



Coordinating multi-site construction projects using federated clouds



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ARTICLE INFO

Keywords:

Coordination
AEC projects
Building information modeling
Collaboration
CometCloud
Clouds

ABSTRACT

The requirements imposed by AEC (Architecture/Engineering/Construction) projects with regard to data storage and execution, on-demand data sharing and complexity on building simulations have led to utilising novel computing techniques. In detail, these requirements refer to storing the large amounts of data that the AEC industry generates — from building schematics to associated data derived from different contractors that are involved at various stages of the building lifecycle; or running simulations on building models (such as energy efficiency, environmental impact & occupancy simulations). Creating such a computing infrastructure to support operations deriving from various AEC projects can be challenging due to the complexity of workflows, distributed nature of the data and diversity of roles, profiles and location of the users.

Federated clouds have provided the means to create a distributed environment that can support multiple individuals and organisations to work collaboratively. In this study we present how multi-site construction projects can be coordinated by the use of federated clouds where the interacting parties are represented by AEC industry organisations. We show how coordination can support (a) data sharing and interoperability using a multi-vendor Cloud environment and (b) process interoperability based on various stakeholders involved in the AEC project lifecycle. We develop a framework that facilitates project coordination with associated “issue status” implications and validate our outcome in a real construction project.

1. Introduction

In the Architecture/Engineering/Construction (AEC) industry, projects are increasingly being undertaken by consortia of companies and individuals, who work collaboratively for the duration of the project. Such projects are complex and the consortia members provide a range of skills to the project from its inception to completion. During this process, various data artifacts are also generated that need to be stored and shared between project members (generally using access control strategies — which limit what can be accessed at a particular stage of the AEC project lifecycle). The planning, implementation and running of these AEC industry projects requires the formation of secure Virtual Enterprises (VEs) to enable collaboration between its members by sharing project information and resources. An important feature of the consortia is that they are dynamic in nature and are formed for the lifetime of the project [2]. Members can participate in several consortia at the same time and can join or leave a consortium as the project evolves. Cloud computing offers an important computing infrastructure to facilitate the establishment and coordination of such VEs. Cloud computing is expected to enhance capabilities that were generally offered through services made available over the Internet. As well as

remote access, Cloud computing also provides enhanced security infrastructure including single sign-on capability, security between consortia members, simple setting up of networks to support VEs, distribution of computationally intensive jobs across multiple distributed processors (based on shared information about available resources) [4]. Each organisation involved in a VE may have access to its own Cloud computing system (privately managed internally within the organisation, or acquired through a public provider such as Amazon.com or Microsoft (via their Azure platform)). As it is unlikely that all members of a consortium will share the same platform, integration across multiple platforms is therefore an essential requirement for such VEs to function in an efficient and reliable manner [1].

In the computer science research, various efforts have been proposed to implement such multi-Clouds with research efforts focusing on Cloud interoperability e.g. the Open Cloud Computing Interface (OCCI) efforts at the Open Grid Forum [6]. OCCI provides an API and a set of protocols to enable management capability to be carried out across multiple Cloud providers. A variety of implementations are currently available, in systems such as OpenStack and OpenNebula (two open source Cloud platforms). An alternative approach to interoperability is through the development of specialist gateway nodes which enable

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mapping between different Cloud systems and the implementation of specialist gateways to connect different Cloud systems, the development of a Cloud Operating System (CloudOS) to connect distributed Clouds (European FP7 “UNIFY” project) to the use of specialist in-network capability to process data in network elements between different end points (GENICloud [7]). Similarly, on-line sites such as CloudHarmony [8] report over 100+ Cloud providers that offer capability ranging from storage and computation to complete application containers that can be acquired at a price, primarily using service-based access models.

On the other hand, in the AEC industry there is an increased interest in Building Information Modelling adoption. Such modelling process for various construction projects represents a complex task. This complexity comes from the construction projects which often require collaboration between employers, designers, suppliers and facilities managers through a range of design and construction tasks. Therefore, using cloud federation in a BIM context can provide a number of benefits such as: (a) reduced project failure caused by lack of effective project team integration across supply chains (b) emergence of new challenging new forms of procurement i.e. Private Finance Initiative, Public-Private Partnership and the design-build-operate and (c) decreasing the whole life cost of a building through the adoption of BIM in facilities management [3,5].

