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# Real-time visualization of building information models (BIM)

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ABSTRACT

This paper highlights and addresses the complexity and challenges involved in visualizing large and detailed Building Information Models (BIM) in real-time. The contribution of the paper is twofold: (a) an in-depth analysis of four commonly used BIM viewers in terms of real-time rendering performance and (b) the development and validation of a prototype BIM viewer specifically designed to allow real-time visualization of large and complex building models. Regarding existing BIM viewers our results show that they all share limitations in their ability to handle large BIMs taken from real-world projects interactively. However, for the same test models our prototype BIM viewer is able to provide smooth real-time performance without sacrificing visual accuracy. By taking advantage of an efficient visibility determination algorithm, our prototype viewer restricts rendering efforts to visible objects only, with a significant performance increase compared to existing BIM viewers as a result.



## 1. Introduction

In recent years, there has been a shift from vision to realization regarding the use of Building Information Models (BIM) within the architecture, engineering and construction (AEC) industries. Using modern modeling tools, such as Revit Architecture, ArchiCAD or Tekla Structures, the content produced by architects, designers and engineers has evolved from traditional 2D-drawings, sketches and written specifications to parametric, object-oriented 3D-models embedded with information to describe any building or facility in detail. As a digital representation of the physical and functional characteristics of a building, a BIM serves as a repository of information supporting a multitude of applications along the design and construction processes, including cost-estimation, energy analysis and production planning [1]. As all of the data is available in 3D, the concept of BIM further fosters the use of real-time visualizations as a tool to communicate ideas and share information among and between different stakeholders in a project. Currently, several different BIM viewers – both commercial and free – are available for the purpose of interactive presentations, walkthroughs and design reviews. During these sessions the interactive 3D visualization model becomes a common frame of reference supporting a shared understanding across interdisciplinary groups. Architects can explore design options in real-time together with the client while engineers have the ability to explain the assembly order of complex structural details for steel workers – all made possible from a single source of data.

However, as BIMs are primarily created to describe a complete building in detail, many 3D datasets extracted from them provide a challenge to manage in real-time [2]. A fundamental feature of any type of real-time rendering system is to provide interactive and real-time updates. Failure to do so can reduce the benefit or even defeat the purpose of using the technology in the first place. A too low or fluctuating update rate will make navigation and other interaction tasks more demanding and may also cause participants to lose orientation or even feel sick [3]. In order to serve as a platform for efficient communication it is therefore important that the visualization software can deliver sufficient rendering performance to provide a smooth and interactive experience, even for large and detailed BIMs.

In this paper we highlight and address the complexities and challenges involved in visualizing large BIMs interactively. The contribution of our work is twofold. First we present our findings from analyzing four commonly used BIM viewers – DDS CAD Viewer, Tekla BIMsight, Autodesk Navisworks and Solibri Model Viewer – in terms of real-time rendering performance. We have used several BIMs received from real-world projects as test cases and show that all viewers share limitations in their ability to handle large and detailed building models. Secondly, we have developed a prototype BIM viewer to evaluate modern algorithms and strategies for real-time rendering of large 3D-models. Given the limitations found in the existing viewers, our work aims to contribute with a solution that provides both accuracy and interactivity, even for large and detailed BIMs.

The remainder of the paper is structured as follows: In the next section we review related work. Section 3 outlines the methodology and in Section 4 we present our findings from analyzing the existing BIM viewers in terms of real-time rendering performance. In Section 5 we motivate the choice of acceleration technique and provide implementation details for our developed prototype BIM viewer,

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together with a performance analysis of it. Finally, Section 6 concludes the paper.

## 2. Related work

### 2.1. BIM and real-time visualization

With the introduction of BIM the use of real-time 3D visualization as a communication tool has become more accessible. As 3D data can be extracted directly from the design authoring environment, there is no longer a need to create a separate 3D model for the sole purpose of visualization. However, as evident from several recent studies this development within the AEC field has also introduced new challenges. Very often models become so large and complex that they exceed the capacity of the computer which causes problems in viewing the models real-time [4–6]. Even for partial models, commonly used software tools for BIM visualization would either fail to load the 3D data or be unable to render it in real-time [2]. Furthermore, [7] discussed that even the latest hardware would quickly become overloaded, forcing architects and designers to 'wipe out' parts of the models to be able to work with them. Given the complexities involved in manipulating large BIMs interactively, a common work-around today is to split up the main model in different sub-models [8,9]. Nevertheless, besides restricting visualization sessions to sub-sets of the complete project, this approach typically introduces additional modeling work, as not only the initial, but also any revisions of the model need to be broken up [10]. When considering handheld and portable devices, similar issues have also been raised [11]. Given that these devices are typically equipped with much less powerful hardware the problems in terms of interactivity naturally become even worse.

