# Adoption challenges of building information modelling (BIM) and off-site construction (OSC) in healthcare construction
## Are they fellow sufferers?

Tan, Tan; Mills, Grant; Ma, Xiaolin; Papadonikolaki, Eleni

**DOI**
10.1108/ECAM-03-2023-0287

**Publication date**
2024

**Document Version**
Final published version

**Published in**
Engineering, Construction and Architectural Management

**Citation (APA)**
Tan, T., Mills, G., Ma, X., & Papadonikolaki, E. (2024). Adoption challenges of building information modelling (BIM) and off-site construction (OSC) in healthcare construction: Are they fellow sufferers? *Engineering, Construction and Architectural Management*, *31*(13), 390-410. https://doi.org/10.1108/ECAM-03-2023-0287

Received 26 March 2023
Revised 4 February 2024
Accepted 18 April 2024

# Adoption challenges of building information modelling (BIM) and off-site construction (OSC) in healthcare construction: are they fellow sufferers?

Tan Tan
*Department of Real Estate and Construction, The University of Hong Kong, Hong Kong, China and*
*Department of Management in the Built Environment, Delft University of Technology, Delft, Netherlands*
Grant Mills
*Bartlett School of Sustainable Construction, University College London, London, UK*
Xiaolin Ma
*Medical Architecture Design and Research First Institute, China IPPR International Engineering Co., Ltd, Beijing, China, and*
Eleni Papadonikolaki
*Department of Materials, Mechanics, Management and Design, Delft University of Technology, Delft, Netherlands and*
*Bartlett School of Sustainable Construction, University College London, London, UK*

## Abstract

**Purpose** – Off-Site Construction (OSC) has received much government and public attention during and after COVID. Building Information Modelling (BIM) is an initiative discussed widely to promote OSC implementation. Although many policy promotions have been published, there are many challenges to implementing BIM and OSC in real life and questions of whether they really offer value to healthcare design professionals. This research aims to investigate BIM and OSC to understand their commonalities and differences of challenges by collecting empirical evidence from China's healthcare construction.

**Design/methodology/approach** – This exploratory research adopted a mixed method with a questionnaire survey and interviews. A total of 261 questionnaires were received (with 183 valid), followed by 31 semi-structured interviews.

**Findings** – This research reveals that although both OSC and BIM face similar adoption challenges and suspicious attitudes in real-life projects, their challenges' connotations and reasons are different. OSC faces scepticism for its customisation costs and technical constraints, while BIM is seen as limited in utility and complex to integrate. Highlighting these as socio-technical challenges, the research advocates for an integrated framework to effectively implement OSC and BIM, addressing both technical and collaborative needs in healthcare construction.

**Originality/value** – This research examines OSC and BIM within the context of healthcare construction, a focus that is relatively underexplored. The research provides a juxtaposition of the perceived and practical



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

Engineering, Construction and Architectural Management
Vol. 31 No. 13, 2024
pp. 390-410
Emerald Publishing Limited
0969-9988
DOI 10.1108/ECAM-03-2023-0287

challenges of adopting these technologies, revealing a gap between the industry's expectations and the current capabilities of OSC and BIM, thereby contributing to the development of modern methods of design in healthcare.

**Keywords** BIM, Healthcare construction, China, Off-site construction, Adoption challenges

**Paper type** Research paper

## 1. Introduction

Building Information Modelling (BIM) and Off-Site Construction (OSC), respectively, are the most representative digitalisation and industrialisation pathways impacting the construction industry and are also two key initiatives that many national governments are actively promoting through their policies. The term OSC refers to the process of manufacturing and preassembly elements or components of a construction project at a location different from the installation location and usually consists of planning, design, manufacturing, and assembly in purpose-built factories (Goodier and Gibb, 2007). The meaning of OSC sometimes appears in the literature and practices through some interchangeable terms, such as "prefabrication", "industrialised construction", "off-site manufacture", "manufactured construction", "modular integrated construction", and "modern methods of construction" (Arif and Egbu, 2010), although specific differences exist among them. This research uses OSC throughout to maintain consistency and regards it as a typically perceived measure of industrialisation in the Architectural Engineering and Construction (AEC) industry. OSC is regarded as a promising approach with capabilities in production safety, economies of scale and sustainability to overcome construction challenges and transform the industry (Abanda *et al.*, 2017; Jiang *et al.*, 2018). However, many OSC challenges and implementation difficulties still exist, such as high initial set-up costs, immature techniques, and a lack of skilled labourers (Arif *et al.*, 2012; Gan *et al.*, 2018; Mao *et al.*, 2015; Pan and Sidwell, 2011). Moreover, in traditional building design, designers do not need to consider many manufacturing and construction issues, which is the opposite in the case of OSC.

On the other hand, the adoption of digitalisation approaches, such as BIM, has become an increasingly prevalent topic. BIM can transform traditional information management and integrate data from different disciplines (Eastman *et al.*, 2011; Sacks and Pikas, 2021). BIM enables the integration of various stakeholders horizontally while integrating information at different project stages vertically (Chang and Shih, 2013; Gaur and Tawalare, 2022). As a collaborative methodology, BIM contributes to sharing project information throughout a building's life cycle (Emmitt and Ruikar, 2013; Meng *et al.*, 2020). This research uses the definition of BIM as "*a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital formats throughout the building's life cycle*" (Succar, 2009). Many studies have shown BIM's profound impact on designing and implementing healthcare projects. Studies have reported the successful implementation of BIM in healthcare construction in different countries, including the Netherlands (Sebastian, 2011), Norway (Merschbrock and Munkvold, 2015), Australia (Mignone *et al.*, 2016), the UK (Davies and Harty, 2013), and the US (Kokkonen and Alin, 2016). Many articles describe BIM as being incredibly beneficial in designing hospital spaces with numerous technical appliances and demanding performance requirements. However, implementing BIM is challenging. Many studies highlight the adoption barriers of BIM and question its real use in many practices.

This research explores BIM and OSC in healthcare construction to understand their commonalities and differences in terms of adoption challenges. China is used as the empirical setting to understand digitalisation and industrialisation in real-life practices. China's rapid development in healthcare construction provides rich opportunities and contexts for evaluating BIM and OSC adoption challenges. Healthcare architecture is more complex than other architectural sectors, and in many countries, it is primarily driven and constructed by the government as a major public and civil welfare project. As such, it serves as a real "experiment" site for the implementation of BIM and OSC. Compared to the requirements of other types of buildings, the complexity of healthcare facilities in the built environment provide a scenario of high-quality adoption needs for the investigation of BIM and OSC. Consequently, the conclusions drawn can also be generalised to the practices of other, simpler types of building construction. In addition, insights gained from China's unique policy environment, technological innovation drive, and cultural and organisational structures can offer valuable lessons for other nations facing similar challenges in integrating advanced construction technologies. This research can thus serve as a benchmark for comparing and enhancing BIM and OSC adoption strategies in diverse global settings.

This research poses two exploratory Research Questions (RQ) within the context of China's healthcare construction: (1) *How do designers perceive the key factors influencing the adoption of BIM and OSC? (RQ1)*; (2) *What are designers' attitudes towards the adoption challenges of BIM and OSC? (RQ2)*. This research seeks to determine whether BIM and OSC are "Fellow Sufferers" in the design stage, meaning that they share similar challenges and the underlying reasons for these challenges. By comparing the adoption challenges of these two transformative technology pathways, this research sheds light on how the construction industry might be transformed both theoretically and practically. It offers insights into whether these technologies share common challenges, thereby highlighting the need for integrated strategies for their successful implementation. These findings could also guide future policy and educational efforts to address shared challenges more effectively.

