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Advantages and barriers of modular construction method in constructing buildings

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This study aims to investigate the advantages of and barriers to the modular construction method that could facilitate leveraging of this method in practice by effectively overcoming barriers in the process. Three typical modular construction cases, Leishenshan Hospital in Wuhan (China), the media residence hotel for the 2018 Winter Olympic Games in Pyeong-Chang (South Korea) and Global Academy in Hayes (UK), were selected and analysed. The findings show that the modular construction method can shorten the construction time, facilitate collaborations between stakeholders, enable effective management, save labour and costs, reduce waste and minimise impacts on the local community. The eco-friendly design allows modular buildings to be recycled or relocated for some other purposes. The engagement of current engineering technologies upgrades the construction quality and enhances project management. It is expected that modular design and construction would be an appropriate option for constructing multifunctional buildings, particularly for short-term events or under some urgent circumstances. On the other hand, it is suggested that more effective logistic approaches should be used to transport modules to the site, and new technologies focusing on flexibly resizing or reshaping modules could be developed. Modular technology is expected to be employed in constructing more permanent buildings by improving quality and sustainability.

Keywords: built environment/construction/sustainability/UN SDG 11: Sustainable cities and communities

1. Introduction

Modular construction, as an innovative construction approach, is the employment of modular units, which are manufactured and assembled at a plant, to construct a building (Musa *et al*., 2016). It saves time and costs for the construction process, improves quality, reduces site disruption and waste and increases safety (Paliwal, 2019). To date, Sweden has become the leading country in modular construction, with 84% of individual houses having employed prefabricated timber structures (Amer *et al*., 2019). However, modular technology has not been widely used across the world – for example, only 5% of individual houses in the USA, the UK and Australia have employed modular architecture (Deere *et al*., 2021). Modular design and construction have been largely applied in construction of a range of different buildings – for example, hospitals and health quarantine camps (Zhang *et al*., 2021; Zhou *et al*., 2021), health centres (e.g. Anon, 2019a), hotels (e.g. Anon, 2019b) and film studios (e.g. Anon, 2019c).

It is predicted that modular design and construction could bring technical innovation to the construction industry. This innovative method can simplify and accelerate the construction process and minimise the impacts on the environment that may have long-term technical influence on the construction industry. As prefabricated modules allow faster on-site construction and installation than the traditional construction approach, the modular design and construction method shortens the site construction process, which significantly saves labour and machinery costs. Also, modular design and construction effectively avoids material waste on the site, as all module components are prefabricated and tried to be installed in the plant, which can guarantee precise assembly on the site. Thus, compared with the traditional construction method, the modular design and construction approach could be more economical and cost saving. For social impacts, modular construction facilitates a shorter construction process that reduces the impacts of construction on local communities. Less on-site construction waste and a more environmentally friendly construction approach effectively protect the local environment.

However, it is argued that modular buildings are designed as temporary buildings, there are some difficulties in module transportation and contractors may be inexperienced in conducting projects (Paliwal, 2019). This study aims to investigate the advantages of and barriers to the modular construction method by analysing three various modular construction cases, which could facilitate leveraging of this method in practice by effectively overcoming barriers in the process. Three selected typical modular construction cases provide empirical evidence to highlight the advantages of and barriers to the modular construction method in real-life practice.

This research is significant, as the current study systematically reviewed three typical recent cases applying modular construction as an innovative approach to construct buildings for different functions and purposes. The research findings highlight both the advantages of and barriers to modular technology in construction and suggest the application of effective strategies to overcome barriers in order to leverage the modular construction method in practice, which could provide efficient references for future construction design and management in a similar context. The following section reviews a range of different projects applying modular construction and suggests some potential gaps to be investigated by the current study.

2. Literature review

Zhou *et al*. (2021) discuss the construction of a Covid-19 field hospital – Huoshenshan Hospital in Wuhan, China – by employing modular technology after the outbreak of the epidemic. It is found that all the construction components were prefabricated in factories by using modular construction design and technology. The component production error is within a millimetre, which ensures appropriate site assembly. Compared with the traditional construction method, this method reduces construction waste by more than 80% and shortens the building assembly time by 40%. Additionally, the construction materials for modular wards are environmentally friendly and are characterised with excellent fire resistance.

Also, modular design and construction was applied to the construction of a quarantine camp in Hong Kong, China (Zhang *et al*., 2021). It was the first Covid-19 isolation facility built with innovative modular technology in Hong Kong. It is argued that the application of modular buildings can speed up on-site construction and ensure time accuracy. As all modules are prefabricated in the factory, it is easier to control the product quality and minimise costs, bringing financial benefits. Moreover, it is noted that using the modular construction method can improve environmental sustainability and reduce safety risks and carbon dioxide emissions during the building life cycle.

