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# Zero latency: Real-time synchronization of BIM data in virtual reality for collaborative decision-making

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ABSTRACT

Virtual Reality (VR) has attracted increasing attention of the Architecture, Engineering, Construction and Facility Management (AEC/FM) industry in recent years, as it shows a great potential to improve workflow efficiency through enhanced common understanding. A problem with current VR applications in AEC/FM is that the manual conversation from official design data (e.g., a BIM model) to VR displays is difficult and time consuming. There is a lack of automated and efficient data transfer approach between BIM and VR. In this paper, we will introduce a BIM—VR real-time synchronization system called BVRS, which is based on an innovative Cloud-based BIM metadata interpretation and communication method. BVRS allows users to update BIM model changes in VR headsets (such as Oculus Rift DK2) automatically and simultaneously. We tested BVRS in a variety of design change scenarios including changing object dimensions, changing object locations and changing object types. Results confirmed the usability and efficiency of BVRS.

## 1. Introduction

In the past two decades, the Architecture, Engineering, Construction and Facility Management (AEC/FM) industry has witnessed a steady increase of interest in Virtual Reality (VR) to improving existing work processes [78]. As an immersive multimedia technology, VR creates enriched virtual environment, allowing users to interact with the digital objects in real time [79]. VR has been used to tackle a variety of design, construction and operation problems, including design coordination [54,80], project planning [19], construction education [40,63], safety training [66], construction operations coordination [8], facility management [67] and real estate [13].

Despite the well-documented potentials of VR applications in the AEC/FM related problems, various technological limitations of current practices have impeded the progress of VR adoption in the industry. One of the most critical issues is related to the difficulty of converting design data into VR displays. Unlike VR applications in other areas, most AEC/FM VR applications start with an established design built in traditional platforms, such as CAD or BIM [5]. The modelers usually convert standard design models into VR displays instead of building them from the ground up in game engines [5]. This conversion process is a natural result of the business model used the AEC/FM industry (i.e., a formal, approved design as the common ground of project communications) and has led to a variety of problems.

First, the present Design-to-VR process is time consuming and complex that could affect the efficiency of AEC/FM VR implementation. Due to the different data protocols in use, a typical workflow of AEC/FM VR modeling is to render a finished BIM model, such as a Revit file, in third party graphing programs (e.g., 3D studio Max), and then transfer the rendered FBX file into a game engine (e.g., Unity 3D) for VR programming [5]. Even for a simple model, this process could take several hours to several days to complete. And issues are always seen including missing material information [19]. Moreover, this process requires professional skills in modeling and programming, which are not always available for most industry users. As a result, some industry practitioners seek help from consulting companies, but it only adds more lead-time to the VR conversion process.

Second, current Design-to-VR process does not support real-time data synchronization between design data and VR displays; changes to a design cannot be interactively illustrated in VR devices. It will inhibit quality decisions at the individual and collective levels. Changes are very common in modern construction projects. If they can be discussed and addressed in a timely manner, unnecessary reworks and wasters are usually avoidable. Nonetheless, feedbacks are always delayed in the AEC/FM industry. A recent industry survey finds that using the traditional approaches to exchange information, such as formal Request for Information (RFI), the average response time is more than 10 business days [32]. It suggests an extremely high information latency between a

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request and the feedbacks. As for AEC/FM VR applications, due to a lack of inter-platform data transfer protocol, to show any design updates in VR, the modelers have to repeat the entire Design-to-VR process. High information latency makes decision makers reluctant to seek for alternative approaches [17], affects collaboration [9], and always leads to suboptimal solutions [60]. Without a low or zero latency solution, project stakeholders tend to push confusions and problems backward, which creates more reworks and wastes.

Third, with the present Design-to-VR method, it would be very difficult to maintain data integrity if changes happen frequently. In many projects, changes or updates are initialized by multiple parties in an unpredictable manner [18]. Owners, contractors or even trades who are working on specialized tasks often need to revise work plans, designs and construction methods contingent upon the actual job conditions [1]. The information network must allow different parties to synchronize data in real time for better data integrity, i.e., completeness, accuracy and consistency of the data [61]. As for AEC/FM VR applications, it means a stricter requirement on the interoperability and efficiency. Ideally the system should be able to exchange data in a variety of formats supported by different platforms, and it has to be done in real time otherwise any delays in updating information could introduce inconsistency issues [30]. Unfortunately although literature has proposed several information system architectures to support cross-platform data transfer in Design-to-VR applications [82], they are at a conceptual level. There is no existing working prototype that enables real-time updates of information in multiple design and VR platforms.