## 2. Literature review

### *2.1 The implementation of OSC in healthcare construction*

The traditional construction method is struggling to both keep pace with the rapidly increasing demand for healthcare services and adapt to emerging requirements (Pan and Zhang, 2022). Awareness and acceptance of Off-Site Construction (OSC) for healthcare construction have gradually increased in recent years. OSC is an advanced pathway to accelerate capability development and revolutionise traditional healthcare delivery (Adebayo *et al.*, 2006; Pan and Zhang, 2022). For healthcare facilities that use OSC, some or all components are manufactured in off-site factories rather than at hospital locations and then transported to the construction sites for assembly.

The healthcare sector has a long history of implementing OSC (Adebayo *et al.*, 2006). According to archaeologists, the earliest use of OSC occurred in the British Isles during the Roman era (Gibb, 1999). The largest of the construction was the Legionary Fortress at Inchtuthil, Scotland, built between AD 83 and 86. Inchtuthil's 170 buildings include a large 600-bed hospital (Adebayo *et al.*, 2006). The modern off-site built hospital originated in 1854, soon after Britain entered the Crimean War. Due to the decrepit conditions in the Turkish Selimiye Barracks at Scutari, which the British had converted into an army hospital, the British government erected the first modern offsite-built hospital that had been transported by ship to the installation site in Crimea in 1855 (Verderber, 2015).

Since the outbreak of COVID-19, various countries have taken advantage of OSC to rapidly construct and retrofit emergency healthcare facilities (Pan and Zhang, 2022). OSC also offers a promising means for dealing with excess temporary or non-temporary COVID-19 medical wards by disassembling and recycling their materials in a sustainable way (Kucan *et al.*, 2024). Some governments have published policies to expand their healthcare capacity through off-site and modular construction techniques (Pan and Zhang, 2022).

However, some people question the suitability of OSC for healthcare construction (Pan and Zhang, 2022), particularly for facilities beyond standardised wards and outpatient clinics. For example, flexibility is essential in healthcare construction, but OSC is ill-suited for incorporating last-minute design changes (Jang and Lee, 2018). In addition, many parts of healthcare construction are conventionally procured on a project-by-project basis, and they are designed, manufactured, and constructed as bespoke projects. Project-specific manufacturing results in high costs and slow production processes (Mittal *et al.*, 2020; Tillmann *et al.*, 2010).

Linear, fragmented, and non-repetitive production methods hinder the healthcare sector's adoption of OSC; producing prefabricated buildings requires collaboration and interdisciplinary work across a variety of technical areas and with a variety of stakeholders (Abdul Nabi and El-adaway, 2020; Innella *et al.*, 2019). A wide range of established professions and disciplines, represented by a variety of professional bodies and trade organisations, exist in the AEC industry (Emmitt, 2010). Inter- and transdisciplinary knowledge transfer creates severe challenges for productive interactions between a project's design, manufacturing, and assembly phases. Complex-building settings and hyper environments (i.e. healthcare facilities) exacerbate those challenges (Adebayo *et al.*, 2006).

### *2.2 Understanding the implementation of BIM in healthcare construction*

Some studies have tried to understand the practices, activities, and implementation process of BIM in healthcare construction (Tan *et al.*, 2024b). The case study method is widely used in this exploration, including single cases and multiple cases. As shown in Table 1, various studies have analysed BIM from different country backgrounds (e.g. Netherlands, Norway, United Kingdom, United States, Australia, etc.), building stages (e.g. design, construction) and theoretical background (e.g. diffusion of innovations theory, organisational discontinuity theory, sense-making theory and social network theory).

However, healthcare construction projects were mostly used as a typical example of high-complexity building to explore the adoption and implementation of BIM (Tan *et al.*, 2024a).

| Author | Case location | Number of cases | Use stage of BIM Design | Construction | Theoretical background |
|---|---|---|---|---|---|
| Sebastian (2011) | Netherlands | 2 | ✓ | ✓ | N/A |
| Merschbrock and Munkvold (2015) | Norway | 1 | ✓ | | Diffusion of innovations theory |
| Mignone *et al.* (2016) | Australia | 1 | ✓ | ✓ | Organisational discontinuity theory |
| Love and Ika (2022) | Australia | 3 | | ✓ | Sense-making theory |
| Davies and Harty (2013) | United Kingdom | 1 | | ✓ | N/A |
| Merschbrock *et al.* (2018) | Norway + Australia | 2 | ✓ | | Extended Leavitt sociotechnical model |
| Li *et al.* (2021) | China | 1 | | ✓ | Social network theory |
| Harty *et al.* (2010) | United Kingdom | 2 | | ✓ | N/A |
| Kokkonen and Alin (2016) | United States | 1 | | ✓ | Deconstruction and reconstruction theory |
| Pikas *et al.* (2011) | United Kingdom and United States | 12 | ✓ | ✓ | N/A |

**Table 1.** Research of BIM adoption and use in hospital projects

Although many studies emphasised the complex and unique characteristics of healthcare construction compared with other building types, such as simple office or housing construction, many of these studies did not distinguish healthcare construction from others. For example, Harty *et al.* (2010) investigated the adoption and utilisation of BIM through two UK-based hospital projects. Kokkonen and Alin (2016) explore how practitioners are actively involved in a change through reflective learning when implementing BIM through a US-based hospital project. Li *et al.* (2021) studied BIM's formal and informal collaborative networks in traditional procurement through a China-based hospital project. Healthcare construction can be considered among the most intricate building categories. Thus, it remains essential to concentrate solely on healthcare construction to explore its distinct and comparable contexts, challenges, and execution situations. Thus, it remains essential to concentrate solely on healthcare construction to explore its distinct and comparable contexts, challenges, and execution situations. Healthcare facilities can be regarded as complex building types to understand the implementation of BIM, but the unique functional and spatial requirements make BIM research specifically necessary for healthcare building types.

The second gap is the difference between BIM adoption and implementation in various building stages. Although the team and disciplinary integration among different companies of a project are always necessary in the literature, the collaboration between different stakeholders in projects is always fragmented. It cannot be denied that the adoption and implementation of BIM for different stakeholders, such as design institutes, contractors, suppliers, and facility users, would be totally different. Their different roles have an impact on their utilisation of BIM and also other digital technologies. Some studies have explored the early stages of BIM implementation. For example, Merschbrock and Munkvold (2015) study the hospital's BIM implementation of effective digital collaboration in the design stage. Davies and Harty (2013) investigate the "Site BIM" in the hospital's construction stage. However, there is no study that explores BIM and OSC in the design stage to understand their commonalities and differences in terms of adoption challenges.

## 3. Methodology

### *3.1 Research design and methods*

An exploratory study is a research approach used to investigate a topic or a problem that is not well understood, aimed at gaining insights, identifying patterns, and forming hypotheses that can lead to further research and understanding (Swedberg, 2020). Some research has shown the capability of exploratory study for BIM implementation in different sectors and countries (Han and Golparvar-Fard, 2017; Hochscheid *et al.*, 2023; Le *et al.*, 2022; Shojaei *et al.*, 2023; Troiani *et al.*, 2020; Wang *et al.*, 2022). This exploratory study used a mixed method combining a survey and semi-structured interviews, two typical methods in exploratory studies. Exploratory survey research is conducted in the initial phases of investigating a phenomenon. Its purpose is to gather initial insights about a topic, serving as a foundation for more comprehensive surveys later on (Forza, 2002).