Findings show that innovative modular technology could be used to construct hospitals and isolation facilities to respond effectively to the epidemic. The prefabrication of all modules can greatly reduce production errors, ensuring product quality. It can speed up on-site construction and ensure the accuracy of the construction, ensuring that the facilities are used on time. In addition, innovative modular technology saves manpower, enhances personnel management, reduces safety risks and protects the environment. However, it could be a big challenge to organise contractors for module manufacturing, transport and site construction in a tight and short period of time. Considering that China has strong productivity in different industries, both projects were completed within the planned time frame. The current study intends to examine modular construction from the aspects of manufacturing, logistics and construction in the global context, which might work out some workable cycles to ensure construction.

Anon (2019a) describes the application of modular design and construction to constructing a permanent community health centre in New York, USA. It is found that customised facilities were completed in the factory to ensure the precise assembly and completion of all functional components and systems, thereby reducing on-site installation time. After completion, the building was deconstructed and transported to the site for installation, which reduced on-site construction activities and time, as well as the interference to the local community. It was estimated that the modular construction saved up to 9 months for this project compared with traditional construction.

Anon (2019d) also assesses the use of modular technology to construct the Inspira Oncology Center in Woodbury, NJ, USA, which provides assistance to cancer patients. The decision to use modular construction allowed a faster construction speed and better construction quality to provide medical services to patients. The module manufacturer co-operated with the Health Network Group in developing and designing the centre, and this highly technological, advanced and innovative medical centre was completed in less than 1 year.

Modular technology was also used to replace one lost operation centre in a health centre in Brooklyn, NY, USA (Anon, 2016). As all the module components were prefabricated and tried to be installed in the plant to guarantee precise assembly, the on-site construction and installation process was greatly shortened with all the exterior bricks installed and a high level of the interior was completed. Additionally, this innovative construction method reduced project-management costs and labour costs.

A continuing health community in Twin Falls, ID, USA, employed modular technology to speed up its construction and operation as well (Anon, 2018). It is found that manufacturing of modules at the plant and on-site installation could be carried out simultaneously, which saved construction time as well as labour and machinery costs, facilitating the completion of this project and the operation of the health community within 1 year. Additionally, the modular structure provides a way to monitor and control quality, ensuring that the project satisfies the requirements.

Modular buildings are found to be used widely in community medical centres, which could reduce the construction time and ensure construction quality. They allow quick completion and operation of centres that could efficiently provide community people with secure medical services. While the plant fabricates modules, the degree of the completion of the interior is also high, which also facilitates on-site construction and improves the building quality. This is another aspect that could be considered in the current study.

Anon (2019b) describes a hotel in New York, NY, USA, that used modular construction technology to achieve earlier completion. It was indicated that all the guest room modules were built in the factory, which allowed a high level of interior completion. It helped achieve a more efficient construction process and a higher construction quality. The 15 floors of guest room modules were completed when the base building site work was finished, thus shortening the overall construction schedule and saving costs. It took only 259 days for the hotel to complete the on-site construction.

In British Columbia, Canada, modular construction is used to address population housing problems, considering its reusable and reconfigurable design features (Anon, 2019e). The flexible module arrangement allows units to be added or removed to suit sites of different sizes. Its temporary nature permits the modules to be repositioned and reconfigured in different locations in the future, and the time and costs of constructing new buildings are only a small part of it. The design of the building also integrates energy-saving and environmental protection aspects to reduce long-term environmental impacts and daily operating costs.

It is noted that modular technology has been started to construct hotels and residential buildings to solve housing problems, as modular buildings have a shorter construction time and the facilities can be put into use quickly. When modules are added to the detachable design, the use of modular buildings becomes more flexible, as modules can be added or moved to satisfy different requirements, and modules can be disassembled and transported to other locations to be reused. The current study also examines the application of relocatable modular buildings in real-life practice.

In Oakland, CA, USA, some retail units also used modular design and construction to build human-scale amenities in dense urban areas (Anon, 2019f). Prior to delivery, the development of modules, as well as their testing and manufacturing, was completed at the plant. The modules were designed to be plugged and played and connected with public facilities, which can reduce the costs of on-site construction and protect the environment. Compared to the brick-and-mortar construction approach, this 570 square feet (53.0 m^2) project was completed in just over 100 days and saved around 50% of costs.

Anon (2019c) reports that Hawaii Studio chose to employ modular construction to produce a new studio to meet the deadline and the budgets. As the studio was fabricated in the factory, it saved time and met the noise requirements at the site. The designer worked closely with the factory to make the studio satisfy all the technical needs of the film studio. The design also allowed for future expansion so that the studio could be relocated, and new configurations could be created as needed. Moreover, modular construction minimised on-site clean-up.

