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RESEARCH ARTICLE

Virtual Reality in Construction Activities: Barriers for Adoption in China

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Abstract

The paper presents a study of the barriers that hamper industry adoption of Virtual Reality (VR) for construction activities in China. A qualitative research methodology was adopted, using semi-structured interviews to collect data from participants. The initial set of codes was established through an open coding method for the subsequent content analysis of data. The findings obtained identified the economic issue as the main barrier impeding the adoption of VR to deliver construction projects in China. Other barriers identified include insufficient technical depth and awareness, and the fragmented nature of the supply chain within the industry. The study proposed recommendations on raising awareness, setting up workflows and government support to mitigate the limiting barriers. The findings of the study provide valuable insights to researchers and Chinese construction industry practitioners to better understand and promote VR in the delivery of construction projects.

Keywords

Barriers; Construction; Technology Adoption; Virtual Reality

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Introduction

The construction industry contributes to about 7% of China's Gross Domestic Product (GDP) and its economic development (The National Bureau of Statistics, 2022). VR is one of the new emerging technologies identified since 2018 (CeArley, et al., 2016). With the ability to offer multi-sensory experience in the three-dimensional (3D) environment, VR fulfills the high requirement for visual communications during the construction process and other AEC activities (Kim, et al., 2013). The prospect of VR adoption in construction has attracted extensive attention and its advantages have been widely acknowledged in various countries around the world, e.g., in Asia (Pan, Shi and Lu, 2000), Europe (National Infrastructure Commission, 2018), as well as the U.S (Ozcan-Deniz, 2019). The development and research work on VR within China's AEC organisations and academia started in the early 1990s (Pan, Shi and Lu, 2000). However, to date, in China, VR technology is still having an extremely low industry adoption level (Kim, et al., 2013). Hence, VR application needs to overcome the hype phase and provide benefits in practice. To better promote VR application and explore its full potential, it is necessary to investigate the barriers that impede its practical adoption in the construction industry environment.

As part of digital reform, the Chinese government has published tentative policies and strategies to encourage VR development in various industries (e.g., National Development and Reform Commission, 2019; Ministry of Industry and Information Technology, 2018). Many Researchers in China are also currently making efforts to study the barriers to VR adoption in construction (Yang and Zhong, 2020). Issues such as missing unified standards and routines (Ji, 2018), poor communication among various stakeholders (Huang, 2010), and the requirements for massive capital support (Tian, 2010) have been studied in recent times within China's construction industry. However, most of these studies still stopped at expounding the practical advantages of VR application, particularly in the AEC industry sector in China (e.g., Lu and Su, 2007; Wang and Hu, 2009; Li, 2005). Few studies have investigated concrete limitations of large-scale adoption in the industry, much less of them among practical practitioners. However, there has not been any in-depth study that has examined the key barriers of VR application within the construction industry in China.

The main objective of this paper is to explore the barriers that are hampering the adoption of VR technologies in the delivery of construction projects in China's construction industry. The study sets out to address the following research question: How are the current barriers impeding the adoption of VR in China's construction industry? To achieve this, the paper adopted a qualitative research methodology with semi-structured interviews to collect data from 11 key experts/participants involved in the construction activities in China's construction industry. It starts with an introduction to VR technology applications, followed by literature review, methodology, discussion of the findings, and finally presents a conclusion.

Literature review

VIRTUAL REALITY TECHNOLOGY DEVELOPMENT

With the advent of digital transformation of the construction industry's activities, immersive technologies such as VR have been gaining prominence and are being adopted by many construction organizations across the world (Hajirasouli, et al., 2022). VR is seen as a technology that can create multisensory virtual 3D environments using computer science. It allows information exchange between virtual and reality by providing immersive experience and interaction for users (Li, Ding and Wang, 2006; Zhu and Fan, 2016). Based on its main characteristics of immersion, interactivity, and imagination, VR has been applied in a vast range of fields (Shan, 2019; Lu and Davis, 2018). Initially, it was adopted in the entertainment sector, extending to marketing, tourism, sports, and education (Gawai, Ingole and Dahane, 2022; Delgado, et al., 2020). Exploration of VR applications in the AEC area began in the 1990s (McMillan, 1994; Pan, Shi and Lu, 2000). Architects first identified the advantages of adopting VR technologies in architectural engineering. However, currently, VR has experienced an increasing application by other construction practitioners in all areas of the construction industry, covering the life cycle of architecture, engineering, construction, and facilities management.