A sample survey consists of three methodologies: sampling, designing questions, and data collection (Fowler, 2013). The study population is a nationally representative research sample of healthcare building designers in China. The data collection for the study primarily occurred during the COVID-19 pandemic control period in China, which presented many challenges and restrictions for data gathering, including limited access to participants. Therefore, voluntary sampling was used for the healthcare construction survey (Murairwa, 2015), as it is impossible and unnecessary to survey all practitioners in China's healthcare construction. Voluntary sampling facilitates remote data collection in situations like a pandemic or in geographically dispersed populations. For exploratory studies, voluntary sampling can provide initial insights and trends, which can inform larger, more structured studies in the future. Then, this research developed a survey instrument and questions through a literature review, information interviews, and discussion with leading researchers and industrial contacts from healthcare construction. Documents and literature from China's leading organisations and governments were mainly used to design the survey better to fit the language and education of local practitioners. For example, the research referred to measures and characteristics published by the Chinese government regarding BIM and OSC to design the survey questionnaire. A pilot survey with a few research colleagues was conducted to verify the validity and reliability of the survey. Finally, a questionnaire survey was established. Both qualitative and quantitative questions were included in the survey with a methodical use of rating scales, Likert scales and open-ended questions. Section 1 aims to establish an overview of the sampling, including their company types, professionals, and work years. Section 2 explores the industrialised practices in healthcare construction. Section 3 explores digital technologies in healthcare construction. Section 4 and section 5 search for the adoption factors of OSC and BIM, respectively. Section 6 investigates attitudes and recommendations for the industry to increase the take-up of industrialisation or digitalisation practices in healthcare construction.

While efficient for broad data collection, surveys often lack depth due to their structured format (Fowler, 2013). Interviews provide detailed insights but are time and resource-intensive, limiting their scalability (Gubrium and Holstein, 2002). Integrating both methods enhances research by combining the breadth of surveys with the depth of interviews, offering a more comprehensive and in-depth understanding of the subject matter (Jain, 2021). Voluntary sampling of the questionnaire survey, where participants self-select to be part of a study, is advantageous for its ease and low cost but can suffer from bias and lack of representativeness, limiting the generalizability of its findings (Murairwa, 2015). Thus, this study designed a supplementary interview stage after the questionnaire survey. Purposive sampling is ideal for this study's supplementary interviews, as it can include specific experts from varied design levels (Etikan *et al.*, 2016), ensuring in-depth insights into China's advanced BIM implementation in healthcare design.

*3.2 Data collection*

Tencent Questionnaire, the largest online questionnaire platform in China, was used to distribute the questionnaire and collect data. This distribution is designed for practitioners with healthcare construction experience. The survey data collection was completed in October 2021. A total of 261 questionnaires were received, of which 78 were excluded for being invalid due to them containing many homogeneous choices, contradictory choices, and/or incomplete choices. After the screening, this research was left with 183 valid questionnaires, representing a response rate of 29%, which is acceptable according to Moser and Kalton (2017), who suggest that response rates of less than 20% or 30% in social surveys may make the results of little value. As shown in Table 2, the survey responses are divided into five sections: institution type, job type, the building stages in which they specialise, the number of years worked, and institution size. The average completion time for the survey was 7 min and 8 s.

Regarding interview data collection, all of these interviewees come from leading institutes in healthcare building design in China, which can represent the most advanced BIM implementation of healthcare building design in China. Both senior designers, such as leaders and principals, and junior designers were included for a better understanding of various levels of design. Phone calls or online calls were used to contact potential interviewees and schedule interviews. As shown in Table 3, the sample of interviewees includes 31 designers from six disciplines.

| Options | Percentage% | Total |
|---|---|---|
| *1. Please describe the type of institution you are working for* | | |
| Owner | 15.30% | 28 |
| Designer | 18.60% | 34 |
| Consulting service | 9.80% | 18 |
| Construction contractor | 37.70% | 69 |
| Construction equipment supplier | 4.90% | 9 |
| Medical equipment supplier | 3.30% | 6 |
| Decoration material supplier | 1.60% | 3 |
| Operation service provider | 4.90% | 9 |
| Other____ | 3.80% | 7 |
| Total | | 183 |
| *2. Please describe your job type* | | |
| Pre-planning of hospital projects | 5.50% | 10 |
| Hospital equipment configuration and management | 4.90% | 9 |
| Project planning and design | 23.50% | 43 |
| Hospital engineering construction | 24.00% | 44 |
| Project implementation management | 31.10% | 57 |
| Hospital operation management | 4.90% | 9 |
| Other____ | 6.00% | 11 |
| Total | | 183 |
| *3. What stages of healthcare construction your institution is mainly involved in?* | | |
| Planning | 30.10% | 55 |
| Design | 41.50% | 76 |
| Manufacture | 15.80% | 29 |
| Construction | 54.60% | 100 |
| Operation | 19.70% | 36 |
| Other____ | 3.80% | 7 |
| Total | | 183 |
| *4. How many years have you been in the AEC industry?* | | |
| 0–5 | 20.80% | 38 |
| 6–10 | 46.40% | 85 |
| 11–15 | 18.60% | 34 |
| 16–20 | 5.50% | 10 |
| >20 | 8.70% | 16 |
| Total | | 183 |
| *5. What is the size of your institution?* | | |
| Miniature (1–10) | 2.70% | 5 |
| Small (11–50) | 22.40% | 41 |
| Medium (51–250) | 43.70% | 80 |
| Large (>250) | 31.10% | 57 |
| Total | | 183 |

**Table 2.**
Survey responses

There are four major categories of information required in the research: (1) general information of interviewees; (2) general information on healthcare construction; (3) design strategies for healthcare construction; and (4) adoption of industrialisation and digitalisation techniques. Following these four categories of interviews, the additional five (see "other" in Table 4) would let interviewees share what they think might be significant for healthcare design and provide them opportunities to ask questions towards the interviewer. The interview time ranged from 30–90 min. All interviews were recorded, translated, and transcribed.

| Code | Specialization | Role | Years in industry |
|---|---|---|---|
| P01 | Architectural design | Leader | 22 |
| P02 | | Leader | 13 |
| P03 | | Leader | >16 |
| P04 | | Leader | >16 |
| P05 | | Designer | 4 |
| P06 | | Designer | 11–15 |
| P07 | | Designer | 6–10 |
| P08 | | Designer | 1.5 |
| P09 | Structural engineering | Leader | 9 |
| P10 | | Leader | >16 |
| P11 | | Leader | >16 |
| P12 | | Leader | >16 |
| P13 | | Designer | 3 |
| P14 | Water supply and drainage | Leader | N/A |
| P15 | | Leader | >16 |
| P16 | | Designing principal | >16 |
| P17 | | Designer | 11–15 |
| P18 | | Designer | 11–15 |
| P19 | | Designer | 6–10 |
| P20 | | Designer | 3 |
| P21 | HVAC | Leader | N/A |
| P22 | | Leader | 5 |
| P23 | | Leader | >16 |
| P24 | | Designing principal | >16 |
| P25 | | Designer | 11–15 |
| P26 | | Designer | 12 |
| P27 | Electrical engineering | Leader | 17 |
| P28 | | Leader | >16 |
| P29 | | Designing principal | >16 |
| P30 | | Designer | >16 |
| P31 | Power engineering | Leader | 15 |

**Table 3.**
Sample of interviewees

| Areas of information required | Information required |
|---|---|
| General information about an interviewee | Roles of interviewees<br>Working years (both in the general AEC industry and healthcare construction)<br>Responsibilities in previous healthcare construction projects |
| General information on healthcare construction | Differences between healthcare construction and other sectors<br>Difficulties in healthcare construction<br>Requirements of healthcare construction |
| Design strategies for healthcare construction | Participants and stakeholders for healthcare design<br>Integration and collaboration between design and construction<br>Design evaluation method<br>Decision-making in design<br>Integration of design guidelines/strategies |
| Adoption of industrialised and digitalised techniques | Approaches/techniques for the improvement of manufacturability and assemblability<br>Digital approaches/techniques to facilitate design |
| Other | Significant experience from previous projects can be used for following projects<br>Significant experience and suggestions for sharing |

**Table 4.**
Areas of information required in the interviews

### 3.3 Data analysis

For survey analysis, both Microsoft Excel and Tencent Questionnaires were used to store data. The latter was used to analyse, illustrate and present the data. Descriptive statistics are used to describe a summary of the basic characteristics of the sample and observations made in a study (Fisher and Marshall, 2009). Both quantitative summary statistics and visual simple-to-understand graphs are used to form simple summaries about samples and measures, which form the basis for a preliminary description of the data as part of a broader statistical analysis. In addition, they may also be in and of themselves for a particular investigation (Trochim, 2006). Univariate analysis is a major data analysis method in this part of the research (Ho, 2006), focusing on analysing one variable at a time to understand its distribution, central tendency, and spread. It helps in identifying trends, detecting outliers, and summarising the characteristics of the data (Huberty and Morris, 1992).