It is found that modular buildings have also been utilised in some public infrastructures, as they are flexible and easy to be expanded and relocated. At the same time, they save time, reduce costs and protect the environment in the construction process. However, there has been almost no research to date that systematically analysed successful cases of the application of the modular construction approach in terms of its advantages and barriers. Thus, the current study aims to fill this gap.

3. Methodology

3.1 Case study

Three typical modular construction cases – Leishenshan Hospital in Wuhan, China, the relocatable media residence hotel for the 2018 Winter Olympic Games in Pyeong-Chang, South Korea, and Global Academy in Hayes, UK – were selected and analysed in terms of location, design, materials, structures, construction technology, environmental impacts, costs, project management and construction time frame. Relevant, reliable and recent sources were retrieved from University of Technology Sydney Library databases for analysis. The characteristics of each case were identified and described in detail that provided empirical data to evidence the advantages of and barriers to the modular construction method.

3.2 Data analysis

The three successful cases, which used the modular construction method, were showcased from the aspects of purposes of the projects, locations, project design, construction materials and structures, employed construction technologies, project management and costs, construction periods and environmental impacts to work out the advantages of the modular construction method and the effectiveness of modular construction for a range of different purposes in various contexts. Also, some barriers to the modular construction method were discussed.

3.3 Validity of results or findings

To ensure the validity of potential results and findings, reliable data need to be collected. This can be achieved through careful data collection and keeping. All three selected cases are published in professional engineering journals in 2020 and 2021, which ensures the reliability of data collection and increases the validity of the current study. Also, precise data analysis by comparing and contrasting well the collected data can increase the validity of the results and findings. Detailed case study can ensure the accuracy of result descriptions, as well as the discussion of later findings.

4. Case studies

4.1 Leishenshan Hospital in Wuhan, China

In response to the Covid-19 outbreak in Wuhan, China, in January 2020, the Wuhan City Disease Prevention Headquarters agreed on the construction of Leishenshan Hospital to treat Covid-19 patients. Leishenshan Hospital was built on the field of the parking lots of the 2019 Military World Games village, which is located north of Qiangjun Road, Jiangxia District, Wuhan. This field was idle after the games. The flat and hardened floor of the parking lots allows the construction of temporary buildings, and

also, the traffic is convenient, as the roads around the area are open. The foundation was consolidated by casting a 200 mm thick C30 concrete hardening layer in the green zone or where the hardened floor cannot satisfy the stress requirements in order to bear the upper load (Chen *et al*., 2021).

The hospital covers an area of 21.87 ha, and the building area is about 79 900 m^2. Compared with Huoshenshan Hospital, Leishenshan Hospital is much more extensive, as it provides 1600 therapeutic beds and a dormitory for 2300 medical workers. Figure 1 shows the area plan of the Leishenshan Hospital project. It commonly takes 3–5 years to construct an infectious disease hospital of such a scale. However, Leishenshan Hospital was required to complete the construction and be in service within 2 weeks' time frame. It is apparent that the traditional construction method cannot compress the years of construction tasks into 2 weeks. Thus, this construction project had to apply the modular construction method so that prefabricated modules and structures were employed in the construction to guarantee a much faster process.

The modular design was applied to the therapeutic isolation area, the staff living area and a general logistic area of Leishenshan Hospital (Chen *et al*., 2021). Considering the high infectiousness of Covid-19, the therapeutic isolation area was separated from the other areas with a strict streamlined plan in terms of the therapeutic and patient care, logistics and sewage. Higher standards of sewage-treatment technology were employed in Leishenshan Hospital to prevent pollution. Containers, which formed different functional modules, were used for modular assembly in the process of the construction of the hospital. Additionally, building information modelling (BIM) technology was utilised to assist in on-site construction of the modular assembly, which, to a great extent, shortened the construction time (Chen *et al*., 2021).

As containers use a steel structure skeleton with colour steel composite board walls as a whole, they can ensure the safety of the hospital due to the strong integrity of the structure and high bearing capacity. In addition, the mainframe beams and columns of containers are welded with cold-formed steel, which reinforces the strength of walls, as well as top and bottom plates. Each container, as the basic unit, can be used alone, or containers can be combined to form a spacious space in accordance with the construction requirements. Two box-type room units (2 × 6 × 2.9 m and 3 × 6 × 2.9 m) were employed in Leishenshan Hospital considering the manufacturing conditions at that time (Chen *et al*., 2021). The prefabricated modules were manufactured in factories and transported by truck to the roads around the site and then assembled and hoisted to the site, with reserved and embedded pipelines in the ward modules. This project employed a scientific transportation plan that guaranteed on-time delivery of all the prefabricated components to the site. Additionally, the basic unit was utilised to form a spacious space for some function rooms in the hospital – for example, pharmacies.