However, although the challenge of visualizing large BIMs in real-time has been recognized, there are still many uncertainties surrounding the topic. For instance, none of the studies cited above, except [2], mentions any information regarding the size of the models that have been used. Instead of actual figures specifying number of individual objects or polygons, models are referred to as 'large', 'complex' or 'of high level of detail'. Similar observation can be made regarding hardware as none of the studies except [11] provide any description of the systems in use. Thus, without any further specification of model complexity or hardware present, it becomes very difficult to either compare the findings or map them to other circumstances. Moreover, as the actual problems encountered are only vaguely described, it becomes equally difficult to understand the magnitude of them. Without using a suitable metric, such as frame rate, statements like 'sluggish model manipulation' and 'viewing problems' are hard to transform into more concrete knowledge other than that the problem exists. The current problem space also seems to be restricted to only two variables – model size and computing power. As such, any limitation in the software's ability to efficiently utilize available computing power is not considered. In fact, none of the studies above except [2] and [10] even make any references to the actual software used. Since the studies mention that a problem exists, but do not specify details concerning hardware, software, size of models or present more explicit information concerning the problem this article highlights that currently there is a gap within the AEC research literature. So far, the challenge of visualizing large BIMs in real-time has merely been identified and is far from being addressed or even properly analyzed. Although visualizing large amounts of 3D-data in real-time is an active research topic by itself [12], there has been surprisingly little attention given to the specific case of visualizing large BIMs in real-time. Notable exceptions include recent approaches to take advantage of cloud computing to leverage sufficient rendering performance on mobile devices [13,14]. However, although this represents an interesting future research direction, current solutions either suffer from low image quality [13] or are unable to provide real-time performance [14]. Recent studies have also advocated the use of so-called game engines to visualize BIMs in real-time [15,16]. The arguments put forward is that typical game engines, besides providing high rendering performance, offer the ability to add more elements of interactivity to the visual simulation. Still, these types of demonstrators typically use very small models. As such, they are not representative for BIMs received from real-life projects. Similar limitations also apply to the work presented in [17], where specific BIM-data, such as spaces and room definitions, were utilized in order to provide high rendering performance for large BIMs. Although the algorithm developed was successfully evaluated on large test models, these were not taken from real-life projects. Based on our own observations, the data required for the algorithm to be fully functional is not always present in models received from real-life projects.

In the current study we address the observed gap within the research literature in two ways: first, we report on the current state within the AEC industries regarding real-time visualization of BIMs by providing an in-depth analysis of the rendering capacity offered by commonly used BIM viewers. Secondly, by evaluating and implementing recently developed algorithms for efficient real-time rendering of large 3D-datasets in a prototype BIM viewer, we address the challenge of visualizing large BIMs and provide a report on what is currently possible using recent technological advancements. In the following subsection we continue our review of related work, focusing on our metric for real-time performance – frame rate.

### 2.2. Importance of interactivity and frame rate

An important property for any type of real-time rendering system is its ability to maintain a sufficiently high frame rate. Although this number is highly dependent on the context, there seems to be support for a threshold of around 15 Hz for a number of different applications. For simple heading tasks [18], movement and shooting tasks in first person shooter games [19] as well as overall ease and comfort of navigation in virtual environments [20], user performance has been shown to be substantially degraded when the frame rate goes below 15 Hz. When considering everyday use of 3D design and engineering applications, similar observations have been made. Experiments conducted at The Boeing Company show that low frame rate decreases a subjects feeling of continuous motion and that massive model visualization users require at least 16 Hz in order to be considered acceptable [21,12].

Still, even if 15 Hz represents a minimum frame rate in terms of acceptable performance or experience, it is generally not considered to be a preferred or satisfactory level. For many applications 30 or even 60 Hz is often advocated. In [22] 30 Hz was found to be a minimum satisfactory frame rate for an interactive visualization of a proposed university research and technology park. Below 30 Hz users would start to experience lag and imperfect renditions. For other urban and architectural visualizations similar observations has also been reported by [23] and [24], where frame rates below 25 Hz were found to produce a jerky experience where the impression of continuous movement was lost. The aim for higher frame rates is also apparent in modern 3D computer games. 30 Hz is often considered minimum in order to give players a smooth and responsive experience, and game level design becomes inherently dictated by this target [25].

In line with the above research we chose to define the *minimum*, *satisfactory* and *optimal* levels of frame rate as 15, 30 and 60 Hz, respectively. For the tests and analysis presented in this paper we will use these numbers as a metric for interactivity and real-time performance.

### 2.3. Acceleration techniques for real-time rendering

Even if the performance of central processing units (CPUs) and graphics processing units (GPUs) has increased tremendously during the last years there is always an upper limit in the amount of 3D-data that can be interactively managed by any system out-of-the-box. Fortunately, a number of acceleration techniques exist that allow us to