THE DESIGN AND CONSTRUCTION OF PUBLIC SERVICE BUILDING IN DEVELOPING RURAL REGIONS DURING THE POST COVID-19 PERIOD: CASED ON A CHINESE VILLAGE CENTRE

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The spread of COVID-19 has caused an increasing demand for public medical room. Cases of Chinese Huoshenshan Hospital and mobile cabin hospitals proved the effectiveness of constructing emergent medical buildings. However, these cases, usually with strict requirements on technology and infrastructure, are hard to implement in developing rural regions. Therefore, there is an urgent need for adapting industrial construction to the rural situation. This research introduced an adaptive approach for rural projects delivery during COVID-19. It is based on a longitudinal case study, recording and analysing the construction process of a village centre in Jiangsu, China, from 2019 to 2020. By comparing the construction process of actual operation and traditional method, the advantages in a shorter building period and lower labour density were verified. This research pointed out neglected risks in developing countries and provided a practical construction approach in these areas. It supported the prevention of COVID-19 global wide.

Keywords: public service building; rural regions; post COVID-19; design

INTRODUCTION

COVID-19 had spread to 221 countries by 11th March 2021, with 118,006,153 cases (Coronavirus Resource Center of Johnes Hopkins University 2021). Its rapid expansion and extreme high transmission rate have triggered an urgent demand for medical space (Gbadamosi *et al.,* 2020), i.e., wards and treatment rooms. The number of visiting patients exceeded the maximum hospital load by 40% in Wuhan during the first month of 2020 (Cao *et al.,* 2020). The increasing demand for medical never subsided as the infection ratio increased from 29 per 100,000 (3215 in 11.2 million in Wuhan, 2020) to 8,900 per 100,000 (29 million in 328 million in America, 2021). As pointed out by the Epidemiological Report of the World Health Organization (2021), the developing area is facing a growing threat because of the scarce medical resource.

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Outbreaks in several developing countries further indicated that these regions deserve special concern.

Current solutions aim at establishing treatment space within a short period, relying on modern construction equipment and skilled labours. For instance, during the construction of Leishenshan Hospital, which took less than 12 days, there used to be over 1,500 workers and more than 800 construction machines working simultaneously (Luo *et al.,* 2020). Whilst this approach would not be effective in less developed regions because of the weak industrial fundamental (Sun *et al.,* 2019). Although the adequate workforce used to be an alternative in rural regions (Mostafa *et al.,* 2016), the social distance constraint of COVID-19 has prevented delivering projects rapidly with such a labour-intensive construction approach. Therefore, there has been an urgent need of developing adaptive industrial construction methods for these places. It could promote worldwide prevention and global economic resilience. Moreover, the construction approach with limited labour source and equipment adapts to the requirement of current prevention operations (e.g., social distance) well, which may also support medium-sized and small enterprises to survive in such a severe environment.

This paper proposed an adaptive industrial construction method appropriate for less developed rural areas, filling the need for both high efficiency and low labour density. It was tested for the effectiveness within a case study of a village centre located in Jiangsu Province, China. The construction process from December 2019 to January 2021 is recorded and compared with the conventional approach. The outcomes showed that it effectively decreased the labour density and construction quantity and proved it practical in a COVID-19 environment implementation.

LITERATURE REVIEW

Construction in Rural Areas

Rural construction varies across areas for diverse cultural and geographical features, economic levels, and resource availability (Hu *et al.,* 2021), e.g., residences with masonry structure in central China (Zhang *et al.,* 2019), huts of marl and branches in Africa (Von Seidlein *et al.,* 2019), and houses with beamed drywall in Turkish (Sağıroğlu 2017). Previous rural construction research focused on three fields, i.e., heritage preservation, sustainability improvement, and disaster reconstruction (Yuan *et al.,* 2021). Heritage preservation studies are characterised by employing local materials and traditional construction methods. For instance, Guan and Li (2002) constructed the foundation with local stones and filled the envelope with straw and bamboo. Picuno *et al.,* (2017) explored the possible restoration of traditional rural constructions in the Adriatic-Ionian Area based on the characteristic analysis. Sustainability improvement study optimises the thermal performance and energy efficiency through specific technologies like renewable energy (Zhu *et al.,* 2011), and sustainable envelope (Hu *et al.,* 2021). Although received the most concerns, studies in these two areas seldom considered construction efficiency and safety. They are, therefore, of limited meanings. Disaster reconstruction is the most relevant direction among these three fields. It aimed at providing projects with limited resources for afflicted areas. Zhu (2011) built two eco-schools in the quake-hit area of Sichuan with a lightweight structured system. Hsieh (2016) employed a similar structure in the 2015 Nepal reconstruction. Ban (2017) explored the implementation of paper structure since 1995 in temporary project delivery. These studies provided abundant experience in rapid rural construction, but they seldom considered the limitation on the workforce. Local labours were gathering at a close range, according to their records. It is undoubtedly a powder keg during the spread of COVID-19.

