity regarding the multiskilled workers used in the model. The proposed model does not refer to any specific set of skills for construction workers, which may reduce the specificity of the findings of this study. Nonetheless, this assumption provides flexibility to the model to generalize the findings of this study to different contexts. Given the international scope of the current pandemic, it is important that models and tools proposed to study and improve the management of the construction workforce against the current pandemic provide adaptable and transferable solutions to multiple construction contexts.

Another limitation is the lack of data about how construction workers behave in construction projects during the current pandemic context; however, due to the COVID-19 pandemic, the data collection process in construction fields may represent a health risk for researchers and workers. In this context, the application of simulation and modeling tools may provide a safe way to better understand how construction projects are being impacted by the COVID-19 pandemic. To minimize the influence of these multiple limitations, this study develops multiple scenarios so the lack of actual data and uncertainty related to the effects of the COVID-19 pandemic can be accounted for.

3. Results

Figures 2-4 show the deficit of workers required to perform critical activities in the simulated construction project for the six scenarios presented in this study based on the level of multiskilled workers participating in the project. Additionally, Table 4 shows the average deficit of workers for the six scenarios presented.

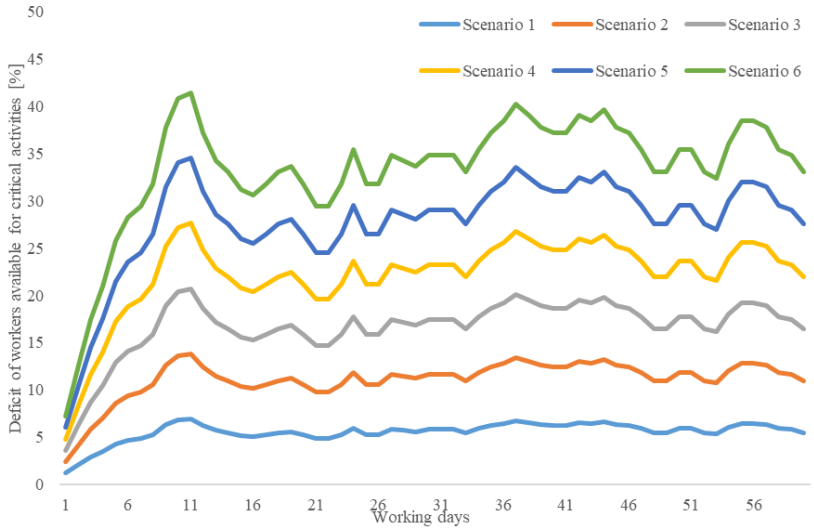

Figure 2. Deficit of workers for six scenarios with 0% of multiskilled workers available.

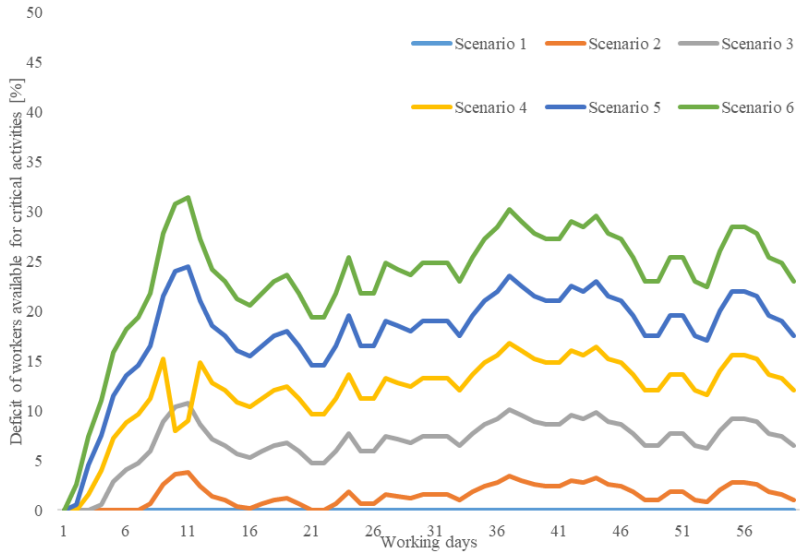

Figure 3. Deficit of workers for six scenarios with 10% of multiskilled workers available