These technological limitations will ultimately affect the applicability of VR technologies in facilitating collaborative decision making in AEC/FM projects. It should be noted that given the increasing complexity of modern projects, critical decisions are often made collectively [4]. Construction organizations are increasingly viewed as information processors that process relevant and available information to perform intellectual tasks [37]. Without an effective approach to synchronize design data in VR environments, the potential of VR technologies would not be fully utilized for intelligent information processing in AEC/FM projects.

Therefore this research aims to develop an innovative data transfer protocol that automates the updates of design information in VR displays in real time, called BVRS (BIM−VR Real-time Synchronization). To achieve this goal, we used a metadata interpretation system and a Cloud based infrastructure. We will test the hypothesis that by creating a metadata communication protocol with a cross-platform Cloud infrastructure, real-time synchronization of BIM data in VR devices is possible.

## 2. Theoretical background

### 2.1. BIM and VR

As "*a modeling technology and associated set of process to produce, communicate and analyze building models*" [20], BIM consists of vast amounts of information that makes it excellent source material for virtual simulations [48]. The challenge is pertaining to the transformation of established BIM models into human navigable and human interactive environment. A solution is through the use of game engines i.e., computer game applications that provide powerful 3D rendering and representations of physical laws [57]. A lot of works have been done to create a highly credible environment for the project participants to analyze project data using BIM-based game engines [65]. Evidence indicates a variety of benefits of these applications in improving the common understanding among project participants in different phases [83], including improved design process, reduced misunderstanding, better construction hazards recognition and safety awareness [15,46,55,68]. Attributed to the latest technological development, BIM-based game engine has been extended to VR, providing potential implementations to transform project communication paradigm. VR is a computer generated immersive environment that can be adjusted and manipulated by the players in real time [79]. Unlike the traditional BIM-based game engines, VR provides not only the interactions with various construction components [38], but also an immersive experience to the participants [6]. Cumulative evidence has indicated that VR can provide a strong illusion of presence [29] and triggers similar user behaviors as in physical environments [28]. As a result, VR is recognized as a promising method to improve the quality of the entire AEC/FM workflow [25,54,59,63,80,81]. It should be noted that the latest versions of major game engines, such as Unity, have already contained built-in VR modules, which makes the VR implementation easier in the AEC/FM area.

However, like what many studies have proven, exporting the BIM model in a game engine compatible format (and eventually VR compatible) is not a straightforward task, and can vary depending on the intended use of the environment [7,27,53,83]. In addition, due to different protocols in use, these processes often introduce mistakes, such as missing material information, and thus additional steps are always needed [19], If any modifications occur to the model after this alteration step, a re-import and re-build may need to occur, complicating the entire workflow [7]. All of these limitations ultimately lead to a more serious problem relevant to information latency.

### 2.2. Information latency and collaborative decision making

A general definition of information latency is "a time delay between the moment something is initiated, and the moment one of its effects begins or becomes detectable" [58]. In information technology literature, information latency is always defined as a delay that data flow experiences from the source to its destination, due to the limited capacity of data transaction with which any physical information system can process [30]. Based on the review of relevant literature, we categorize information latency into two main classes: *External or Technical latency*, and *Internal or Cognitive latency*. The first class is attributed to the technical delays pertaining to the query, collection, entry, transfer, storage and processing of data [16,22,30,31]. The second class relates to a series of perceptional and cognitive processes including the perception, evaluation (associative memory), judgment, and arbitrary response selection [12,24,71]. Table 1 lists the categories and causes of information latency. In group decision making of AEC/FM tasks, it is not difficult to conclude that both categories of information latency contribute to the total latency.

Despite the subtle difference in definition (and measurement methods), it has been well documented that information latency plays a vital role in decision making at both individual levels and group levels. One of the representative works was done by Brehmer in 1989 to investigate the effects of feedback delays in dynamic decision making using a simulated Fire-fighting experiment [9]. The results showed that information delays had disastrous effects upon the subjects' performance [9] - in the delay condition, test subjects always misidentified and misinterpreted the situation, and gave suboptimal commands [9]. Although a variety of studies have proven the effects of information latency to be nonlinear in cognitive tasks such as decision-making [2,33,42,44], in dynamic tasks where the subjects have to respond to the stimuli continually [26], effects of information latency are uniformly negative [49]. Most decision-making tasks in the AEC/FM area rely on a multidisciplinary and multi-organizational process that builds on a continuous feedback loop among different project functional units [41]. As a result, it is not surprising to anticipate a negative impact of information latency on the quality and efficiency of AEC/FM related decisions.

### 2.3. BIM and metadata

As projects are becoming more complex, AEC organizations will increasingly rely on an expanded view of metadata to both create new