A 'three zones and two channels' structure was applied to Leishenshan Hospital, which were clean, semi-contaminated and contaminated areas and the patient channel and the medical care channel (Chen *et al*., 2021). This was easily achieved by steel-framed containers, as the basic unit can either be used alone or be combined with another to form a spacious space, such as

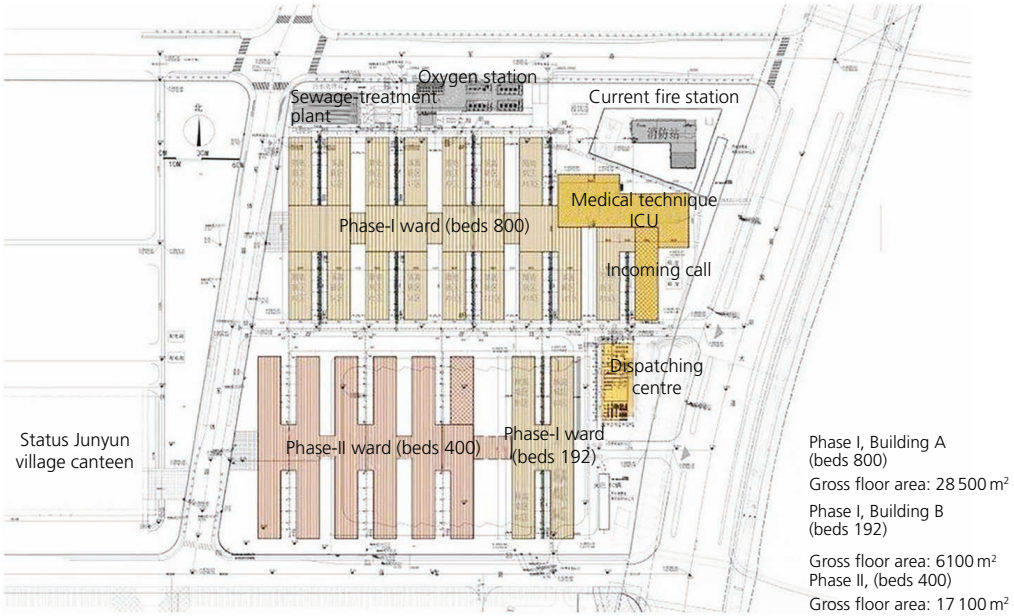

Figure 1. Introduction to the Leishenshan Hospital project. ICU, intensive care unit (source: Chen *et al*., 2021)

isolation wards, ward nursing units, intensive care units, medical technology units and reception area in the hospital.

It took a total of 12 days, from 26 January 2020 to 6 February 2020, to construct Leishenshan Hospital, as BIM technology played a key role in the engineering design and construction process. A BIM model was set up in accordance with the detailed requirements of prefabricated buildings. If there were any changes in the input data, relevant data changes could happen in terms of the parameters of the design of the structure types, sizes and materials, which minimised drawing errors. Module manufacturers were promptly informed of corresponding changes so that they could make changes in the manufacturing process. In the construction process of Leishenshan Hospital, the BIM model was also used to determine the reasonability of the site design and effectiveness of material storage yard, oversee the dynamically changing information of the site model in accordance with the schedule and adjust some unreasonable layout.

The success of the construction of Leishenshan Hospital largely benefited from the application of modular buildings in construction as well as BIM technology in the design and construction process. The prefabricated light steel structures and modules allowed fast assembly on the site so that the large-scale building construction was completed within a short period of time. BIM technology provided an information-interactive platform by sharing information among a range of different stakeholders throughout the engineering design and construction process, which enhanced the effective collaboration to ensure the on-time completion of the project.

4.2 Relocatable media residence hotel for the 2018 Winter Olympic Games in Pyeong-Chang

A relocatable media residence hotel was constructed for the 2018 Winter Olympic Games in Pyeong-Chang, South Korea, from June to December 2017, including 4-month factory production. The hotel was designed to provide accommodation for journalists and broadcasters during the Olympic Games and be transported to another site and be converted into a university student dormitory building afterwards. Thus, the modular construction method was applied to construct the hotel considering its recycling purpose, construction quality, environmental performance and the time limits. The four-floor hotel had a total of 300 rooms, with a 10 305.5 m^2 gross area and a 2749.16 m^2 building area (Shin *et al*., 2020). It took a total of only 184 days to construct the hotel, 18 months shorter than the time of using the traditional construction method to construct a concrete building of the same scope.