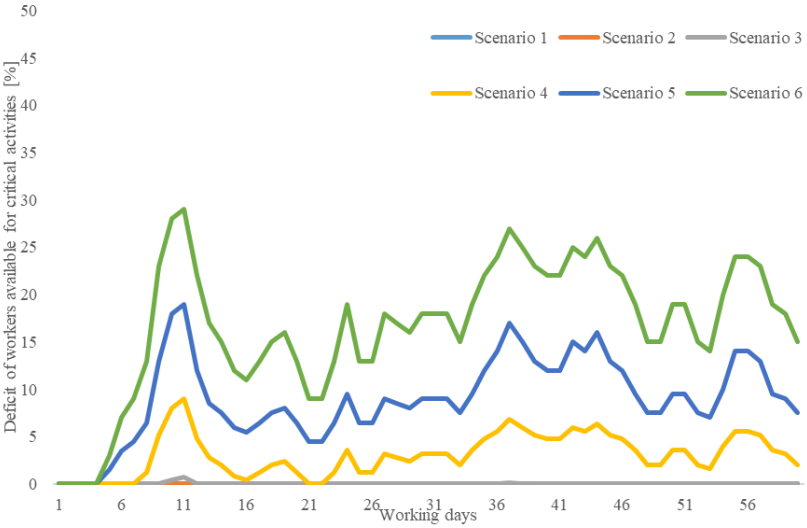

Figure 4. Deficit of workers for six scenarios with 20% of multiskilled workers available

Table 4. Average percentage of deficit of workers for six scenarios.

Percentage of multiskilled workers	Percentage of workers needed to perform critical activities					
	10%	20%	30%	40%	50%	60%
0%	5.6%	11.1%	16.7%	22.3%	27.9%	33.4%
10%	0.0%	1.5%	6.9%	12.1%	17.9%	23.5%
20%	0.0%	0.0%	0.0%	3.1%	9.0%	16.8%

4. Discussion

The proposed agent-based model simulates the influence of having multiskilled workers available to develop a construction project while facing the spread of COVID-19 among construction workers. The model quantifies the deficit of workers required to develop the simulated project, used as a case study, to implement the six scenarios proposed in this study. Our results illustrate that there can be a high variability in the workforce deficit during a construction project in the current pandemic context (see Figures 2-4), reaching peaks in which there is roughly a 40% deficit of workers (see Figure 2). Conversely, cases

in which there is no deficit of construction workers (see Figure 4). Of note, such variability in the workforce availability represents a challenge for construction managers and the successful development of construction projects according to the estimated cost and duration. These findings are aligned with existing literature discussing that one of the aspects in which COVID-19 has been more disruptive for the construction sector is the variability in the construction workforce available for construction managers to develop construction projects during the pandemic (Araya, 2021; Araya and Sierra, 2021; Alsharef et al., 2021; ENR, 2020c).

The results of this study show that the highest deficits of construction workers occur in the scenarios where 0% of multiskilled workers were available (see Figure 2 and Table 4). Namely, scenario 6 showed the highest deficit of workers with an average deficit of 33.42% of workers. These results are expected as the combination of having 0% of multiskilled workers available and having 60% of workers required to perform critical activities (i.e., scenario 6) generate the most difficult conditions regarding the availability of workers to develop a construction project; thus, resulting in a deficit of roughly one out of three workers. Similarly, when comparing scenarios with 10% and 20% of multiskilled workers available, scenario 6 shows the highest average deficit with 23.47% and 16.75% of workers respectively (see Table 4). These results provide an estimated quantification of the impact that the spreading of COVID-19 may have during the development of a construction project from a workforce standpoint. These results provide valuable insight to construction managers regarding the potential deficit of workers that they might expect during a construction project in the current pandemic context.