In China, for instance, the development and application of VR technology have continued to gain attention from AEC organisations. However, despite the relatively mature manufacturing chain, applications in specific areas such as the AEC industry are still insufficient. The central and local governments have introduced numerous policies and strategies in recent years to promote VR development as well as VR applications to support other industries (e.g., institutional education, media and entertainment, health care, trade and exhibition, etc.). Yet, only a few of them are aimed at the AEC industry sector. A number of these policy initiatives and strategies have largely focused on building and construction materials production sector, resulting in the adoption of VR in the AEC industry of China to be lagging its comprehensive development and application in the delivery of construction projects.

BENEFITS OF VR APPLICATION IN CONSTRUCTION

As an area where various stakeholders are supposed to communicate regularly and actively in a dynamic project management environment, the AEC industry highly relies on visual communication. VR application could be seen as a solution to the current barriers to communication by providing a platform for collaboration among stakeholders (Gawai, Ingole and Dahane, 2022; Zhang, et al., 2020) working on numerous AEC projects. It is regarded as one of the major technologies in Industry 4.0 and 5.0 for the digitalization of construction activities and processes towards the successful delivery of AEC projects (Wen and Gheisari, 2020). Because of the COVID-19 pandemic, telework demand has been notably increasing and VR products have continued to surge. Hence, its advantages in the AEC field could be seen to be inevitable.

Specifically, VR applications involve various departments and processes in the whole lifecycle of projects in the AEC industry. In the design stage, VR technology supports immersive design drafting and design review. In construction, VR facilitates all planning, monitoring, safeguarding, safety education and operative phases of AEC projects (Gawai, Ingole and Dahane, 2022). In construction planning, VR supports complex construction tasks during the planning, layout, and decision-making activities and processes. It can support the implementation of remote monitoring, particularly for dangerous sites. Rahimian, et al. (2020) proposed an integrated approach of BIM models and as-built image data in unity to achieve progress monitoring in a virtual environment. Alam, et al. (2017) presented a VR-based Internet of Things (IoT) platform, monitoring extreme environment work to improve safety and reduce errors. VR also supports teleoperation, mainly in demolition tasks in a dangerous environment (Delgado, et al., 2020). In construction safety, VR can contribute to training and education on health and safety, and hazard identification and inspection of construction professionals (Gawai, Ingole and Dahane, 2022). For instance, Zhang, et al. (2019) developed a crowdsourcing application based on BIM, and VR which can be used to conduct fire safety inspections for commercial buildings.

In the post-construction phase, some scholars have indicated that integrating facility asset data and the reality mesh can help to visualize construction activities such as maintenance scheduling decisions and improve maintenance resource distribution (Jiang, Messner and Dubler, 2017). VR can also improve precise evaluation for disaster scenarios, such as earthquakes or fires (Cao, et al., 2019). Besides construction activities associated with the delivery of construction projects, VR can facilitate stakeholders' engagement in various real estate walkthroughs (Pratama and Dossick, 2019), such as campus virtual walkthroughs

(Xia, 2013) and facilitate shared immersive experience and project communication in an interactive VR environment (Du, et al., 2018a).

BARRIERS TO ADOPTION OF VR IN CONSTRUCTION

Previously, scholars from various countries including China have discussed some challenges to VR adoption in construction activities within the AEC industry. Most VR devices were developed for the entertainment sector, lacking capabilities for application in the engineering and construction sectors (Delgado, et al., 2020). Pham, et al. (2018) noted battery limitations as VR technology has enormous energy consumption and intensive computation, generating multiple workloads. In China, Wang (2018) stated that most VR products circulating on the Chinese market were at the "low end". Besides hardware, Li (2005) identified VR technology lacking consistent interfaces and open technical standards, causing interoperability and data-sharing issues among different platforms and software.

Currently, in China, there is a lack of trained workforce who are accustomed to VR applications on the market (Delgado, et al., 2020). There is also lack of awareness, making practitioners to be aversive or reluctant to adopt the VR (Teixeira, et al., 2021). Similarly, practitioners are still used to the traditional technology in the construction process and management, lacking the understanding and expertise about the content, advantages, and approaches of VR application (Li, 2005). Besides, the AEC industry in China is highly fragmented and involves various stakeholders, bringing high requirements for communication and coordination.

There are also challenges such as legal, institutional, and ethical issues, VR adoption is likely to generate in terms of data privacy and ownership when an open-access model is applied to projects or production (Boyes, 2015). For the aforementioned legal, institutional, and ethical issues, China lacks laws, guidelines, and regulations regarding ethics and integrity regarding new digital technologies in the construction industry about VR technology (Li, 2005; Li, et al., 2024). Also, the governmental approval process for new technologies such as VR has not been updated regularly nor in a timely fashion (Wang, 2018).

