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LEVERAGING CLOUD-BIM FOR LEED AUTOMATION

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SUMMARY: *Synergies between building information modelling (BIM) and Leadership in Energy and Environmental Design (LEED) have been recognized early on, since the industry started embracing BIM. However, current practices of implementing BIM in LEED projects remain ad hoc, resulting in job-specific success difficult to replicate. As both BIM technology and LEED systems are making continuous improvement, it has become overwhelming for project teams to work out an optimal strategy to exploit their technology and management strength in LEED project delivery. This paper looks at a rising trend in recent BIM development, which is the cloud-deployed BIM server (cloud-BIM) technology, and proposes a new business paradigm so project teams can leverage cloud-BIM to achieve LEED Automation. The new paradigm overcomes the limitation in capacity and communication of conventional desktop computing and stand-alone BIM. It empowers the project team with scalable and concurrent collaboration that was essential to delivery high performance sustainable projects such as LEED projects. A framework that integrated strengths of cloud-BIM, various LEED dedicated SaaS (Software as a Service) solutions and open information exchange protocols is created to delineate possible implementation strategies for this new paradigm.*

KEYWORDS: *Cloud computing, building information modelling, LEED Automation, cloud-BIM, framework.*

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1. INTRODUCTION

Green building market transformation in the United States is largely represented by the on-going popularity of the Leadership in Energy and Environmental Design (LEED) green building rating systems. As of 2011, the cumulative LEED-certified buildings have exceeded 1.6 billion square feet. More importantly, as a percentage of total construction, LEED-certified buildings continued to increase their market share of annual New Construction in the US, going over 20 per cent of new floor area put in place for the first time in 2011 (Watson, 2011). A major driver of the LEED momentum are government entities, who own and occupy 27% of all LEED projects, and have instituted various types of initiatives and incentives at national, state and municipal levels (USGBC, 2011a). Stakeholders in the AEC/FM industry are facing unprecedented opportunities as well as challenges from LEED market penetration, as gradually more mandates for implementing LEED have been enforced in various states, federal agents, and institutions.

To meet the certification requirements prescribed by comprehensive green building rating systems like LEED, project teams typically possess a spectrum of expertise in a myriad of disciplines to perform according to the metrics set forth in the LEED environmental categories, including site, water, energy, materials, indoor environmental quality, and innovative and/or regional design. Simulation has been traditionally used in architectural and engineering projects to validate designs created by individual domain experts, and is usually performed on reduced-complexity system models in order to contain the overall analysis time and cost (Iorio and Snowdon, 2011). However, the insufficient accuracy of the reduced-complexity simulation model cannot satisfy the stringent performance requirements of LEED projects, which usually demand more sophisticated and larger-scale simulations. Challenges associated with such new simulation practices include the exponential growth of intensity in data processing and exchange, and the escalating complexity of data formats, considering the multitudes of variables and dynamics entailed to represent the whole building systems. Utilization of traditional CAD systems no longer seems to be efficient and needs to be replaced by more powerful model authoring and analysing tools, which is made possible with the advent and rapid prevalence of Building Information Modelling (BIM).

In addition to explicit provisions on building performance, LEED also necessitates enhanced collaboration and communication between project stakeholders. Designers should bear in mind the owner's project requirements (OPR), while contractors need to understand the basis of design (BOD). Field crews have to ensure that installed building systems and furnished materials are eligible for pursued LEED credits. BIM facilitates information-centric project management in contrast to the conventional document-centric approach. Nevertheless, it is observed that one of the key barriers to BIM adoption is that data across the project lifecycle and supply chain lacks an overall data management policy (Titus and Bröchner, 2005, Howard and Bjork, 2008, Tsai, 2009). Model information is usually isolated by individual disciplines on local computers with limited computing power, network connectivity and accessibility, which undermines the capacity of using BIM as the project life cycle information repository and as the ideal vehicle for enhanced collaboration.

Taking into account that a standalone BIM is inherently limited and cannot represent BIM at its full potential, this research proposes a *cloud-BIM* approach, i.e. the deployment of BIM over the cloud infrastructure, to leverage the LEED project delivery and certification process. Cloud-BIM has become a new trend in the AEC industry and has stirred some critical thinking among BIM practitioners on BIM implementation and development. It is believed that as the LEED green building certification market continues its momentum, better and more cost-effective strategies to accomplish LEED certification can be formulated on the basis of the smarter technology and process offered by cloud-BIM. The goals of this research are:

1) To investigate the possible synergies between cloud-BIM in the LEED project context; and
2) To propose a prototype framework of a new business paradigm that implements cloud-BIM solutions in accomplishing LEED Automation.

2. BACKGROUND

LEED is arguably one of the most popular green building rating systems in the world. There are also counterparts of LEED such as the Building Research Establishment Environmental Assessment Method (BREEAM) from the UK, the Comprehensive Assessment System for Built Environment Efficiency (CASBEE) from Japan, and Green Globes from Canada. The U.S. Green Building Council (USGBC) introduced the first LEED green building rating system in 1998 as LEED for New Construction (LEED-NC). As new systems were introduced, LEED gradually became a portfolio of rating systems to address the specifics of a spectrum of building types and facilities (Fig. 1). The tenets of each individual rating system in the LEED family kept on evolving and advancing as the result of the continuous improvement of technology sophistication, and the rationales behind and understanding of green building systems. The current LEED v3.0 consists of three major parts:

- LEED 2009 version of all rating systems, including New Construction, Core and Shell, Commercial Interior, Schools, etc.;
- LEED Online v3 (a web-based tool LEED project teams use to manage the LEED registration and certification processes); and
- Certification Model: an expanded certification infrastructure based on ISO standards, administered by the Green Building Certification Institute (GBCI) for improved capacity, speed and performance.