As the relocatable modular construction method is more complicated than the traditional construction method and permanent modular construction method, a range of different stakeholders, including modular manufacturers and construction companies, were engaged in the initial project planning and decision-making stage so that each stakeholder's responsibilities could be specified and effective communication could be achieved in the construction process (Shin *et al*., 2020). A modular consultant was involved in the design and manufacturing process, who provided expertise advice to the task team to ensure the process of the project.

Considering the characteristics of the residence hotel, the modular construction method was applied well to manufacture and construct repetitive hotel rooms (3.3 m × 7 m × 3.2 m) (see Figure 2), which improved both module manufacturing and the field construction speed. The design considered the future recycling purpose so that bolting methods were employed rather than welding operations in the field assembly while ensuring achievement of structural performance as required. In addition, all the modular units had good environmental performance, as they were recyclable and minimised waste. The new materials used to manufacture the modular units were durable and sustainable for recycling.

The shop drawings were used to guide the production of high-quality modular accommodation units of the hotel. This project applied schedule management to plan and organise the entire manufacturing procedures, which ensured a smooth production

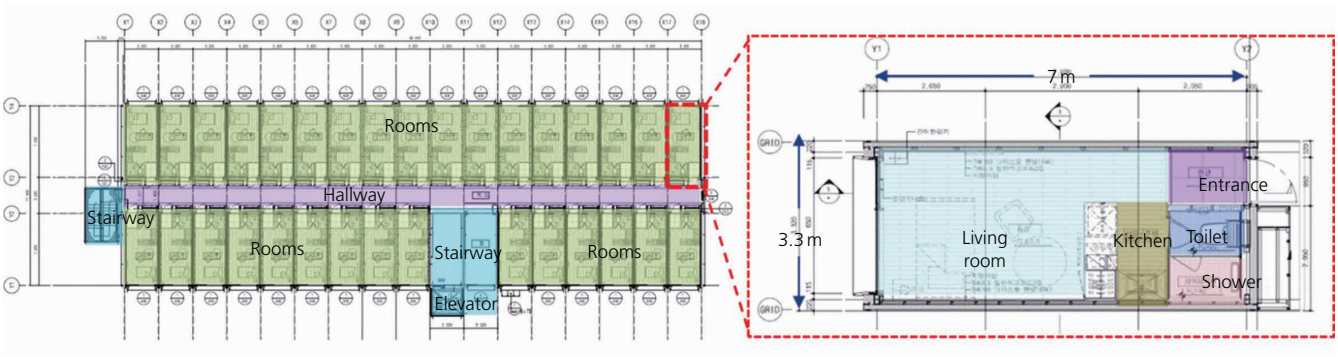

Figure 2. Diagram of second-floor plan of the modular hotel and an enlargement of the floor plan of a typical module (Shin *et al*., 2020)

process of modular units. A former shipbuilding factory was selected to manufacture multiple modular units, as it was capable of producing 200 modules at the same time and had adequate space to store the units, which minimised material waste in the production process (Shin *et al*., 2020).

To satisfy the recyclable purpose, durable and sustainable materials were used in manufacturing modules that could be disassembled and transported to the new site without damage. For example, a steel sheet was designed and used as the interior material. Also, the design and production of modules had to satisfy the standards of the structural and environmental performance in South Korea. For instance, the design specification of the live load is 3.0 kN/m^2, meeting the code requirement of 2.0 kN/m^2 (Shin *et al*., 2020). All modular units were inspected, underpinning appropriate quality standards, prior to delivery to the site, which could ensure transportation, site construction and disassembly.

It took around 40 days for all room modules to be transported to the site by truck and assembled on the site. As most modular units used in the construction were standardised and over 90% of the unit construction work had been completed in the factory, the site installation was efficient and faster than planned. The on-site work time was significantly shorter than that for constructing a building using the traditional construction method. However, the site construction period could have been faster due to the restriction of the unit shipment from the factory, which was 327 km away from the construction site.

To consolidate the structure of the buildings, the post-tension method was employed to reinforce the integrity of the joints between modules, which also made future demolition and reassembly easy. In addition, H-beams were used in foundation construction, which made the recycling of the foundation easy (Shin *et al*., 2020). The hotel was disassembled back into modules once it was removed after the Olympic Games. As planned, the modular units were recycled and used as university students' dormitories. The disassembled modules and materials, which were documented, were shipped to the next destination for installation.

The relocatable media residence hotel for the Pyeong-Chang Winter Olympics has provided a successful exemplar of application of the modular construction method in constructing buildings for short-term international events. It helped satisfy the temporary high housing demand during the Olympic Games. The application of recyclable modules and materials in hotel construction allowed the recycling of the modular units to be installed in other areas for some other purposes after the Olympic Games. The modular construction method also employed appropriate engineering technology from the very beginning of the planning and designing stage of the project to the manufacturing, construction and disassembly and reconstruction stages, which leveraged the advantages of this method to benefit the project.