Finally, VR applications require massive capital investment and support. Besides VR devices and extra training costs, additional investment is also required to provide spaces or dedicated rooms in which to set up the VR equipment (Teixeira, et al., 2021). Similarly, the hardware and software development of VR technology in China is still lagging, requiring huge financial resources for VR technology to be imported from foreign countries at a relatively high price (Huang, 2010), and this is also limiting the adoption of VR technology within the AEC sector.

Methodology

This study adopted a qualitative research methodology using semi-structured interviews to collect primary data from experts within China's construction industry. The semi-structured interview technique was adopted because it allowed a richer and deeper exploration and understanding of the issues from the experts. A qualitative research approach with a semi-structured interview method is seen as the most suitable way to explore issues in-depth to understand experts' opinions, behaviours and experiences about VR application in China (Creswell, 2003). Another major advantage associated with the qualitative research approach includes its ability to produce more detailed explanations of human phenomena. It also allows in-depth data to be collected from selected experts in a natural setting where the phenomenon under investigation is being experienced (Creswell, 2003). This leads to ensuring the trustworthiness of the findings. According to Lincoln and Guba (1985) and Levitt, et al. (2018), trustworthiness (which involves credibility, dependability, confirmability, and transferability) is a significant component of qualitative research. Hence, for the researchers, trustworthiness of the findings was an important objective for the selection of a qualitative methodology for the study.

DATA COLLECTION PROCESS

Sampling is fundamental to any research work as it enables researchers to estimate, identify and obtain detailed information from experts within a targeted population. The sample size, if rightly estimated, enables researchers to draw inferences from the study population and ensure the reliability and validity of their findings. The study adopted a purposive sampling technique through the identification and selection of key experts involved in the use of VR technology in China's construction industry. The rationale for adopting a purposive sampling approach was to enable data to be collected from key professionals who have expertise in the subject matter being investigated (Benoot, Hannes and Bilsen, 2016). The participants for the study were purposefully identified (via direct industry e-magazine and personal contact) and selected for the study to enable the researchers to explore the issues in-depth (Creswell, 2003). Similarly, for the research findings to be considered trustworthy, the issue of methodological integrity (which outlines research processes from the selection of participants to the presentation of the findings) is also very crucial. Therefore, to ensure methodological integrity, the researchers gave careful consideration to the selection of participants, the data collection, data analysis, and the presentation processes for the study (Levitt et al., 2018).

All participants came from organisations in the construction industry, including construction companies and organisations' activities related to the construction industry. Initially, 15 experts were sampled and invited to participate in the study. However, 11 experts finally agreed to participate in the study. According to Polkinghorne (1989), cited in Creswell (2016), a sample size of between 5 -25 interviews with participants (experienced in a particular phenomenon) is appropriate to investigate a phenomenon for qualitative research. The sample size (of 10-15 experts) used for the study was in line with the aforementioned sample size and also with the analogous number of experts for similar studies carried out by Whyte (2003), and Teixeira, et al. (2021) who have conducted between 10-15 interviews with experts to investigate various issues relating to VR with compelling outcomes.

The selection criteria were mainly based on their knowledge and working experiences in the construction industry and their involvement in the use of VR at the technical or management level (middle to senior level managers) of VR and digital intelligence technology as shown in Table 1. P1-11 provides the list/background of interviewees for the study. Although gender was not the objective of the selection criteria, it is worth noting that there was only one female who participated in this study. The unbalanced ratio of gender can be due to the construction industry which is still one of the most male-dominated sectors, while women remain under-represented (Sang and Powell, 2012).

Table 1. The list of the participants interviewed with their information

No.	Organization	Gender	Position	Relevant Experience (Years)
P1	Construction company	Male	Commercial engineer	3
P2	Construction company	Male	Head engineer	23
P3	Construction company	Male	Technology head	13
P4	Water company	Female	Technology director	25
P5	Construction technology agent	Male	Engineer	6
P6	Academy of Building Research	Male	Engineer	8
P7	Design company	Male	Head architect	13

Table 2. continued

No.	Organization	Gender	Position	Relevant Experience (Years)
P8	Construction company	Male	General manager	14
P9	Construction company	Male	VR technology group member	7
P10	Construction company	Male	Construction management director	24
P11	Construction technology agent	Male	Sales manager	5

To begin the qualitative data collection process, all the selected experts were invited through formal letters to participate in the study. They were informed about the rationale of the study and the mode of data collection was agreed on (Akotia and Opoku, 2018). Telephone in-depth semi-structured interviews were then conducted with the practitioners, each interview lasting between 40-90 minutes in an interactive and open manner. A semi-structured interview was chosen as it allowed a flexible approach to be adopted by the researchers to probe deeper into the issues requiring further explanations and clarification from interviewees. A deeper understanding of the participants' responses was developed during the interviews. The interview questions explored the current VR application situation and the core barriers to industrial adoption in construction activities in China. Data saturation was reached at the 11th semi-structured interview conducted with the experts. A review of other seminal works by Boddy (2016, p.429) has found data saturation to be "evident at six in-depth interviews and definitely evident at 12 in-depth interviews" with participants.