Conventional Construction During COVID-19

As the largest industry in the global economy, the construction industry experienced a strong impact of COVID-19 (Ribeirinho *et al.,* 2020). The coronavirus-induced recession crushed or significantly delayed construction plans (Ecker 2020), causing a wide-range job loss in the construction industry in **2020(**Currie 2020). Governments have declared rules and regulations to relieve such threats since 2020 (Gostin and Wiley 2020). Specific self-protection solutions concerning construction including 1) wearing masks, 2) staying a distance from others, 3) avoid crowds and poorly ventilated space (American CDC 2021; Chinese CDC 2020). However, implementing these solutions in construction is challenged due to the inherent labour-intensive nature of construction projects (Zheng, Chen and Ma 2021) and the heavy financial pressure (Johnson *et al.,* 2021). Araya (2021) simulated the spread of COVID-19 on construction works by agent-based modelling. He reported a 90% workforce reduction in the worst situation. The number was even more than 30% within the optimised solutions.

Industry's Adaption to COVID-19

Although the industry is directly exposed to the risk of COVID-19, it is vital to provide structures and infrastructures to recover from the epidemic. Many researchers considered construction efficiency the most significant criteria to evaluate suitable construction approaches during this specific period. Luo *et al.,* (2020) made a detailed introduction of Leishenshan Hospital. It pointed out that BIM and the Product, Organization, and Process (POP) model contributed to the ultra-rapid delivery. The modular and offsite construction has been highlighted by (Gbadamosi *et al.,* 2020) for its rapid delivery. However, these industrial approaches rely on a reliable supply chain and transport system. Considering the current situation in which the epidemic is raging in underdeveloped areas, adaptive method carted to limited technologies deserves more consideration.

On the other hand, scholars put efforts into the personal monitor to alleviate the risk of aggregated infection. Araya (2021) managed to delay the spread among labours by maximising the low-risk construction activities. However, the approach is limited implemented for difficulty in risk classification. Pavón, Alvarez and Alberti, (2020) used a mathematical model to simulate occupant distribution among the building. By BIM integration, the approach is proved effective in personnel density prediction. Although not construction-oriented, the model is an excellent example of labour management. However, no standard concerning specific solutions (e.g., a numerical criterion on the labour density) was observed. It led to subjective and loose management in practice, which left the industry at risks.

In conclusion, previous research pointed out the current challenges of the construction industry and possible approaches to project delivery. Existing rural studies improved the quality of construction but remain labour-intensive. COVID-19 presses on both labour safety and resource supply. A trade-off between the labour density and resource dependency demands to be achieved in developing an appropriate approach to rural project delivery. Therefore, the following sections introduced an adaptive approach that realised industrial construction by local labours, equipment, and retrofitted agricultural machinery.

METHOD

This study is based on an actual project in a rural district in Jiangsu province, China. The technology integration developed by a case-study organisation (CSO) was studied, including a series of management events and development work within the project. A two-storey building was considered a technology integration due to its application of specific production techniques and organisational effects in the construction process. A longitudinal case study using data collection was employed and revealed technologies synthesised to alleviate the negatives caused by COVID-19. The researched project stretched from the detail design phase that led to the construction and included onsite building until the end of the project, a period of 5 months. The effect and advantage of integrated technology were studied through the comparative analysis of data collected during the project and the simulated data.

As for construction analysis, construction efficiency, precaution performance, and technology dependency are selected as the main criteria. The construction duration and labour amount are considered two related indicators of construction efficiency. Because a construction time reduction usually has the same effect of labour amount reduction, they were considered synonymous in the specific operation evaluation within the Case Study section. A detailed elaboration on the other performance analysis was given in the Data Analysis section.

Case Study

The proposed construction approach was implemented in a village centre, as shown in Fig 1. It is a two-storey residential service centre with an area of 574.44 m2 (319.29 m2 for 1F and 255.15 for 2F). Its construction was monitored and observed for four months. A summary of the site record is shown in Fig 4.