4.3 Global Academy in Hayes, west London, UK

Located in Hayes, west London, UK, the Global Academy is Britain's first university technical college using the off-site modular construction method to construct its building (King, 2020). The four-storey building, which is approximately 8700 m^2, is sitting on a 7 ha area in the Old Vinyl Factory. Additionally, this building is one of the most energy-efficient off-site modular buildings ever been built in the UK to date. The site construction solutions effectively integrated off-site modular construction technology that made it possible for this project to resolve well the challenge of constructing a building on a constrained area. Compared with the traditional construction method, the off-site modular construction method saved 12 months in construction, half of the construction time, as a large amount of construction work was completed in the manufacturing factory in York.

As there was only 4 m between the new building and the boundary, the college construction area in the Old Vinyl Factory was extremely limited. The construction of a new electricity substation, as well as the complicated groundworks, left almost no space for storage of construction materials. Thus, the off-site modular construction method assisted in resolving this issue, as significant construction work was completed in the factory and modules were only required to be assembled on the site. On the other hand, the building employed traditional steel frames in constructing the double-height theatre, cinema, studios and sports halls in the far eastern end, as well as the full-height atrium in the centre. The combination of the steel frames and modules formed the hybrid structure of the building (see Figure 3), which created shared internal spaces and took half the time less than the traditional construction method (King, 2020).

A total of 112 3.75 m × 9.75 m prefabricated modules were installed in the two four-storey stacks within 3 weeks, which consisted of 65% of the building construction and were separated by the atrium in the centre. Both the atrium and the remaining sections of the building were built in steel frames, which occupied up to 35% of the building construction. The classroom modules support the steel-framed atrium, including the link bridges, floor spaces and the sculptural staircase, to form a single structure, which could take stable loads and resist gravity (King, 2020). Considering the specific requirements of the acoustic performance of the theatre, cinema and studios, the high specification acoustic floors were prefabricated off-site and installed on the site. All prefabricated modules were pre-installed in the manufacturing factory prior to being shipped to the site by truck for quality control.

All project stakeholders were engaged in the process of producing modules to ensure that modules could satisfy the quality requirements. The team's frequent visits to the manufacturing factory were to make sure that modular production could meet the

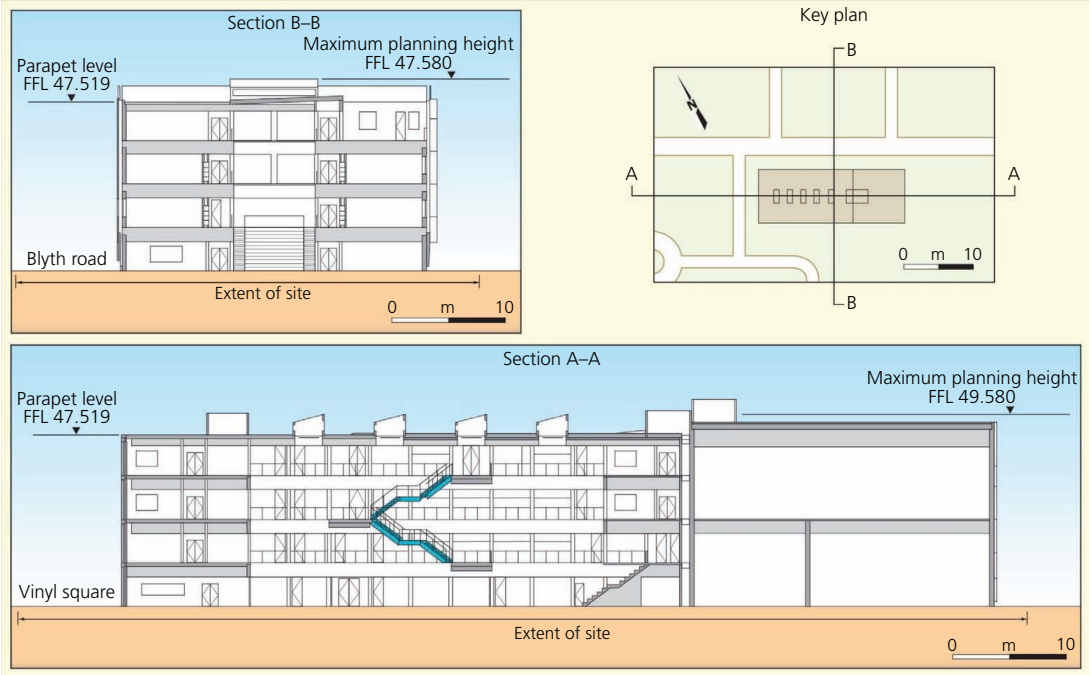

Figure 3. Plot location and sectional elevations of the building (units are in ft). FFL, finished floor level (source: King, 2020)

requirements, as a large amount of construction took place in the factory rather than on the site. There were update meetings held frequently to introduce the process of the project. A showroom was set up to demonstrate the working samples, such as flooring, lighting and boards, which assisted in the team's decision making. Additionally, the clients were involved in the entire design and construction process (King, 2020).