The three main points explored were the technical barriers, social limitations and economic limitations. Some of the key questions that were explored included the level of VR adoption/application in their organisations' practices and the current barriers that were impeding the adoption/application of VR in their organisations' practices.

All the semi-structured interviews were recorded and transcribed verbatim. Each interviewee was assigned a code number (e.g., P1, P2...). The transcribed data was manually examined, sentence by sentence, establishing the initial set of codes through an open coding method for the subsequent thematic content analysis. Specific text segments identified as crucial with consistent meanings were also coded as quotations. These were used to highlight references in the analysis and discussion processes.

QUALITATIVE DATA CODING AND SYNTHESIS

According to Creswell (2003, p.189), it is useful to present the findings for a qualitative study in a "chronology of events, the detailed discussion of several themes… with subthemes, specific illustrations, multiple perspectives from individuals, and quotations" to enhance the understanding of the findings. The transcripts were initially reviewed to extract terms and establish open coding in the 1st-order analysis. After that, codes were further refined to form descriptive concepts in the 2nd-order analysis. Codes were first condensed into several categories that were identified in the literature as existing concepts. Then, other codes that were not mentioned in the existing literature formed the new concepts. They were given extra attention to present specific phenomena in the circumstances. All the existing and new concepts constituted the 2nd-order themes, which can explain the situation observed in the industry. Finally, the emergent 2nd-order codes were distilled into 2nd-order 'aggregate dimensions'. The 1st-order, 2nd-order codes and the aggregate dimensions were used to summarise the findings. In the summary, barriers were ranked based on the level of importance interviewees attached to each barrier. The qualitative data collection and coding process is shown in Figure 1.

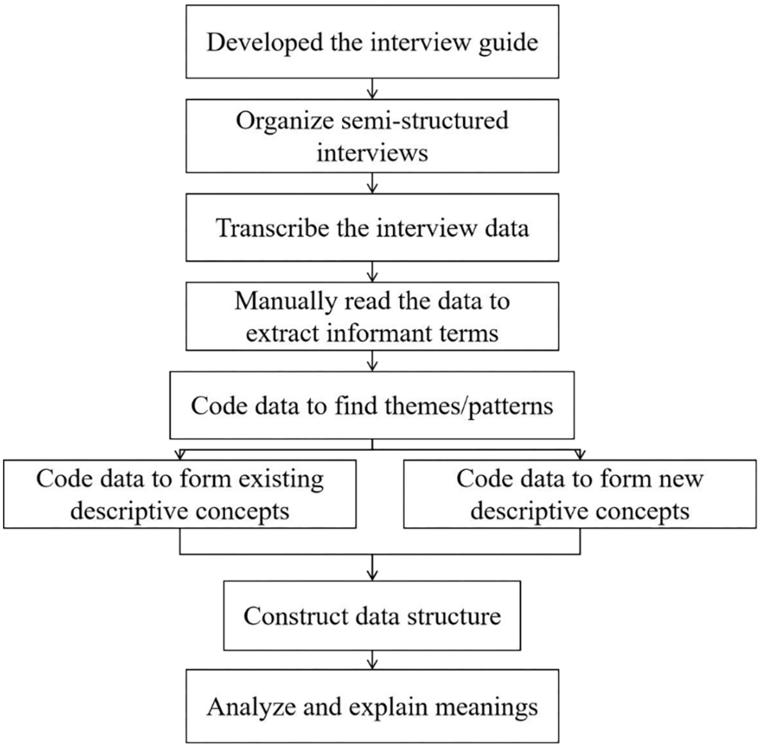

Figure 1. The qualitative data collection and coding process.

Results and discussion

VR CURRENT LEVEL OF ADOPTION

From the findings obtained, eight of the eleven interviewees have varied level of knowledge and understanding of the basic concepts and applications of VR. Surprisingly, P3 who is the head of technology for a construction company, for instance, stated that he hardly encounters or uses VR technology in his daily working environment, neither its concepts nor its application. The construction company where P3 works remains at a lower level of digitization and largely relies on conventional 2D CAD tools in its workflow from building design to construction. Similarly, P10 (Construction management director), who works for one subsidiary of a business group, mentioned that he only uses user-friendly VR devices, but knew nothing about VR concepts and software. The reason can be the small-scale nature of their organizations and the uncomplicated nature of the projects their company has been undertaken. In addition, P10 is not equipped with VR knowledge on the technological level since he works in the sales department.