In this paper, we present the implementation and use of a distributed Cloud system, based on requirements of the AEC sector. The resulting clouds for coordination (C4C) framework can support merging and federation of various models of an infrastructure project from multiple applications, clouds and/or actors using a secure and robust common interface. The process is based on BIM (Building Information Modelling) and data stored by each participant conforms to the IFC (Industry Foundation Classes) data model. We elaborate on the concept of project information “Issue Status” associated with a project in order to determine issuing party's status with responsibility/liability associated and considering the reliance on the data. Our approach involves the implementation of a logical “shared” space that is physically distributed across multiple sites involved in the federation. Such a shared coordination space enables various project members to interact with each other during the stages of a project. We compare our approach to general cloud federation efforts, specifically adapted for the needs of the AEC industry in Section 2. In Section 3, we present the CometCloud system and how this system has been used to create the federated cloud framework, followed by a description of the “Cloud4Coordination” (C4C) system and the associated Application Programming Interface (API) that makes use of CometCloud in Sections 4 and 5. In Section 6, we evaluate the C4C system by devising a project trial based on a real construction project and provide overall conclusions in Section 7.

2. Related work

In this section, we explore several related studies in the fields of AEC collaboration and cloud federation.

2.1. Related AEC technologies

In the AEC industry, the concept of decentralised repositories facilitating data storage across multiple servers represents an emerging topic. Such decentralised environments are currently enabled by specialised software such as Revit Server [24] and Bentley System's ProjectWise [23]. In these systems, data is spread between multiple servers (termed integration and caching servers in the case of Bentley, and hosts and accelerators for Revit Server). However, current implementations do not remove the barriers of centralised repositories. This is due to the fact that despite both Revit and Bentley allowing the distribution of BIM data across multiple servers, there still remains one authoritative (or master) copy of the data, hosted at a central server. This centralised approach leads to both availability/access, security and

liability concerns, as data is being hosted on the server operated by one organisation.

In addition to these commercial offerings, the concept of data storage and collaboration is also a topic of active research in the AEC sector. In their work on SocialBIM, Das et al. [25] have developed a BIM framework that primarily focuses on modelling the social interactions between stakeholders. The key development is SocialBIM's ability to allow users to contribute/download partial BIM models that are then merged/split from a “master” model held in the SocialBIM cloud system (s). While this ability to work with small “fragments” of BIMs which are then federated is a key development, the fact that the end result is still stored in a centralised way in a cloud system will be of concern to many organisations. Other work in this area includes Munkley et al. [27], who have developed technologies to synchronize data between Revit Server and an external storage server, enabling external users to see a read only copy of the Revit (central) model. While this is an interesting way of allowing increased collaboration using Revit Server, it does not adequately provide for the dynamic two way collaboration that is often required in an AEC project i.e. the ability to incorporate the results of other discipline's work (i.e. the architect, mechanical or electrical engineers) as background in your own work. Finally, this approach is further limited as it is only able to utilise the Revit proprietary data format. Additionally, Boeykens et al. [28] have developed a layered client/server approach that provides an event based communications pool between components embedded into BIM authoring packages. This novel communication approach enables the dynamic sharing of data between components. However, all data is still stored on a centralised server that listens to the event based communications and both saves and injects BIM data into the communications pool as needed. Other solutions for supporting construction BIM data sharing and interoperability include IFC ontology and IFC linked data with federated queries [12], semantic linking and semantic web paradigms with orthogonal solution vector [13] and views modelling [14] where companies work on the same model but with individual access and views. The key differentiating factor of our work is the distributed nature of our approach, where the authoritative copy of data is always stored within a discipline's own servers and is only federated with other disciplines when required. Another key differentiating factor is the increased level of dynamic communication that is possible between multiple disciplines using our approach, i.e. when a single discipline makes updates that are visible to other disciplines. These updates are automatically propagated to the relevant disciplines, without a need for the other disciplines to query if any updates have been made.

Many of these seemingly decentralised approaches (at least from a user's perspective), actually make use of centralised storage and coordination infrastructure. This is undertaken to ensure that the centralised system is adequately protected and managed, and can be monitored for any discrepancies or performance bottlenecks. Existing cloud-based deployments are no different — as they make use of a single, centralised data centre. Our approach differs from these, in that we recognise that each institution involved in an AEC project will need to provide their own computing infrastructure, and more importantly will need to integrate their in-house capability with data centre based cloud systems that may be operated by other institutions/companies. Our approach therefore makes use of a Peer-2-Peer based approach, whereby local data centres can be aggregated with those of other institutions in a seamless manner, but still provide a centralised view on the data shared by institutions involved in a single AEC project. This is achieved using the CometCloud system as described in Section 2.2.

2.2. Related cloud federated systems

Through the federation of cloud systems it has become possible to connect local infrastructure providers to a common framework where participants can exchange data and collaborate. The mechanisms used to support cloud federation can bring substantial benefits for service

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