The Global Academy project has evidenced that the off-site modular construction method could facilitate resolutions to hard issues of some challenging projects. The installation of prefabricated modules on the site minimised the on-site construction, effectively reducing impacts on the local environment and community. The off-site modular construction method well managed the schedule of module manufacturing and installation, making it possible to complete the construction of the Global Academy in 12 months. The hybrid design and construction leveraged the advantages of the off-site module method and provided clients with certainty.

5. Discussion

Compared with the traditional construction method, the modular construction method is found to be much more time saving, which is a good option for constructing buildings under some urgent circumstances or for short-term events. Being different from the conventional construction method, modular technology allows a lot of construction work to be completed in manufacturing factories instead of on the construction site – for example, module production and pre-assembly (Anon, 2019a; King, 2020; Shin *et al*., 2020; Zhang *et al*., 2021; Zhou *et al*., 2021). Also, as a range of different manufacturing factories are involved in the module-producing process, various works can be done by different stakeholders, which to a great extent saves construction time (Anon, 2018; Chen *et al*., 2021). On the other hand, site construction, such as foundation construction and electricity substation construction, still proceeds while all modules are being manufactured in the factory, ensuring that the assembly of modules can take place once they are transported to the site, which saves lots of construction time as well (King, 2020).

The success of the construction of two Covid-19 field hospitals – Huoshenshan Hospital (Zhou *et al*., 2021) and Leishenshan Hospital (Chen *et al*., 2021) in Wuhan, China – has evidenced that the innovative modular method effectively guaranteed the construction and opening of the hospitals within 2 weeks' time in response to the Covid-19 epidemic. The modular construction method together with on-site BIM technology ensured the efficient procedure of each construction stage, allowing the quality hospitals to be completed within the planned time frame. The construction of the media residence hotel for the 2018 Pyeong-Chang Winter Olympic Games has also showcased that a temporary building for an international event was completed and put into use within 6 months by employing the modular construction method (Shin *et al*., 2020).

The modular construction method is often found to be employed for construction of short-term or relocated buildings, particularly as a good option for constructing buildings for specific projects.

For example, as specific construction projects in response to the epidemic, both Huoshenshan and Leishenshan Hospitals were designed to work for only 10 years (Chen *et al*., 2021; Zhou *et al*., 2021). To date, modular technology has been seldom used in constructing permanent buildings or has been combined with the conventional construction method in hybrid design to construct a permanent building (King, 2020).

It is also noted that the modular construction method is environmentally friendly, producing less waste, minimising impacts on the local community and recycling modules for future construction projects. It is apparent that the modular construction method could largely reduce construction waste, as all modules are made and sized in the manufacturing factory and only module assembly and minimal construction happen on the site (Shin *et al*., 2020; Zhou *et al*., 2021). Thus, the influence of on-site construction on the local community could be minimised (Anon, 2019a).

As modular technology allows recycling the modules for future projects or repositioning the building in different locations, it benefits the environment and maintains the sustainability of development (Zhang *et al*., 2021). The repositioning of the temporary modular building can also be economical (Anon, 2019e). The relocatable design of the 2018 Olympics media residence hotel leveraged the recycling of all of its structure, modules and materials and benefited the local environment (Shin *et al*., 2020). However, it could be a challenge for the modular construction method, as modules are fixed and hard to resize or reshape on the site due to the limited flexibility so that the use of recycling modules for various buildings construction should be considered and planned at the very beginning of the design stage.

The findings also show that the modular technology is regarded as a good option for constructing a range of different functional buildings considering its unique characteristics being different from those of the conventional construction method, including but not limited to shorter construction time, lower costs, less impact on the local environment, more collaborative management, safer site construction and labour saving. The application of the innovative modular technology in construction greatly saves project-management costs and labour costs due to shortened construction time and less site construction work (Anon, 2016, 2019e; Zhou *et al*., 2021). The closer collaboration of different stakeholders throughout the whole process allows the accuracy of modular manufacturing and site construction (King, 2020; Shin *et al*., 2020; Zhang *et al*., 2021; Zhou *et al*., 2021). It also ensures that the quality of the construction that can satisfy the local construction code requirements (Chen *et al*., 2021; King, 2020; Shin *et al*., 2020; Zhang *et al*., 2021). Modular technology can mitigate the risks in construction, increasing the safety in the process (Zhou *et al*., 2021).

