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A cloud approach to unified lifecycle data management in architecture, engineering, construction and facilities management: Integrating BIMs and SNS

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ABSTRACT

The problem of data integration throughout the lifecycle of a construction project among multiple collaborative enterprises remains unsolved due to the dynamics and fragmented nature of the construction industry. This study presents a novel cloud approach that, focusing on China's special construction requirements, proposes a series of as-built BIM (building information modeling) tools and a self-organised application model that correlates project engineering data and project management data through a seamless BIM and BSNS (business social networking services) federation. To achieve a logically centralised single-source data structure, a unified data model is constructed that integrates two categories of heterogeneous databases through the adoption of handlers. Based on these models, key technical mechanisms that are critical to the successful management of large amounts of data are proposed and implemented, including permission, data manipulation and file version control. Specifically, a dynamic Generalised List series is proposed to address the sophisticated construction file versioning issue. The proposed cloud has been successfully used in real applications in China. This research work can enable data sharing not only by individuals and project teams but also by enterprises in a consistent and sustainable way throughout the life of a construction project. This system will reduce costs for construction firms by providing effective and efficient means and guides to complex project management, and by facilitating the conversion of project data into enterprise-owned properties.

1. Introduction

Data management problems in the architecture, engineering, construction and facilities management (AEC/FM) industry are complex. The main goal of data management is to enable data interoperability so that data generated by one party can be smoothly shared among all participants. While this research has long been conducted in this area and billions are spent each year on interoperability issues, these efforts achieve little added value [1,2].

The complexity of data management in the AEC/FM domain is a function of the industry, with special characteristics including the project-centric nature of the work, the fragmented nature of the industry, and the adversarial behaviour among companies [3]. Generally, a construction project employs multiple heterogeneous IT systems and a project consists of multiple phases (e.g., tender, design, construction, and maintenance) and involves multidisciplinary teams that are geographically distributed (e.g., owners, architects, consultants, contractors, sub-contractors, suppliers, and engineers) [1]. During each phase, users generate and regenerate rich project data that usually cover tens of thousands of one-of-a-kind building components and are produced by incompatible IT systems (often with evolving releases) delivered by various vendors.

Data in the AEC/FM industry are typical of the category of "big data". The term "big data" refers to the "ever-increasing amount of information that organisations are storing, processing and analysing, owing to the growing number of information sources in use" [4]. Challenges in the management of "big data" mainly result from three issues: volume (the increasing amount of data), variety (the wide range of data types and sources), and velocity (the high speed of data input/output) [5]. Construction data are required to be permanently stored as business assets, with the result that the volume of data continually increases as the project proceeds. In project activities, incompatible software programs produce a rich variety of file formats, such as Autodesk's DWG (abbreviation of "drawing"), DXF (abbreviation of "Drawing Exchange Format"), and Bentley's DGN (abbreviation of "design") for engineering

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activities; and DOC/XLS/PPT (Microsoft office format), RM/MPEG (video format), and JPEG (image format) for management activities. These files can be in structured, semi-structured, or non-structured form. Empirical data show that individual file sizes currently range from Megabytes to Gigabytes, however there is an apparent trend of increasing file size. Therefore, the total volume of data in a construction project tends to be huge, with tens of thousands of files. These files are generally required to be rendered on demand for all participants, whether are they located at construction sites or corporate offices.

In addition to these challenges, some other requirements also exist such as layered distribution in storage. Project data evolve from an active state to a non-active state as time elapses. Data are frequently revised before a construction process is completed, and then they are delivered, archived, and occasionally accessed thereafter, mostly for facility management purposes. Another requirement is that construction data are treated as assets that are owned not only by temporary project teams but also by enterprises, organisations, and government agencies. While it would be a great benefit for enterprises/organisations to take all of their project data under their own control, it is unfortunately difficult to achieve in current practice [6,7].

In short, data management and communication issues in the AEC/FM sector are complex, challenging, and are not currently well addressed by current technologies and applications [8–10]. "The key issue in this area has historically been, and remains, how to achieve inter-operability between multiple models and multiple tools that are used in the whole product lifecycle" [2].