This interview research adopted qualitative content analysis, which refers to systematically describing the meaning of qualitative data in an essentially descriptive way (Schreier, 2012). This research adopted the three-step framework proposed by Forman and Damschroder (2007) to approach qualitative content analysis, including (1) data immersion, (2) data reduction, and (3) data interpretation. Data immersion is about how researchers engage and obtain a sense of the data (Forman and Damschroder, 2007). Data reduction aims to (1) reduce the amount of raw data to the amount relevant to answering the research question; (2) break down the data (including transcripts and memos) into more manageable themes and thematic segments; (3) reorganise the data into categories in a way that addresses the research questions (Forman and Damschroder, 2007). Data interpretation refers to the process of reviewing data by adopting predetermined processes for assigning some meaning to the data and then arriving at a relevant conclusion (Forman and Damschroder, 2007).

## 4. Results

### 4.1 Adoption factors and attitudes for OSC

The results suggest that adopting OSC may be hindered in many ways (see Figure 1). One of the interviewees, P21, an HVAC leader, said, "*There are not a lot of real OSC in Beijing, especially in healthcare construction*". The difficulty of adoption is mainly concentrated on the specific application level of OSC. Many practitioners recognise the technical challenges around OSC in the field of healthcare construction, and this kind of challenge hinders their implementation. For example, an architect leader said;

> If it's a hospital, we feel it's not quite suitable . . . For example, with CT-scanners, if they [building components] are assembled from separate pieces, we think there might be gaps in the shielding, and radiation could leak out. Also, in many areas requiring waterproofing, if you're using pieced-together panels underneath, we also feel it might not be that safe.

The technical limitations of OSC have created a dilemma where there must be a compromise between functional requirements and manufacturing costs. That is, only through expensive investments can some specific medical functions be met, which would be cheaper with conventional construction methods. For instance, P01, an architect said;

> Moreover, in hospitals, when moving beds and equipment, or, for example, moving X-ray machines, they are relatively heavy. A few years ago, when we were working on a project in Miyun, we also evaluated prefabricated flooring manufacturers. At that time, the load requirements we proposed could not be met by them . . . or, if they could be met, it was very expensive . . . Many components need to be remodeled according to our requirements, which can be costly . . . It might even be more expensive than cast-in-place construction, significantly more so.


**Figure 1.** Adoption factors for OSC

The second lowest score is for the complexity of the various professional synergy mechanisms around OSC, demonstrating that the adoption of such strategies in the field of healthcare construction involves the collaboration of multiple disciplines. For example, P21, a HVAC leader, said;

> From the design to the final assembly stage of healthcare construction, the client adjusts the medical process again and again, according to the use needs of each medical department. Every medical process adjustment results in an entire professional design adjustment. Since the OSC is processed and assembled at one time, the split design volume at this time will be larger for the designers.

This collaborative work is challenged and made more complex by the adoption of OSC, which also interacts and co-exists with the previously mentioned complexity of technical difficulty.

OSC also score low in terms of continuous investment and software and hardware support, which shows that many practitioners believe that there is a lack of sufficient funds, software, and hardware to solve the aforementioned problems in healthcare construction. In the interview, P14, a drainage engineering leader, said, " … *because it is still the promotion period, including the selection of its related technologies, may not be very mature. Or there are not so many options on the market, so the cost may be relatively high now"*.

The lack of financial support and the lack of performance of OSC in terms of revenue growth contributed to the relatively low score for this adoption factor. At the same time, many practitioners believe that clients are not motivated to adopt OSC. For example, P01, an architect lead said, "*We believe that prefabricated concrete construction actually has many limitations for hospitals … Therefore, we generally do not recommend clients to pursue this approach and advise against using prefabrication"*.

Despite recognising the role of OSC in COVID-19 emergency healthcare facilities, the findings reveal that many practitioners remain sceptical about the applicability of OSC to major complex hospitals. For example, the survey results implicate that three main factors, namely cost barriers, the complexity of adoption, and healthcare uniqueness, may be reasons for this attitude. The results show that complexity mainly involves twofold aspects: the complexity of the OSC technology itself and the complexity of the required collaboration for implementing the design for OSC. The former is primarily a technical issue, while the latter is a socio-technical challenge. Solving the complexities of the technology itself depends on developing and improving the entire OSC supply chain in the healthcare construction field, which would also contribute to the reduction of adoption costs.

This research then investigates the attitudes of healthcare construction practitioners towards the adoption of OSC, initially by investigating the differences in the ways in which OSC are perceived by practitioners in healthcare facilities and other building types, to understand whether there is a need for OSC that is different for healthcare construction projects. This hypothesis serves as a premise and basis for understanding practitioners' attitudes towards adopting OSC specific to healthcare facilities. This research shows from the results that most practitioners believe that, in past practice, Healthcare facilities have adopted OSC that are different from other building types (see Figure 2). However, there are still a small number who have reservations or objections to this difference. For example, a structural lead, P09 said, "*In fact, there is not much difference in terms of design for manufacture and assembly approaches for OSC. They are all designed in the normal way used for traditional buildings*". About 90% of practitioners believe it is necessary to improve the level of industrialisation in healthcare facilities (see Figure 3), while over 10% take the opposite position. For example, interviewee P01, an architect lead, highlighted; "*We think that concrete OSC actually have a lot of limitations for hospitals* … .... *so we generally advise our clients against it"*. P09, a structural leader, said that;

> Because, from the bottom of our hearts, we still reject it. Anyway, I personally think that even if the policy is to promote OSC, it is not necessary to apply it to hospitals because hospitals are actually a people's livelihood project or a lifeline project, and OSC, as an experimental thing, may not be suitable.

This section shows that (1) the implementation of OSC is still in its infant development stage in China's healthcare construction and (2) the perceived measures from practitioners might deviate from the essence of OSC, which poses challenges to the building systems integration due to unmatured adoptions.

*4.2 Adoption factors and attitudes for BIM*

As shown in Figure 4, the distribution of the results for BIM is similar to that of the OSC strategy in many ways. For example, the difficulty of adoption is dependent on the specific

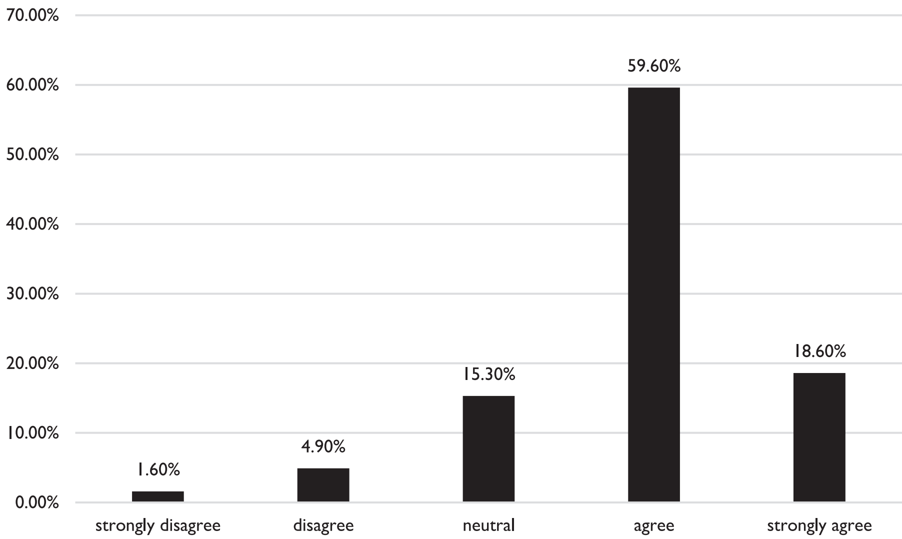


**Figure 2.**
Institutions have adopted a different approach to OSC in healthcare construction than other building types (e.g. residential, office buildings)