However, transportation of the modules from the manufacturing factory to the site is found to be a concern that may impact the construction process. As prefabricated modules are produced in the factory and the manufacturing factory might be hundreds of kilometres away from the construction site, the delivery of modules may take a long time, which could influence the site construction speed (Shin *et al*., 2020). Some assembled prefabricated modules might be oversized, which makes them hard to transport (Zhou *et al*., 2021). Also, road conditions around the site could have impacts on the transport of modules (Chen *et al*., 2021), leading to the delay of the process of the site construction. Therefore, the location of the construction site, as well as its surrounding transport situation, needs to be considered well when planning and managing module transport.

Compared with conventional buildings, modular buildings do not have sustainable structures, which are not suitable for all building types or locations, particularly high rises and buildings on areas with strong seismic activity. Thus, this method is often used to construct lower-level buildings, which is evidenced by three cases presented in the current study. Mafas *et al*. (2019) highlight that a modular building is found to have an indication of a higher risk of collapse under seismic loading in comparison with a conventional building. A more sustainable structure needs to be designed and applied to modular buildings, particularly the first few storeys, as they are critical under seismic loading (Mafas *et al*., 2019).

In addition, some other challenges, such as contractors' relevant modular construction knowledge and experience, construction plans and technology, site management and related regulations and codes, are suggested to be obstacles in largely applying the modular construction method in practice. However, the success of real-life projects, such as Huoshenshan and Leishenshan Covid-19 field hospitals (Chen *et al*., 2021; Zhou *et al*., 2021), Hawaii Studio (Anon, 2019c), the 2018 Olympics media residence hotel (Shin *et al*., 2020) and Global Academy (King, 2020), has evidenced that all the challenges could be overcome with efficient collaborations between different stakeholders in the manufacturing and construction process. The application of new technologies – for example, BIM and H-beams – and the combination of modular and traditional construction methods ensures the project process and quality, facilitating the success of modular technology in construction (Chen *et al*., 2021; Shin *et al*., 2020).

The advantages of the modular construction approach are summarised as follows.

- The modular construction approach shortens the construction time.
- It saves labours and costs in the process.
- It reduces site waste and minimises the impacts on the community in the construction process.
- A range of current technologies – for example, BIM and H-beams – are used in construction.
- The modular construction approach facilitates effective collaborations between stakeholders.
- It is eco-friendly, allowing recycling or relocating of modular buildings.

- It is suitable for constructing short-term buildings.
- The modular construction approach is a good option to construct different functional buildings.

The disadvantages of the modular construction approach are summarised as follows.

- It is hard to resize or reshape modules on the construction site.
- It is a challenge to transport modules, particularly large-sized modules.
- The modular construction approach is not appropriate for constructing long-term buildings.
- It is not suitable for constructing all types of buildings, particularly high rises or buildings on areas with strong seismic activity.

6. Conclusions

The modular construction method is suggested to be one of the most promising and high-technology approaches in future construction development (Generalova *et al*., 2016), which generally has more advantages than disadvantages. The findings of the current study coincide with those of the previous research (e.g. Anon, 2018, 2019b, 2019f; Chen *et al*., 2021; King, 2020; Zhou *et al*., 2021) that the modular construction method can shorten construction time, facilitate collaborations between stakeholders, enable effective management, save labour and costs, reduce waste and minimise impacts on the local community. It is implied that high-quality modules and construction make modular buildings satisfy the performance requirements of the by-laws of the respective countries. It could also be concluded from the case study that the eco-friendly design allows modular buildings to be recycled or relocated for some other purposes. The results also highlight that the combination of off-site modular method with the traditional building method can bring maximum benefits. It is suggested that modular design and construction would be an appropriate option to construct multifunctional buildings, particularly for short-term events or under some urgent circumstances.

Another conclusion of this study is that resizing or reshaping modules on the site, as well as the transport of modules, could be the challenges for the modular construction method. Thus, it is required that more effective logistic approaches should be used to transport modules to the site and new technologies focusing on flexibly resizing or reshaping modules could be developed. The modular technology is also suggested to be employed in constructing more permanent buildings by improving the quality and sustainability to satisfy relevant industrial regulations. Moreover, it might be a challenge to avoid miscommunication among a range of stakeholders in real practice. Therefore, it is essential to set up effective channels for communication and collaboration at all stages in the process to mitigate the potential miscommunication. Additionally, a cost–benefit type of analysis could be utilised to analyse the costs and benefits in the process for the use of the modular construction method in the long term. As the current study analysed only three typical cases utilising the modular construction method in construction, relevant findings can represent only the cases in a similar context and may be premature. A larger study that systematically investigates a number of typical cases in different contexts could be carried out in the future, which can collect more relevant data for wider analysis to increase the reliability of the outcomes.

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