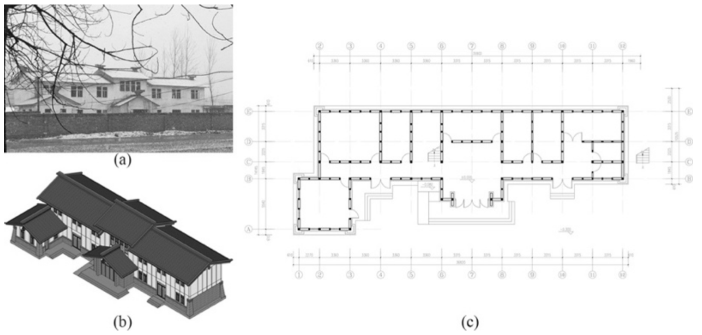

Fig 1. Photograph (a), 3D models (b), and the plan (c) of the study case

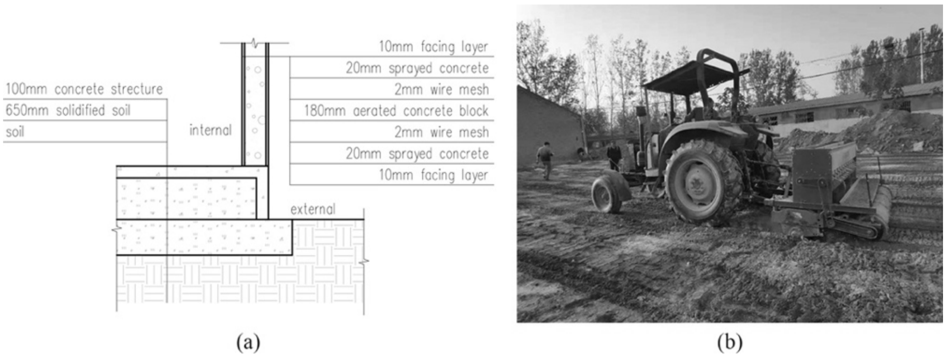

Fig 2. Construction detail (a) and the construction process (b) of the foundation

Adaptive construction methods were used in the foundation and structure. This project integrated the approach of roadbed construction, as shown in Fig 2. Firstly, labourers excavated the earth to the height of -0.75m with a small-type excavator (8t). The excavated soil was then mixed with quick lime and curing agent for 4 to 8 hours to remove moisture and increase the strength. After that, preliminary treated soil was stirred with cement and compacted to form the foundation to the height of -0.10m. A 100-mm cast-in-situ reinforced concrete was constructed on it as the floor to the height of 0.00m. As no masonry or reinforcement foundation is needed, it saved time for masonry (masonry foundation) or formwork, reinforcement construction, and concrete curing (reinforcement foundation). Additionally, Fig 2-b gives information on how local labourers adapted the local scarifier to construction equipment for soil stirring, reducing the dependence on professional equipment.

The structure is similar to a masonry one in which the load-bearing walls work as enclosure components. Fig 3 gives a detailed description of the construction process.