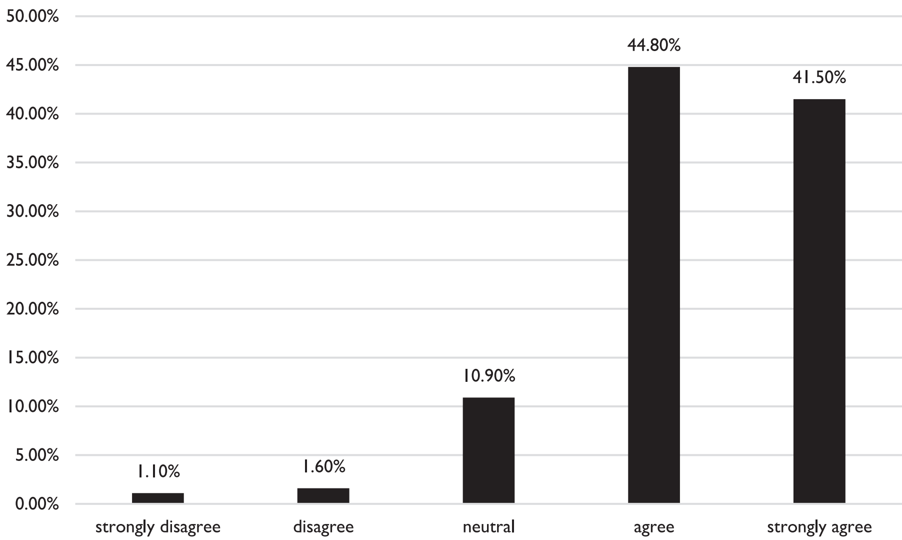


**Figure 3.**
The necessity to increase the proportion of OSC in healthcare construction

application level of BIM; technical difficulty received the lowest score, which shows that many practitioners recognise the technical challenges surrounding BIM in healthcare construction, and these challenges hinder the promotion of BIM strategies. The second worst score is for the complexity of the various professional synergy mechanisms around BIM, demonstrating that adopting BIM involves the collaboration of multiple disciplines, which is a challenge and exacerbates the complexity of the technical difficulty cited above. In an interview, P21, a HVAC leader, said that;


**Figure 4.** Adoption factors of BIM

> Just using BIM for building modelling may not be very slow yet, but after all the professions are involved, the model will become bigger and bigger because it has a lot of information in it, so it will be slower to use . . .... In fact, it is equivalent to an additional workload.

The lack of performance of BIM in terms of revenue growth also contributed to the relatively low score for this adoption factor.

Many practitioners believe that clients have little motivation to adopt BIM. Compared with the adoption factor of OSC, there is a relatively low level of support for BIM adoption from the external environment. For example, in terms of continuous investment and software and hardware support, BIM scored the lowest, which shows the mistrust of practitioners towards BIM adoption in terms of financial support and outcomes. P13, a structural engineering designer, said, "*But the software of structural engineering on BIM is very* *immature . . .... For structural engineering, it is very bad to use at the moment*". These factors scored the lowest in terms of improving company competitiveness and industry and policy trend requirements. The highest driving factor, on the other hand, comes from improving customer satisfaction, scoring much higher than it did in the adoption of OSC.

The research then investigated the attitudes of healthcare construction practitioners towards BIM adoption, beginning with an examination of how BIM is perceived in healthcare facilities compared to other building types to determine whether the need for BIM in healthcare differs from that in other types of construction. This hypothesis serves as a premise and basis for understanding practitioners' attitudes towards the adoption of BIM in the specific context of healthcare facilities. The results show that the vast majority of practitioners believe that healthcare building projects have adopted BIM differently from other building types (see Figure 5), although a small number disagree. In order to improve the level of digitalisation in healthcare facilities, about 87% of practitioners believe it is necessary (see Figure 6), leaving around 13% unconvinced. P13, a structural designer, said;

> If it is a very convenient software, everyone will use it without promotion. Now every project is wildly promoting the use of BIM, and yet everyone is still not using it, which means that BIM is not very useful for the project results.

Regarding the perceived measures of BIM, the research shows that BIM as a set of digital modelling software has very limited use and gains little trust from China's practitioners in the healthcare design stage. Healthcare construction shows strong public attributes, and most of them are built by the government and have complex functions and ultra-high investment, making their BIM adoption different from many other buildings, such as residential, office buildings, etc. The survey results implicate a paradoxical attitude in that the vast majority of practitioners believe that BIM is important for healthcare construction but do not implement BIM as such in practice.

Besides, the results reveal that practitioners believe that healthcare construction has unique needs and characteristics for using BIM compared to other building types. The adoption of digital technologies, such as BIM, in healthcare construction is not merely a

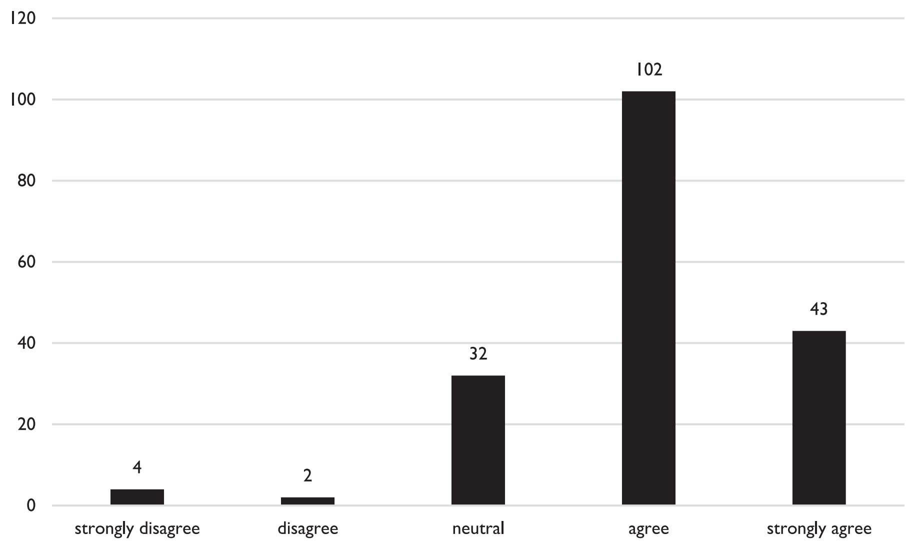


**Figure 5.** Institutions have adopted a different approach to BIM strategies in healthcare construction than other building types (e.g. residential, office)

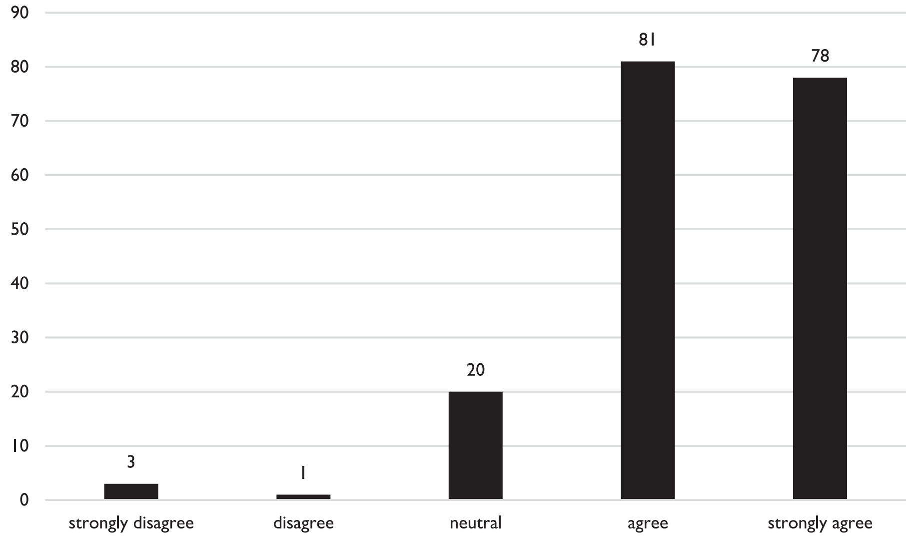


**Figure 6.**
The necessity to increase the proportion of BIM in healthcare construction

technical challenge; like the adoption of OSC, it is a socio-technical issue that involves transforming and coordinating the design process, project organisation, and supply chain.