Additionally, the results of this study indicate that the more multiskilled construction workers were available in the workforce, the lower the deficit of construction workers due to COVID-19. This is illustrated for the scenarios with 20% of multiskilled workers, in which 0% deficit was found for scenarios 1, 2, and 3 (see Table 4). Moreover, when comparing the results of scenario 6 for 0% of multiskilled with scenario 6 for 20% multiskilled workers, the deficit is reduced in almost half (see Table 4). In turn, similar percentages of deficit of workers were obtained for scenario 6 (with 20% of multiskilled workers) and scenario 3 (with 0% of multiskilled workers). These results emphasize that the use of multiskilled workers represents an alternative to reduce the impacts of COVID-19 in the workforce's availability in construction projects. These findings quantify the influence that multiskilled workers may have on reducing the workforce deficit due to the COVID-19 pandemic in construction projects. Identifying and quantifying the influence of alternatives to minimize the impacts of COVID-19 on construction projects is a fundamental step in understanding the consequences of the pandemic for the construction sector, and for construction managers to be better equipped to manage construction projects during the pandemic.

It is recognized that the proposed simulation framework it is a simplification of real-life conditions in construction projects, and no specific set of skills was discussed in the proposed model. However, multiple scenarios were developed to account for real life projects' conditions, so the findings of this study can have a practical contribution for construction professionals and to the industry.

4.1 *Study contribution*

This study contributes to the body of knowledge by providing a modeling framework to quantify the influence of multiskilled workers in the availability of construction workforce during the COVID-19 pandemic. This contribution provides insight in understanding the influence of multiskilled workers in managing the construction workforce during a pandemic context; namely, by estimating the influence of multiskilled workers in construction workforce availability. Additionally, this study provides a practical contribution by quantifying the consequences of having multiskilled workers available in the construction workforce to develop a construction project. Having an estimation of the effect of using multiskilled workers assist construction managers to be better prepared to manage the disruptions due to COVID-19 during construction projects.

5. Conclusions

The COVID-19 pandemic has heavily disrupted the operation of the construction industry by generating variability in the workforce availability to develop construction projects due to the contagion of workers. In this context, this study used an agent-based modeling approach to simulate the influence of multiskilled workers in developing construction projects in the

current COVID-19 pandemic. Multiple scenarios were developed to represent real-life conditions from construction projects and the deficit of construction workers was quantified for each scenario. This study found that using multiskilled workers reduced the deficit of workers required to perform critical activities in construction projects, which reduces the workforce variability. More specifically, it can reduce the average deficit of workers roughly in half when compared with the alternative of using only single-skilled workers from 33.4% to 16.7% of deficit. Therefore, using multiskilled workers is identified as an alternative to minimize the impacts of COVID-19 in the workforce availability in construction projects. These findings provide valuable information for construction managers in terms of identifying an alternative and quantifying its impact to deal with the consequences of COVID-19.

Future work should aim to expand the work presented in this study. One way to do so is by being more specific regarding the skills of construction workers used for simulation purposes. For instance, generating simulations for a variety of skills and identifying which skills may have a greater influence regarding the development of critical activities of construction projects. In doing so, a prioritization of skills that are more beneficial for construction projects can be proposed. Additionally, it is suggested to explore the simulation of applying multiple alternatives simultaneously to minimize the impacts of COVID-19 in construction projects, such as multiskilled workers and multiple construction shifts. Such a study would provide insight into which set of alternatives might be more effective to fight COVID-19 in construction projects. Another avenue for future work would be to verify the findings of this study with data collected from real construction projects. Nevertheless, it is recommended to be undertaken once it is safe to visit construction sites.

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Conflicts of interest: None.

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