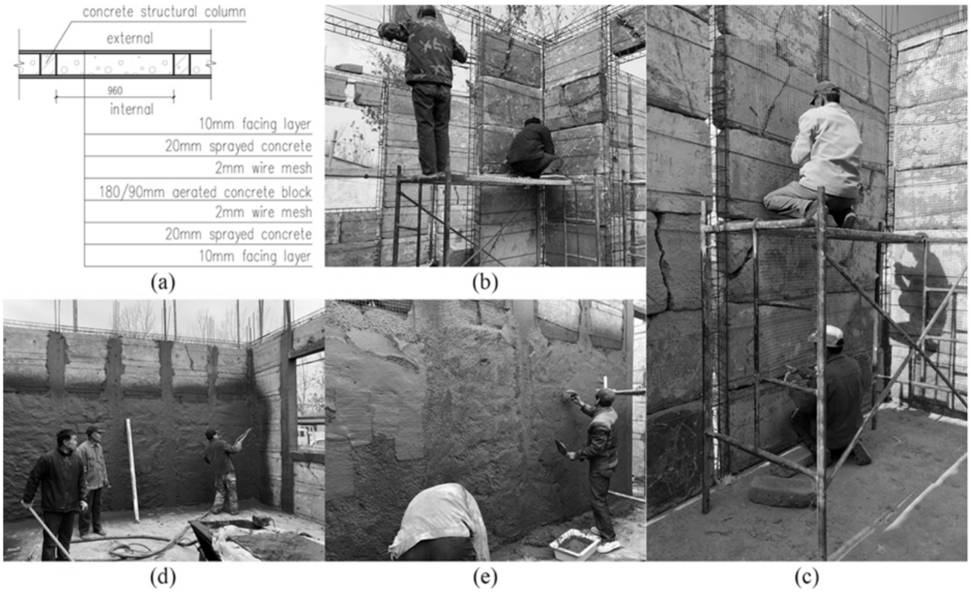

Fig 3: Construction detail (a), and the construction process (c-e) of the wall

The building block is the size of 960mm×180mm×600mm (length × thickness × height). The mix of aerated concrete and straw proves a weight at approximately 25Kg per block. Therefore, labourers could assemble the blocks at a higher speed than before (with blocks of the size of 240mm×115mm×63mm) without lifting equipment. The structural column (130mm×220mm×3600mm in the middle or 220mm × 220mm × 3600mm at the corner) distributes every 960mm, consistent with the size of blocks. Before the construction, the structural columns' reinforcement cages were prefabricated in the size of 130mm×180mm×3500mm. They were directly weld to the foundation's embed parts at first, during which the time for reinforcement cutting and binding was reduced. Labourers then formed the wall with blocks and fixed them with steel bars (Fig 3-b). The 2mm bidirectional mental mesh is attached to both sides of the wall after that (Fig 3-c). The concrete was poured following the sequence of the structural column, wall, and floor. Apart from the floor, paved by a pump truck, concrete was pumped and sprayed by a mobile concrete pump, as shown in Fig 3-d. It was more efficient than manual construction. Labourers only need to smooth surfaces manually at the end (Fig 3-e).

Comparative Construction Simulation

To testify the performance of the proposed approach, a comparative construction simulation of the same building that is masonry structured was chosen as the candidature. The majority of differences between these two structure designs was the design of foundation and wall system, and it could be distinguished from the construction approach. The construction process of a comparative candidate was built based on the empirical data provided by the original project team and organised corresponding to the local construction criteria. Discreet-Event Simulation (DES) was adopted in this section for its ability to capture interaction and interdependence among complex construction processes (Feng *et al.,* 2019). A detailed summary of the construction process is given in Fig 4.

Data Analysis

Many governments have adopted social distance control in COVID-19 prevention, but the indicator is hard to calculate in construction analysis. As an alternative, labour density, i.e., the number of people per unit area, was employed in data analysis. It is calculated in the following equations:

$$D_{i,j} = N_{i,j}/S_{i,j} \tag{1}$$

$$D_{max,i} = \max_{j} D_{i,j} \tag{2}$$

Where $D_{i,j}$, $N_{i,j}$, and $S_{i,j}$ is the labour density (person/m2), number of the labour, and the area of the working place (m2) in the working area j at time i, respectively. $D_{max,i}$ is the maximum labour density onsite (person/m2) at the time i. In this section, the standard working labour density will be 0.60 and 0.32 (person/m2). The former refers to the Chinese government's requirements of crowded places management, and the latter is considering a 2m social distance (3.14 m2 per person).

It is possible to say that reducing the labour number of distributed tasks would alleviate the prevention pressure by adjusting the social distance. However, a low labour density avoids infection but affects work efficiency. Therefore, besides the precaution performance, the production efficiency is also included in the assessment. By setting a limit on the simultaneous working labour, the time consumption would be an evaluation indicator, as shown in Fig 4.

RESULTS AND DISCUSSION

The actual construction lasted 49 days, in which the foundation was built in the first four days. With a 14-day nature curing, the first floor's construction was conducted from the 18th day to the 33rd day. That of the second floor took another 13 days after a 3-day nature curing started by the 34th day. Constructors employed a synchronous construction approach. They divided the project into six areas (i.e., axis 1-5, 5-8, and 8-12 on each floor) and followed a standard procedure (i.e., methods mentioned in the case study) in each area.

The construction schedule (Fig 4) directly compares the construction with proposed approach and two limited conventional approaches. Their process was divided into five categories, i.e., foundation, reinforcement, masonry, formwork and pouring, and cladding, each taking a row in the graph with a unique colour and corresponding labour amount. The Fig shows that the conventional approach had to employ 5-10 more labours in masonry assembly and about four more labours in cladding if required to finish the project within the same period. But less workforce needed for formwork assembly and pouring because the conventional structure consists less constructional columns. Theoretically, it needed to employ 100 and 33 labourers for foundation construction and cladding, respectively, to fill the need. However, these numbers were meaningless in practice indicating no possibility of matching the proposed schedule by conventional construction.