## 5. Discussion

This study investigates the field of healthcare construction in China from two perspectives, namely digitalisation (i.e. BIM) and industrialisation (i.e. OSC). It extends the existing respective discussion of healthcare construction on the implementation of BIM (Davies and Harty, 2013; Merschbrock and Munkvold, 2015) and OSC (Adebayo *et al.*, 2006; Mills *et al.*, 2020). Regarding the nature of these two approaches, this research implicates BIM as an innovation in design processes and OSC as an innovation in design products while, in turn, requiring changes in design processes to achieve such product innovation. In other words, they are transformations in production and design, respectively. Compared with existing related research, this study attempts to compare the implementations of these two initiatives, which can help with the proposition of an integral strategy to promote their implementations. The nature of challenges faced by BIM and OSC differs significantly due to their distinct characteristics, operational mechanisms, and the specific demands they place on the construction process, although they also share some similar challenges and both face scepticism.

For OSC, the primary difficulty lies in its specific application within healthcare construction, where technical limitations and the need to balance functional requirements with manufacturing costs create a significant dilemma. This research result provides a critical reflection on the overheating of OSC hospitals after COVID-19, though much existing research highlights the impacts of OSC on healthcare construction (Assaad *et al.*, 2022; Chen, 2020; Luo *et al.*, 2020; Pan and Zhang, 2022; Tan *et al.*, 2021). The result shows that implementing OSC in healthcare settings faces barriers such as ensuring radiation shielding integrity in areas with CT scanners, achieving waterproofing in critical areas, and meeting load requirements for heavy medical equipment, all of which may necessitate costly customisations. The complexity of professional synergy mechanisms further complicates OSC adoption, as adjustments in medical processes necessitate comprehensive design changes, imposing challenges on designers due to OSC's one-time processing and assembly nature. This research reveals a social perception of the industry that is contrary to the conclusions of existing research. For example, Adebayo *et al.* (2006) concluded that OSC is the most appropriate construction method to achieve cost-effectiveness and speed in healthcare construction. The study revealed that, at least from the perspective of practitioner perceptions, OSC is not a cost-effective construction option because healthcare construction involves many architectural spaces with unique and non-standardised needs.

Although OSC does not inherently mean standardised buildings, the motivation to promote OSC usually relies on its economies of scale through standardisation. Healthcare facilities often require specialised spaces designed to accommodate specific medical functions, posing a significant challenge to OSC's standardisation and mass production advantages. Moreover, the technical requirements of healthcare buildings, such as precise radiation shielding for CT scanners and robust waterproofing measures, demand high precision and quality in construction. These requirements often lead to increased costs and complexities in implementing OSC, challenging the method's cost-effectiveness and adaptability to healthcare facilities' dynamic, evolving needs. Future practices need a mass-customisable layered modular design and future-proofing construction to deal with this challenge.

In contrast, BIM has its unique set of characteristics leading to its adoption challenges in the context of healthcare construction, primarily related to integrating complex systems and maintaining high standards of accuracy and compliance. Healthcare facilities are intricate environments that include various specialised systems (Xin *et al.*, 2024), which need to be coordinated and integrated within the BIM framework. This integration requires significant technical expertise and stringent adherence to precision, given the minimal margin for error in healthcare settings. Furthermore, the collaborative nature of BIM, involving various stakeholders such as medical staff, administrators, and regulatory bodies, adds another layer of complexity. Effective stakeholder management within the BIM process is crucial to ensure clear communication, understanding, and consensus among all parties involved, making adopting and implementing BIM a multifaceted challenge in healthcare construction.

Both OSC and BIM are recognised for their potential to revolutionise healthcare construction, yet practitioners express scepticism about their applicability to complex healthcare facilities. This scepticism stems from cost barriers, the complexity of adoption, and the unique requirements of healthcare projects. Although OSC and BIM share adoption challenges and face scepticism in the context of healthcare construction, the connotations of these challenges differ significantly, primarily due to the characteristics of each approach and the unique requirements of healthcare facility design. Understanding these distinct challenges is vital for successfully implementing both OSC and BIM in healthcare construction. While OSC needs to balance standardisation and customisation, along with addressing specific technical and functional requirements, BIM contends with integrating complex systems within a digital model, upholding high standards of accuracy, and managing extensive stakeholder collaboration.

Addressing these challenges necessitates a focus on improving the OSC supply chain, fostering interdisciplinary collaboration, and enhancing the level of digitalisation and integration of BIM in healthcare facilities. Adopting OSC and BIM in healthcare construction is not merely a technical implementation but a socio-technical challenge that requires a holistic approach to technology integration, process transformation, and stakeholder coordination. This research implicates the necessity of an integral framework for promoting OSC and BIM in healthcare construction. The expected integral framework is a holistic approach that integrates the precision and efficiency of OSC with the collaborative, data-rich capabilities of BIM, which are used to meet the demanding and dynamic landscape of healthcare construction.

## 6. Conclusion

Regarding whether they (i.e. the implementation of BIM and OSC) are fellow sufferers, this research reveals that although both face adoption challenges and suspicious attitudes in real-world projects, their challenges' nature and underlying causes are different. The primary adoption obstacles for OSC include its technical limitations, substantial costs, and the complexity of interdisciplinary collaboration. Scepticism prevails about its suitability for complex healthcare structures due to cost constraints, technical and collaborative complexities, and the industry's distinctive requirements. The infancy of OSC's adoption and its deviation from the core principles add further intricacies. Similarly, BIM adoption confronts technical difficulties, limited client motivation, and scepticism about its financial and operational outcomes. Despite recognising the necessity for higher digitalisation in healthcare, practitioners exhibit a paradoxical attitude towards BIM, acknowledging its significance yet reluctant to apply it in practice. Both OSC and BIM face socio-technical challenges, necessitating not just technological advancements but also a transformation in the design process, project organisation, and supply chain management. The adoption of both OSC and BIM is heavily influenced by socio-technical collaboration, yet OSC faces additional technological constraints due to transportation, manufacturing equipment, and material capabilities. The unique characteristics of healthcare facilities, including their complexity, information/knowledge density, and stakeholder diversity, further impact the adoption and practical implementation of BIM and OSC. The intertwined socio-technical nature of these challenges highlights the need for comprehensive strategies that address both the technical and collaborative facets of OSC and BIM adoption in healthcare construction.

This study is of significant importance for theoretical development and practical application in the field of construction management, especially within the context of digitalisation and industrialisation. Theoretically, contrasting the adoption challenges and attitudes towards OSC and BIM sheds light on the disparities between the advocated technological implementations and actual practices. Furthermore, holistically considering the industrialisation and digitalisation transformation processes establishes a deep understanding of how to foster the realisation of a unified framework for these dual transformations. The study also unveils the intricate conflict between standardisation and customisation, thus contributing to the knowledge system and underscoring the crucial role of collaborative, data-driven decision-making. Practically, the research lays the groundwork for developing an integrated strategic framework that can guide industry professionals in effectively implementing OSC and BIM, thereby enhancing the precision, efficiency, and adaptability of healthcare construction projects. Reviewing BIM and OSC separately, each can be promoted through various social and technical approaches, and many studies are also carrying out corresponding work. However, this research highlights the importance of an integrated strategy. This study suggests establishing an integral framework as a future research direction for overcoming sector-specific challenges and fully harnessing the potential of these innovative construction methodologies.