Eight of the participants' cognition of VR use in construction focuses on the application. They seldom received VR documentation learning or training in the working scenario but learned from other fields in their daily life, such as gaming, medicine, and film industry. In construction, their understanding of VR is limited compared to BIM technology. Most of them consider VR applications as an extension of BIM functions. However, three participants P6, (Engineer) P7 (Head architect) and P9 (VR technology group member) showed a deeper understanding and application of VR, including application development and technical support.

There are mainly three ways these organisations apply VR, showing a step-up maturity level of specialized VR adoption, namely, outsourcing, subdivision of BIM departments and specialized VR departments. In the first case, P4 (Technology director) for instance noted that they solicit third-party services provided by mature technology outsourcers in the market. While the company of P5 (Engineer) as a technology agent purchases VR products, then sells them to construction companies, and provides simple training for use. In the second case, P1 (Commercial engineer), P2, (Head engineer) P8 (General manager) mentioned that they had BIM departments or professional BIM groups in their organisations involved in VR applications development and use. For the specialized VR department, P6 (Engineer), P7 (Head architect), P11 (Sales manager) indicated that they have special VR technology departments or groups equipped with professional technicians in their company for VR applications development.

In China, VR applications in construction currently focus on two aspects, i.e. (1) construction safety; (2) immersive experience for users. Among five participants directly involved in construction activities, P2, and P8 noted that they have equipped facilities with virtuality environment systems on some of their sites. The facilities simulated safety risks in the construction environment to conduct safety education and training for workers, mainly including falling objects or deep foundation pit dropping risks, and the arrangement of construction emergency platform and safety rope. P3, whose company remains at a lower level of digitization also admitted the potential application prospect of VR safety education. As he observed:

> *"We put safety first (in construction activities). Safety is greater than anything today, and related investment will be relatively large ... VR technology certainly helps in safety and efficiency".*

Another application of VR is to provide immersive experiences, presenting the progress or outcome of projects to supervisors and clients, especially when "higher-ups are coming for inspection work" (P4).

P5 confirmed that 70-80% of their clients purchase the VR construction safety service. Large enterprises such as state-owned and better-performing private companies also purchase VR immersive presentation applications. Besides, the government may require and demand VR applications in some essential infrastructure or public building projects.

Participants also mentioned some other areas of VR application on a deeper level. For instance, VR can support the City 3D Models in urban planning and traffic evaluation to better display ground information rather than only geographic information generated in the geographic information system (P6). VR is also used in remote construction (P6). Relevant applications have been developed and put into service since 2016 (P7).

Nevertheless, VR applications in construction activities in China, arguably, remain shallow. P2 stated that the VR simulation on their site was not very deep:

> *"Now VR can only simulate the simplest scenarios. The content given is not so complicated and is limited."*

P7 told the researchers that though their organisation had developed various VR applications on a deeper level for construction activities, it was hard to promote and popularize these products to the market. Besides, general commercial or residential projects tend to adopt the traditional construction process. Only megaprojects as landmark buildings, large event centres and airport projects tend to be equipped and use VR applications. As he opined:

> *"We've been promoting for a long time, but people don't want to pay for it."*

VR ADOPTION BARRIERS

Lack of practical benefits

When the question was put to the interviewees about the practical benefits of adopting VR in China's construction industry, all interviewees agreed that there were limited practical benefits that VR application brings to construction activities, especially economic profit. It was identified as one of the main barriers for VR adoption. When requested to rank the barriers according to how the barriers impacted the adoption in the interview, all participants put the economic issues on the top and emphasized its primary status. In the view of economic benefits in current construction projects, P1 commented:

> *"I can't see what VR can bring to the projects."*

While P4 stated:

> *"VR only emphasizes a kind of immersion experience, rather than solves problems in projects. It cannot improve our management."*

And P8, who provides services for a private construction enterprise, explained:

> *"VR technology currently does not match our business. We have not yet found a suitable application point."*

In other words, VR applications are currently regarded as hype, instead of creating practical benefits or profits. VR is used for "presentation" in situations of awards application, head-ups visiting or responding to the government's innovation agenda. However, it is considered to barely improve the process and management of construction. The study also revealed that organisations and individuals in this industry put profits and practical benefits on top, while VR application has still not been designed or perfected for such a core need. It can be said that the full benefits of VR applications can be realised when construction industry practitioners, particularly in China understand the core values and benefits associated with the adoption and implementation of VR in its totality.