1.1. Construction data category and level of data integration

Data categories are often defined in different ways. This paper uses the terms "PED (project engineering data)" and "PMD (project management data)", defined as follows:

- Project engineering data are geometric presentations, parametric descriptions and legal regulations associated with the construction of a building, such as component position/layer/level, bill, and quota.
- Project management data refer to control and communication information that are generated in and closely related to management activities throughout the construction lifecycle, such as scheduling, monitoring, and work assignment.

Based on these terms, data integration and sharing can be performed in a layered hierarchy, for example at the engineering level, the management level, and a more integrated level combining both engineering and management. Higher levels of data integration can enable the construction process to be accomplished more smoothly. In this sense, two essential questions for construction data management are: "Is it possible to create one comprehensive data model?" and "Is there a single solution that could collect and store the data throughout the lifecycle of a building and further distill those data into domain knowledge?" BIM (building information modeling) has recently received significant interest in both academic and industry circles as one potential answer to these questions. Several studies [9,11,12] have indicated that developing a single BIM model for all construction phases is something of a "holy grail", e.g., from a lifecycle standpoint, there are seven categories of BIMs: *as-required*, *as-designed*, *as-planned*, *as-built*, *as-used*, *as-altered* and *as-demolished*. Some researchers have tried to address the "one solution" issue, e.g., using a single data structure BIM to collect, organise and integrate *as-built* data [13]; adopting concurrent access to shared BIM repositories among multiple organisations [14]; and implementing on-line enterprise planning, scheduling and management tools (P3/e) by Primavera software [6]. However, these studies have concentrated on either the engineering level or the management level, leaving the issue of data integration on both levels unaddressed [15]. In addition, few studies have addressed data exchange among BIMs as well as critical technique issues such as data manipulation and version control.

This study endeavours to establish a unified organisation-level cloud environment that supports all-phase data collection, automatic data correlation, intra/inter-organisation data sharing and diachronic data tracing. With the aim of producing an innovative, organisation-level lifecycle solution, an industry-oriented research project called *LubanWay* has been underway since January 2008, following a ten year software development endeavour in the AEC domain in China. An exhaustive introduction of the project is outside the scope of this paper, and only a portion of the project outcomes are presented here. The contribution of this study is the development of a novel cloud application model oriented towards "big construction data", which includes a series of *as-built* BIM tools, introduces a special-purpose project collaboration platform (called cBSNS, construction business social networking services), and integrates *as-built* BIMs and cBSNS with *as-planned* BIMs.

Purposeful development of *as-built* BIMs is desirable due to the particularities and sophistication of the construction industry in China. Both central and local governments establish thousands of standards or regulations regarding craftwork and flow [16]. Existing commercial BIM tools such as Autodesk Revit™ and Bentley products cannot be used in this phase under such conditions. On the other hand, China is the world's second largest construction market, accounting for half of projects under construction worldwide. It is estimated that by the year 2018 China will surpass the U.S. and become the largest market [16]. Therefore, designing highly usable *as-built* BIMs is not only academically significant but also economically valuable.

The remainder of this paper is organised as follows. Section 2 introduces the research methodology. Section 3 presents an overview of the proposed approach. Section 4 presents the cloud application model of PDAS (project data as a service), along with detailed illustrations of self-organised cBSNS, integration with BIM, the logically centralised data model, and mechanisms of both access/version control and data manipulation. Section 5 discusses the status quo and the potential for deployment of PDAS in cloud storage. Section 6 presents discussions and a case study. Concluding remarks and ongoing research work are presented in Section 7.

2. Research methodology

This research consists of two steps. First, a list of system requirements is established based on a literature review and our ten years of practical experience and domain knowledge. Second, based on a careful examination of state-of-the-art technologies and software reviews/analyses, the design rationale and technical roadmap are established.

A data management solution is generally acknowledged to consist of four basic components: (1) a data collection model; (2) a logical data model; (3) a mechanism for data manipulation; and (4) a physical data storage model. Thus, the design goals of this research can be distilled as follows: (1) simultaneously collect both engineering and management data throughout the project lifecycle in one cloud application; (2) support mutual data exchange among multidisciplinary teams from different organisations in one cloud application; (3) design a unified big-data manipulation mechanism that supports high level data integration and enables data consistency; and (4) design a scalable, high performance storage mechanism that is appropriate for dynamically increasing massive amounts of data. The main objective of this work is to bridge gaps between the disciplines of project engineering and project management and to promote the capacity for big-data management