## References

Abanda, F., Tah, J. and Cheung, F. (2017), "BIM in off-site manufacturing for buildings", *Journal of Building Engineering*, Vol. 14, pp. 89-102, doi: 10.1016/j.jobe.2017.10.002.

Abdul Nabi, M. and El-adaway, I.H. (2020), "Modular construction: determining decision-making factors and future research needs", *Journal of Management in Engineering*, Vol. 36 No. 6, 04020085, doi: 10.1061/(asce)me.1943-5479.0000859.

Adebayo, A.K., Price, A. and Gibb, A. (2006), "Impact of modern methods of construction on healthcare infrastructure", *Paper presented at the Proceedings 22nd Annual ARCOM Conference*, Birmingham, UK.

Arif, M. and Egbu, C. (2010), "Making a case for offsite construction in China", *Engineering Construction and Architectural Management*, Vol. 17 No. 6, pp. 536-548, doi: 10.1108/09699981011090170.

Arif, M., Goulding, J. and Rahimian, F.P. (2012), "Promoting off-site construction: future challenges and opportunities", *Journal of Architectural Engineering*, Vol. 18 No. 2, pp. 75-78, doi: 10.1061/(asce)ae.1943-5568.0000081.

Assaad, R.H., El-adaway, I.H., Hastak, M. and LaScola Needy, K. (2022), "The COVID-19 pandemic: a catalyst and accelerator for offsite construction technologies", *Journal of Management in Engineering*, Vol. 38 No. 6, 04022062, doi: 10.1061/(asce)me.1943-5479.0001091.

Chang, Y.-F. and Shih, S.-G. (2013), "BIM-based computer-aided architectural design", *Computer-Aided Design and Applications*, Vol. 10 No. 1, pp. 97-109, doi: 10.3722/cadaps.2013.97-109.

Chen, W. (Ed.) (2020), *Rapid Construction Technology and General Contract Management for Huoshenshan Hospital*, China Architecture & Building Press, Beijing.

Davies, R. and Harty, C. (2013), "Implementing 'Site BIM': a case study of ICT innovation on a large hospital project", *Automation in Construction*, Vol. 30, pp. 15-24, doi: 10.1016/j.autcon.2012.11.024.

Eastman, C.M., Eastman, C., Teicholz, P., Sacks, R. and Liston, K. (2011), *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*, John Wiley & Sons, Hoboken, NJ.

Emmitt, S. (2010), *Managing Interdisciplinary Projects: A Primer for Architecture, Engineering and Construction*, Routledge, Abingdon.

Emmitt, S. and Ruikar, K. (2013), *Collaborative Design Management*, Routledge, Abingdon.

Etikan, I., Musa, S.A. and Alkassim, R.S. (2016), "Comparison of convenience sampling and purposive sampling", *American Journal of Theoretical and Applied Statistics*, Vol. 5 No. 1, pp. 1-4, doi: 10.11648/j.ajtas.20160501.11.

Fisher, M.J. and Marshall, A.P. (2009), "Understanding descriptive statistics", *Australian Critical Care*, Vol. 22 No. 2, pp. 93-97, doi: 10.1016/j.aucc.2008.11.003.

Forman, J. and Damschroder, L. (2007), "Qualitative content analysis", in *Empirical Methods for Bioethics: A Primer*, Emerald Group Publishing.

Forza, C. (2002), "Survey research in operations management: a process-based perspective", *International Journal of Operations and Production Management*, Vol. 22 No. 2, pp. 152-194, doi: 10.1108/01443570210414310.

Fowler, F.J., Jr. (2013), *Survey Research Methods*, Sage Publications, Thousand Oaks, CA.

Gan, X., Chang, R. and Wen, T. (2018), "Overcoming barriers to off-site construction through engaging stakeholders: a two-mode social network analysis", *Journal of Cleaner Production*, Vol. 201, pp. 735-747, doi: 10.1016/j.jclepro.2018.07.299.

Gaur, S. and Tawalare, A. (2022), "Investigating the role of BIM in stakeholder management: evidence from a metro-rail project", *Journal of Management in Engineering*, Vol. 38 No. 1, 05021013, doi: 10.1061/(asce)me.1943-5479.0000979.

Gibb, A.G. (1999), *Off-site Fabrication: Prefabrication, Pre-assembly and Modularisation*, John Wiley & Sons, Hoboken, NJ.

Goodier, C. and Gibb, A. (2007), "Future opportunities for offsite in the UK", *Construction Management and Economics*, Vol. 25 No. 6, pp. 585-595, doi: 10.1080/01446190601071821.

Gubrium, J.F. and Holstein, J.A. (2002), *Handbook of Interview Research: Context and Method*, Sage, Thousand Oaks, CA.

Han, K.K. and Golparvar-Fard, M. (2017), "Potential of big visual data and building information modeling for construction performance analytics: an exploratory study", *Automation in Construction*, Vol. 73, pp. 184-198, doi: 10.1016/j.autcon.2016.11.004.

Harty, C., Throssell, D., Jeffrey, H. and Stagg, M. (2010), "Implementing building information modeling: a case study of the Barts and the London hospitals", *Paper presented at the Proceedings of the International Conference on Computing in Civil and Building Engineering*, ICCBE, Nottingham (UK).

Ho, R. (2006), *Handbook of Univariate and Multivariate Data Analysis and Interpretation with SPSS*, Chapman & Hall/CRC, Boca Raton, FL.

Hochscheid, E., Falardeau, M., Lapalme, J., Boton, C. and Rivest, L. (2023), "Practitioners' concerns about their liability toward BIM collaborative digital mockups: case study in civil engineering", *Journal of Construction Engineering and Management*, Vol. 149 No. 9, 05023010, doi: 10.1061/jcemd4.coeng-12764.

Huberty, C.J. and Morris, J.D. (1992), "Multivariate analysis versus multiple univariate analyses", in *Methodological Issues and Strategies in Clinical Research*, pp. 351-365, doi: 10.1037/10109-030.

Innella, F., Arashpour, M. and Bai, Y. (2019), "Lean methodologies and techniques for modular construction: chronological and critical review", *Journal of Construction Engineering and Management*, Vol. 145 No. 12, 04019076, doi: 10.1061/(asce)co.1943-7862.0001712.

Jain, N. (2021), "Survey versus interviews: comparing data collection tools for exploratory research", *The Qualitative Report*, Vol. 26 No. 2, pp. 541-554, doi: 10.46743/2160-3715/2021.4492.

Jang, S. and Lee, G. (2018), "Process, productivity, and economic analyses of BIM–based multi-trade prefabrication—a case study", *Automation in Construction*, Vol. 89, pp. 86-98, doi: 10.1016/j.autcon.2017.12.035.

Jiang, R., Mao, C., Hou, L., Wu, C. and Tan, J. (2018), "A SWOT analysis for promoting off-site construction under the backdrop of China's new urbanisation", *Journal of Cleaner Production*, Vol. 173, pp. 225-234, doi: 10.1016/j.jclepro.2017.06.147.

Kokkonen, A. and Alin, P. (2016), "Practitioners deconstructing and reconstructing practices when responding to the implementation of BIM", *Construction Management and Economics*, Vol. 34 Nos 7-8, pp. 578-591, doi: 10.1080/01446193.2016.1164327.

Kucan, G., Tan, T., Grossmann, D., Graser, K. and Hall, D.M. (2024), "Sustainable future-proof healthcare facilities: modular and adaptable design approach", *Journal of Management in Engineering*, Vol. 40 No. 6, 04024053, doi: 10.1061/jmenea.meeng-5942.

Le, P.L., Chaabane, A. and Dao, T.-M. (2022), "BIM contributions to construction supply chain management trends: an exploratory study in Canada", *International journal of construction management*, Vol. 22 No. 1, pp. 66-84, doi: 10.1080/15623599.2019.1639124.