Massive investment requirement

Further exploration of the barriers with the interviewees during the interview revealed that interviewees were concerned with the massive investment associated with the VR application on their projects. According to them, compared to the low benefits identified with VR its adoption requires a massive investment which construction companies, especially the small to medium ones, are unable to afford. For the organizations that independently develop VR, the high investment cost first comes from the hardware. VR application development has a high demand for computer configuration. As P2 stated the barrier to hardware cost for promoting VR within the company:

> *"Although the head company has purchased advanced computer configuration, many of our project departments at the lower level will consider the cost and not invest in configured high-end mainframe computers. Then, they cannot adopt VR applications on-site."*

Another issue is the frequent update rate in software and hardware. P1 mentioned that:

> *"The VR equipment usable these days is likely to be obsolete in a few years."*

Additionally, VR devices easily wear and tear on-site, where the environment is very harsh with many uncontrollable factors (P11).

In the case of purchasing outsourcing services, VR services and equipment provided by construction technology agents are costly as well. And with the large population involved in construction activities, it requires massive Head-Mounted Displays in each project. Another practitioner, P8 noted that a container-size safety construction VR experience facility they equipped on-site needed a building cost of around 100,000 Chinese Yuan (approximately 11,110 pounds).

According to P5 who happens to be an engineer also lamented on high cost of VR on the market, which was impacting construction companies' ability to acquire VR technology for their projects. P5 intimated that it was a kind of excessive pricing:

"There are not enough companies to do VR services development. So outsourcing services can be quite expensive."

The responses from participants also showed other kinds of input, such as human resources and time cost. In practice, dedicated teams are required to support the implementation and maintenance of VR applications. As P2 described:

"In a complex airport project we recently delivered, we configured a team of about seventy staff for solely finishing the modelling and animation demonstration work. It was quite a huge input."

This barrier is closely connected to the small benefits brought by VR in practice. The massive investment further decreases the final profits China's construction industry practitioners gain, making it harder to adopt VR applications in their construction activities. At the same time, financial investment acts as a threshold, excluding small and medium-sized companies without abundant resources. The above findings corroborated the recent work of Teixeira, et al., (2021).

Lack of Business model

Another barrier correlated to high cost is that there is a lack of business models currently for construction companies to adopt VR, neither are there successful business cases to learn from. This became evident during the interview as some interviewees identified the lack of business model which has led some organizations to aim at a high-end application with VR at first and put massive investments, such as building a digital platform. As P2 for instance stated:

"There are no business models to amplify the advantages of VR application with the construction industry. We need something customized to guide our construction companies in the application of VR on their projects".

Lack of client requirements

Delgado, et al. (2020) mentioned that a lack of client requirements also impedes VR adoption in construction activities. From the findings, it is revealed that most business owners are not willing to pay for VR applications in projects with high costs and slender profits. This is more so in small projects of commercial and residential buildings in China. This was corroborated by a response from P7:

"Owners won't pay a cent. They do not have the actual demands for VR."

According to P6, either property developers or the governments can require contractors to adopt traditional construction methods to achieve the project performance without paying extra millions of Chinese Yuan. Hence, contractors cannot gain extra payment from the owner when adding VR applications to the construction process but only increase their costs. The lack of practical benefits has an impact on this barrier. Neither contractors nor owners want to be responsible for the massive investment/cost relating to VR adoption.

Insufficient technical depth in market circulation

Further exploration of the findings indicated an interesting gap between technology developers and users in VR applications in construction activities. All interviewees in non-technology positions/domain who participated in the semi-structured interview agreed that the current VR applications on the market were of insufficient depth. Notably, P4 described it as "in an embarrassing state". Other interviewees such as, P2, P4 and P8 all stated that the current VR technology was unable to bring much improvement to the management and performance of projects, while they had no access to more high-tech applications. Moreover, P4 and P10 for instance deemed that BIM can completely replace the existing functions of VR in construction activities, which is much more mature and cheaper.

P6 was of the view that the construction industry had been equipped with a certain level of technical abilities, however:

> *"Technology is available but not required in engineering and construction."*

The reason leading to this finding is likely to be explained by cost. The desired effect cannot be achieved at a lower price when applying VR in construction activities. In other words, the industry now lacks a template or assembly line to generate VR products.