On the other hand, with a same-level workforce amount, the five projects took 143, 12, 41, 36 and 33 days, respectively. The whole process would last for approximately 178 days which was 129 days more than actual. A significant workforce reduction in formwork assembly and pouring was partly for the same reason mentioned before. Another reason was that less work was conducted simultaneously because of a lower masonry assembly speed. In summary, the construction quantity reduction in foundation construction (25-35%), masonry assembly (85%), and cladding (30-40%) indicated significant advantages of industrial construction in rural area. However, more workforce was consumed in the reinforcement construction.

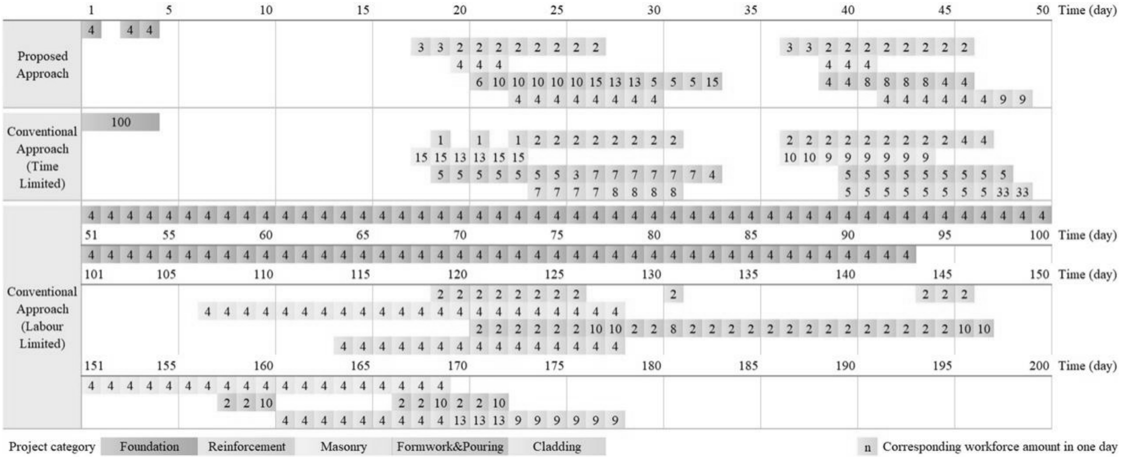

Fig 4: Gantt chart of the construction schedule

Fig 5 gives information on the labour density variation of the proposed approach and the time-limited conventional approach. The period of the foundation was excluded as an impractical scenario. Fig 5 (a) is the line graph of $D_{max,i}$ distribution with time. In general, the labour density was lower when employing the proposed approach. The most significant difference was observed in the first six days, during which 11 more labours were employed in masonry assembly by the conventional approach. The maximum value of the proposed approach was 1.57 on the 12th day when eight workers assembled the formwork and poured the concrete at the southeast corner. That of the conventional approach (2.55) appeared on the 6th day when 20 workers worked at the same place for masonry and formwork assembly. With a threshold of 0.60 (Fig 5 (b)), it was observed that both values distributed at a safety level (below 0) for most of the time. However, the line of the conventional approach was closer to 0 than that of the proposed approach, which indicated a smaller range of labour management in conventional construction. In other words, fewer labours could be added for a shorter construction period if the density is required to below 0.60. Its weakness was magnified when setting the threshold to 0.32 (Fig 5 (c)). The labour density of the conventional approach was higher than the requirement for about half of the time, while that of the proposed approach remained below. It meant that a 2m social distance is harder to keep by conventional construction than the proposed method.

Peaks of the density appeared periodically in Fig 5 because of the synchronous construction by which different operations could be conducted in various parts simultaneously.