Li, Q., Chong, H.-Y., Lee, C.-Y. and Zhang, Y. (2021), "BIM's formal and informal collaborative networks in traditional procurement: insights from the construction phase of a hospital case study", *Journal of Management in Engineering*, Vol. 37 No. 6, 05021008, doi: 10.1061/(asce)me.1943-5479.0000965.

Love, P.E. and Ika, L.A. (2022), "Making sense of hospital project misperformance: over budget, late, time and time again—Why? And what can be done about it?", *Engineering*, Vol. 12, pp. 183-201.

Luo, H., Liu, J., Li, C., Chen, K. and Zhang, M. (2020), "Ultra-rapid delivery of specialty field hospitals to combat COVID-19: lessons learned from the Leishenshan Hospital project in Wuhan", *Automation in Construction*, Vol. 119, 103345, doi: 10.1016/j.autcon.2020.103345.

Mao, C., Shen, Q., Pan, W. and Ye, K. (2015), "Major barriers to off-site construction: the developer's perspective in China", *Journal of Management in Engineering*, Vol. 31 No. 3, 04014043, doi: 10.1061/(asce)me.1943-5479.0000246.

Meng, Q., Zhang, Y., Li, Z., Shi, W., Wang, J., Sun, Y., Xu, L. and Wang, X. (2020), "A review of integrated applications of BIM and related technologies in whole building life cycle", *Engineering Construction and Architectural Management*, Vol. 27 No. 8, pp. 1647-1677, doi: 10.1108/ecam-09-2019-0511.

Merschbrock, C., Hosseini, M.R., Martek, I., Arashpour, M. and Mignone, G. (2018), "Collaborative role of sociotechnical components in BIM-based construction networks in two hospitals", *Journal of Management in Engineering*, Vol. 34 No. 4, 05018006.

Merschbrock, C. and Munkvold, B.E. (2015), "Effective digital collaboration in the construction industry–A case study of BIM deployment in a hospital construction project", *Computers in Industry*, Vol. 73, pp. 1-7, doi: 10.1016/j.compind.2015.07.003.

Mignone, G., Hosseini, M.R., Chileshe, N. and Arashpour, M. (2016), "Enhancing collaboration in BIM-based construction networks through organisational discontinuity theory: a case study of the new Royal Adelaide Hospital", *Architectural Engineering and Design Management*, Vol. 12 No. 5, pp. 333-352, doi: 10.1080/17452007.2016.1169987.

Mills, G., Goodier, C., Kingston, J., Astley, P., Symons, A., Tan, T. and Sherwood, C. (2020), "Challenging Space Frontiers in Hospitals: accelerating capabilities and advancing platforms for modern hospital manufacture", Report prepared for Transforming Construction Network Plus, UCL Bartlett School of Construction and Project Management, London.

Mittal, Y.K., Paul, V.K., Rostami, A., Riley, M. and Sawhney, A. (2020), "Delay factors in construction of healthcare infrastructure projects: a comparison amongst developing countries", *Asian Journal of Civil Engineering*, Vol. 21 No. 4, pp. 1-13, doi: 10.1007/s42107-020-00227-1.

Moser, C.A. and Kalton, G. (2017), *Survey Methods in Social Investigation*, Routledge, Abingdon.

Murairwa, S. (2015), "Voluntary sampling design", *International Journal of Advanced Research in Management and Social Sciences*, Vol. 4 No. 2, pp. 185-200.

Pan, W. and Sidwell, R. (2011), "Demystifying the cost barriers to offsite construction in the UK", *Construction Management and Economics*, Vol. 29 No. 11, pp. 1081-1099, doi: 10.1080/01446193.2011.637938.

Pan, W. and Zhang, Z. (2022), "Evaluating modular healthcare facilities for COVID-19 emergency response—a case of Hong Kong", *Buildings*, Vol. 12 No. 9, p. 1430, doi: 10.3390/buildings12091430.

Pikas, E., Koskela, L., Sapountzis, S., Dave, B. and Owen, R.B. (2011), "Overview of building information modelling in healthcare projects", *Global Health Infrastructure-Challenges for the Next Decade: Delivering Innovation, Demonstrating the Benefits: Conference Proceedings-4th Annual Conference of the Health and Care Infrastructure Research and Innovation Centre, HaCIRIC-Health and Care Infrastructure Research and Innovation Centre*, pp. 286-298.

Sacks, R. and Pikas, E. (2021), "Foundational concepts for BIM", in *BIM Teaching and Learning Handbook*, Routledge, pp. 5-22.

Schreier, M. (2012), *Qualitative Content Analysis in Practice*, Sage Publications, Thousand Oaks, CA.

Sebastian, R. (2011), "Changing roles of the clients, architects and contractors through BIM", *Engineering Construction and Architectural Management*, Vol. 18 No. 2, pp. 176-187, doi: 10.1108/09699981111111148.

Shojaei, R.S., Oti-Sarpong, K. and Burgess, G. (2023), "Enablers for the adoption and use of BIM in main contractor companies in the UK", *Engineering Construction and Architectural Management*, Vol. 30 No. 4, pp. 1726-1745, doi: 10.1108/ecam-07-2021-0650.

Succar, B. (2009), "Building information modelling framework: a research and delivery foundation for industry stakeholders", *Automation in Construction*, Vol. 18 No. 3, pp. 357-375, doi: 10.1016/j.autcon.2008.10.003.

Swedberg, R. (2020), "Exploratory research", in *The Production of Knowledge: Enhancing Progress in Social Science*, pp. 17-41, doi: 10.1017/9781108762519.002.

Tan, T., Mills, G., Hu, J. and Papadonikolaki, E. (2021), "Integrated approaches to design for manufacture and assembly: a case study of Huoshenshan hospital to combat COVID-19 in Wuhan, China", *Journal of Management in Engineering*, Vol. 37 No. 6, 05021007, doi: 10.1061/(asce)me.1943-5479.0000972.

Tan, T., Mills, G. and Papadonikolaki, E. (2024a), “Exploring multidimensional modularity: strategies to reduce complexity in design activities”, *Journal of Management in Engineering*, Vol. 40 No. 3, 05024002, doi: 10.1061/jmenea.meeng-5596.

Tan, T., Mills, G., Papadonikolaki, E., Xu, Y. and Chen, K. (2024b), “Building information modelling in healthcare design and construction: a bibliometric review and systematic review”, *Paper presented at the International Conference on Computing in Civil and Building Engineering*.

Tillmann, P.A., Tzortzopoulos, P. and Formoso, C.T. (2010), “Redefining healthcare infrastructure: moving toward integrated solutions”, *HERD: Health Environments Research and Design Journal*, Vol. 3 No. 2, pp. 84-96, doi: 10.1177/193758671000300208.

Trochim, W.M. (2006), “Descriptive statistics”, in *Basic Science for Anaesthetists*, pp. 40-43, doi: 10.1017/cbo9780511544545.013.

Troiani, E., Mahamadu, A.-M., Manu, P., Kissi, E., Aigbavboa, C. and Oti, A. (2020), “Macro-maturity factors and their influence on micro-level BIM implementation within design firms in Italy”, *Architectural Engineering and Design Management*, Vol. 16 No. 3, pp. 209-226, doi: 10.1080/17452007.2020.1738994.

Verderber, S. (2015), *Innovations in Transportable Healthcare Architecture*, Routledge, Abingdon.

Wang, K., Zhang, C., Guo, F. and Guo, S. (2022), “Toward an efficient construction process: what drives BIM professionals to collaborate in BIM-enabled projects”, *Journal of Management in Engineering*, Vol. 38 No. 4, 04022033, doi: 10.1061/(asce)me.1943-5479.0001056.

Xin, Y., Zhou, Y., Yang, L., Liu, Y. and Tan, T. (2024), “Enhancing healthcare environment design evaluations through an interactive virtual reality-based approach: a design science research”, *Developments in the Built Environment*, Vol. 18, 100440, doi: 10.1016/j.dibe.2024.100440.

**Corresponding author**
Tan Tan can be contacted at: tant@hku.hk