Although technology companies can develop VR products at the high end, it is hard to promote its application, while construction companies cannot purchase high-tech VR applications at an acceptable price. This situation further leads to inadequate VR products at high-end in market circulation. Most construction industry user groups have little access to deep VR technology, and neither do they feel its development. As P11 mentioned:

> *"It is a deadlock."*

Nevertheless, P7 admitted that it would be easier to promote VR applications if the technology were soaring to another height. P7 further noted:

> *"If VR reaches the technological level like the science fiction film industry, it can be totally different." "But that was not the current situation about its application in China's construction industry."*

Awareness of VR issues

Further analysis of the findings indicated that there is also a polarization in the awareness of technology innovation in the construction industry of China. Most of the interviewees, particularly from the small and medium enterprises (SMEs) who participated in the interview regarded the lack of awareness and understanding as a significant barrier to VR adoption in construction activities. This was obvious in one of the responses provided by P3 who is one of the senior technology managers:

> *"People can use something only when they have a basic understanding of it. Otherwise, the forced introduction will cause aversion".*

And P2 also agreed with P3's views by noting:

> *"When the traditional process can achieve the goal, people are not willing to take risks and additional cost to attempt a new technology".*

However, it can be observed that the large-scale private and state-owned AEC companies generally keep an open mind to VR adoption. Because these large-scale companies can be seen to have some level of financial resource to purchase the technology associated with VR, and this has enabled these companies to create awareness of the VR application. Many organisations and groups in China are researching VR applications and leading the way in scientific and technological innovation and this will help to create awareness of the value and benefits of the VR technology and application.

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Participant feelings and health issues

The findings also revealed that health and safety was a major concern for the adoption of VR by construction industry organisations on their projects. During the interview discussion, P4, for instance, reflected on several health and safety problems associated with VR facilities with respect to user feelings: P4 noted that the VR facilities such as the Head-Mounted Displays and VR goggles, were heavy and uncomfortable to wear. P4 also indicated that these VR facilities were not portable to use as users had to stand in some cases for long hours in a fixed position to use these facilities, and this made some users to feel dizzy and nauseous in a situation of immersive spatial simulation.

From the above views, it can be said that the promotion and adoption of VR can only be achieved when adequate attention is given to tackling these health and safety-related issues. Adequate safety and safety training and education can also help to enhance the knowledge and understanding of health and safety issues related to the use of VR facilities and applications. This will also help to promote construction industry practitioners' willingness to use VR devices.

Fragmented nature of construction activities in the construction industry

Another barrier identified from the analysis of the findings of VR adoption is the fragmented nature of China's construction delivery/activities of the construction industry (Huang, 2010). During the interview, P5 mentioned the lack of a coherent system and the interrupted nature of construction activities which does not allow companies to apply VR in their next projects, as commented:

"Due to the fragmented nature of the construction activities, once projects are completed, VR service is not recycled and reused for the next project. In most cases, they are discarded or just thrown away."

P5 further opined that construction companies were short of holistic management in VR adoption and that staff were commonly seconded to operate VR applications. And this was having an impact on promoting the continuous application of VR technology for the projects.

SUMMARY OF THE FINDINGS

The interview data revealed the dominating barriers to VR adoption in the construction industry of China. Figure 2 provides the summary of the main issues explored, the first (1st) and second (2nd) coding/grouping of the responses from the interviewees.

Overall, there are linkages between the three main issues (technical, economic and social limitations) that were explored by the study. These three main issues are interactive and inseparable. The lag in technological development has an impact on social and economic constraints, while the lack of economic profits also has a knock-on impact on technological development. However, the dominant barrier to VR adoption in construction activities in China can be seen to be the economic limitations. It is rational, as the primary goal of enterprises is to make profits, especially in a developing country like China where the construction industry is still developing at a progressing rate. Hence, the issues of high cost associated with the development and acquisition of VR technology need to be given serious attention by policymakers. The government is encouraging new technologies to be developed and applied in the construction industry, but the impact and benefits of VR are yet to be felt and realised. This is further exacerbated by the lack of regulation and legislation to make VR adoption and application mandatory/obligatory. Although some digital technologies are being used on construction on-site, e.g., digital-clock-in/out systems, there are still difficulties in adopting VR as a key technology for the delivery of construction projects. Embracing digital technology such as VR is the way construction companies and the whole industry can be seen addressing the technological gap required to meet the needs of Industry 4.0 and 5.0. requirements. These findings provide useful information for the construction practitioners and policymakers in China in their quest towards the development and adoption of VR technology within China's construction industry.