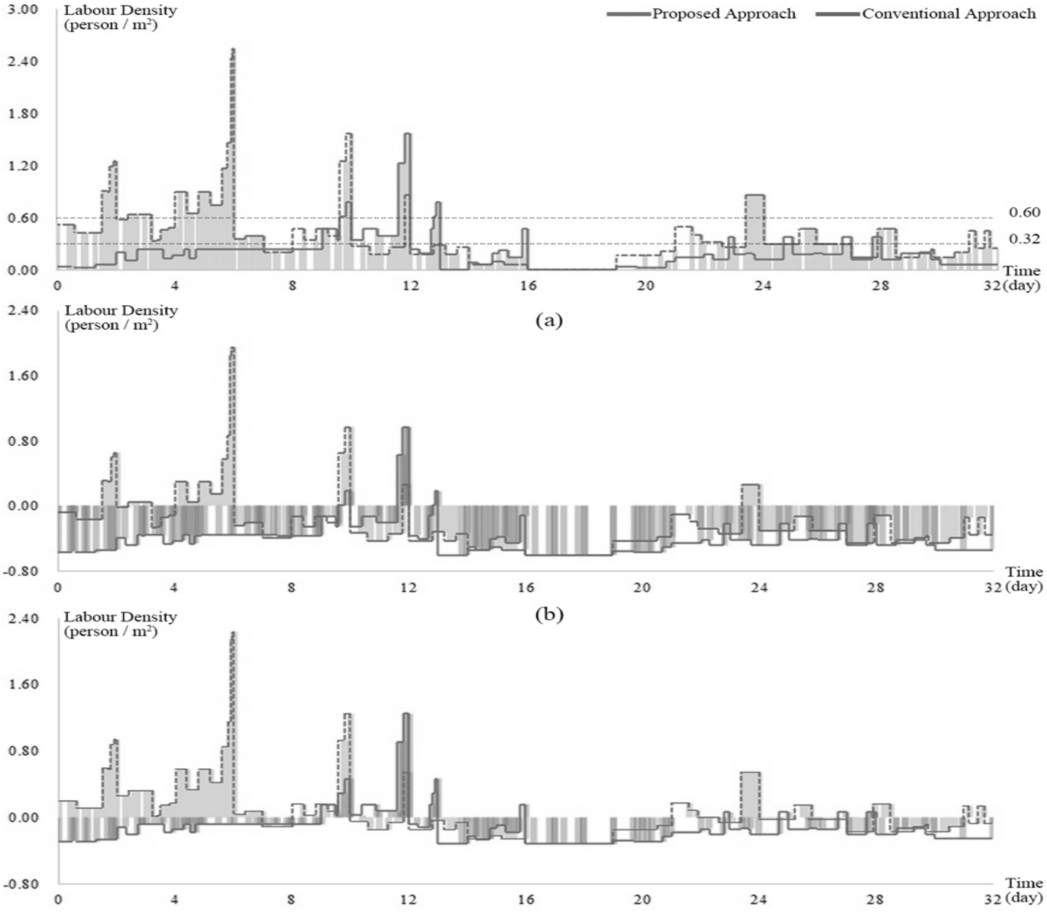

Fig 5: Variation of the $D_{max,i}$ (a), the difference between $D_{max,i}$ and 0.60 (b), and the difference between $D_{max,i}$ and 0.32 (c).

Locating the downstream of the construction process, the east part (i.e., the area of axis 8-12) periodically gathered multiple operations, resulting in a high labour density during the period. Here describe operations during peak periods (i.e., periods in which the labour density was higher than 0.60). As for proposed construction, the formwork assembly and pouring were conducted from the 9th to the 12th day, and four labours were cladding within a limited area simultaneously during another peak period, the 13th day.

Regarding the conventional approach, 15 labours were assembling the masonry from the 2nd day to the 6th day, and 9 of them were conducting the same projects from the 23rd day to the 24th day. The peak periods of the proposed approach can be eliminated by distributing those projects to a longer period, i.e., increasing the labour amount before or after the period. However, it is less possible for conventional construction, as mentioned before. Therefore, the gathering of workers, i.e., the risk of contagion, is more likely to be avoided by adopting the proposed approach.

CONCLUSION

The outbreak of COVID-19 has generated significant pressure on the public medical system and marked an urgent need to provide the medical area for the rural. This paper introduced an adaptive industrial construction approach and documented its application in a public service centre. The construction schedule and labour density were selected as major indicators in comparative estimation. It was found that the proposed construction approach reduced considerable construction quantity in the foundation and structure projects. With a relatively low-level labour density, contractors were more likely to avoid contagion in the construction site. However, this approach has strict demands on the soil condition. The conventional foundation will be inevitable if the soil quality is poor. Moreover, it is suitable for developing regions with basic industrial basis because of using several industrial products and construction equipment. Despite all this, the experience of the studied case can be used as a reference for developing rural areas that are still facing the threat of COVID-19. Additionally, small-type enterprises can employ the methods mentioned to deliver projects with limited sources and technology. Future studies are expected to provide more comprehensive data analysis and implement the method in more cases.

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