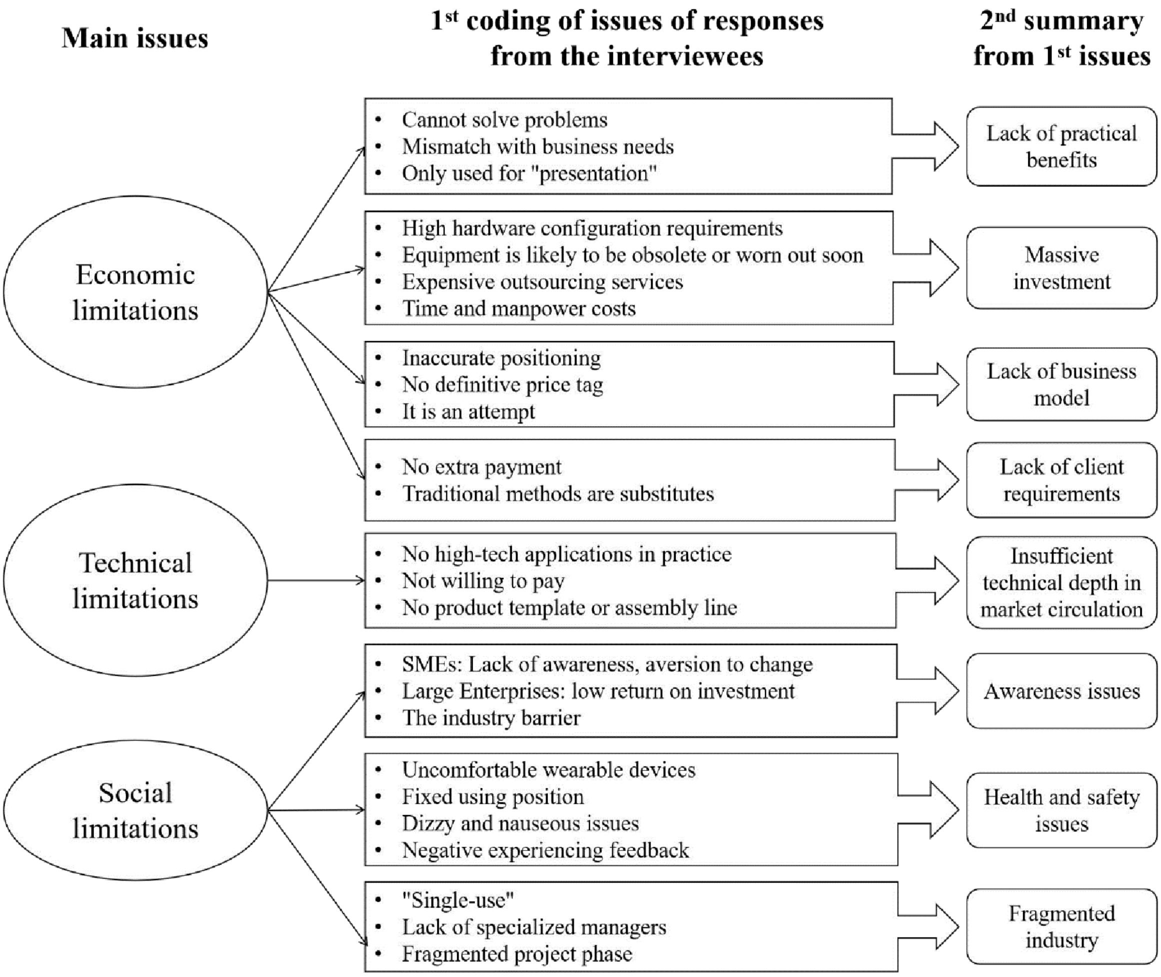

Figure 2. Summary of the findings.

RESEARCH LIMITATION

While the findings of the study can be seen to be compelling, nevertheless, there are some limitations in the study. The current study only focused on the construction activities and companies within the Chinese construction industry, hence future research could include other construction-related areas and consider the whole project lifecycle of construction projects: from design through to the demolition phases, including owners and other stakeholders in the wider AEC sectors. Future studies could also use focus group interviews with practitioners to explore the application of VR barriers in the Chinese construction industry further. A questionnaire could also be used to collect data (together with interviews) to support the qualitative analysis to further affirm, rank, and categorize the barriers.

Conclusions

This study explored the barriers to VR adoption in the construction industry in China through qualitative research. The findings revealed that economic issue was the primary barrier to VR adoption in China's construction industry. Other notable barriers identified include insufficient technical depth and awareness, and the fragmented nature of the construction activities within the industry. The findings of the study provide valuable information for policymakers and AEC industry practitioners to understand the barriers are associated with the adoption and implementation of VR in the construction industry of China. The findings will also serve as a reference document for future studies and academic work. Based on the findings the authors propose the following recommendations: (1) Raise awareness of the importance and benefits of VR application to address the technological gap between the construction industry and other industries. Doing so will also enhance the understanding and knowledge of practitioners and encourage practitioners to promote its benefits and application. (2) Enhance government support. There should be adequate funding support and incentive mechanisms in place by the central/local government to develop VR technology to make it cheaper and available to encourage practitioners within China's construction industry to adopt VR in their construction projects. Doing so will also help to address other key barriers identified in this study.

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