LEED has two key fundamental attributes. First it was developed with an open consensus–based process, with input from a broad range of building industry professionals and other experts, including the U.S. Department of Energy (DOE). Second and common to the other rating systems, using LEED is voluntary. One of the goals behind creating the LEED system was to establish a measurement standard for what is considered a green building, comparing them on an even playing field (Krygiel & Nies, 2008). To promote the adoption of LEED as a nationally accepted benchmark for the design, construction and operation of high performance green buildings, USGBC established a sophisticated third-party certification program called LEED Certification, which has four different levels, Certified, Silver, Gold and Platinum, based on project assessment using a scoring system.

Synergies between BIM and LEED - especially how BIM may be capable of increasing the chances of accomplishing LEED certification - have been conceived, experimented on, and well documented by both industrial reports and scholarly publication. Recent development of BIM server technology and the prevalence of cloud computing have catalysed the transition of desktop BIM applications to be deployed over the cloud. Meanwhile, in apprehension of the deficiencies in existing LEED certification workflow, USGBC restructured their LEED project administration tool – LEED Online, and proposed a brand new business paradigm of LEED certification named *LEED Automation*, to accommodate the increased utilization of BIM tools and streamline the certification process. These changes were perceived as opportunities by BIM and LEED practitioners to reinforce the current success of integrating BIM and LEED, and to push it to the next level facilitated by a more powerful and flexible cloud infrastructure. The following section reviews noticeable initiatives of BIM application in green building design, BIM engagement in LEED projects, impacts of cloud computing on BIM development, and the concept and implications of LEED Automation to cloud-BIM implementation.

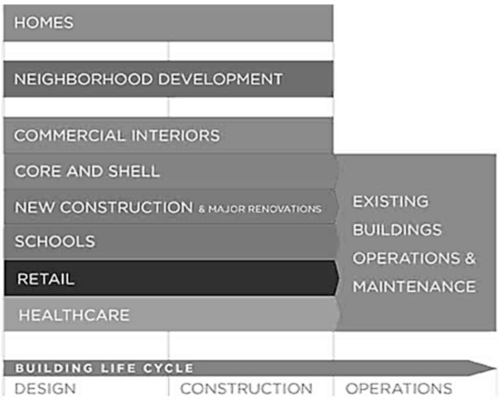

FIG. 1: The family of LEED rating systems (Source: USGBC, 2011b).

2.1 Initiatives of BIM for building sustainability

Sustainability in the building industry is an applied concept of the sustainable development as defined by the Brundtland Report. It bears considerations not only related to building performance, but also attempts to address the *triple bottom line*, specifically, the environmental, economic and social impacts of the building industry. Because of the abundance of needed information, efficient information-technological solutions are desirable. BIM arose as a solution to support the supply, integration and management of information throughout the building life cycle (Häkkinen and Kiviniemi, 2008). In the U.S., the General Service Administration (GSA) is leading the commitment to leverage BIM for high performance buildings. By establishing the National 3D-4D BIM program and publishing the BIM Guide Series, GSA intended to: 1) explore the power of BIM in visualisation, coordination, simulation and optimization to promote building performance; 2) assess BIM as a reliable basis for decision making and to reduce the need for re-gathering or re-formatting information for building life cycle information management; and 3) create policies, standards, and incentives for BIM adoption through partnership with vendors, professional associations, open standard organizations and academic/research institutions (GSA, 2012). The U.S. DOE and its Office of Energy Efficiency & Renewable Energy (EERE) also instituted efforts to utilize advanced modelling and simulation technology via broad stakeholder involvement for significant energy savings in capital projects. The *Building Technologies Programme*, the *Commercial Building Initiative* (CBI) and the *U.S. DOE Commercial Reference Building Models for National Building Stock* are highlights among these efforts (DOE, 2011).

In the European Union (EU), the STAND-INN project commissioned by the Europe INNOVA initiative was directed to facilitate the integration of open standards into the business process to reduce cost while increasing the productivity and promoting sustainable development in the construction sector. The STAND-INN project investigated BIM as a practical approach to achieve life cycle sustainability of construction projects. It evaluated

BIM as a versatile approach with functions that span through the project concept and design, procurement, construction, commissioning, operations and facility management (FM). The project also proposed inter-operability based sustainability via the buildingSMART approach of BIM, which was built upon the information exchange framework using open standards such as the Industry Foundation Classes (IFC), the International Framework for Dictionaries (IFD) and the Information Delivery Manual (IDM). It suggested that IFC-based BIM should vastly improve its usefulness in facilitating sustainable construction (Europe INNOVA, 2008). A more comprehensive initiative, *Energy Efficient Buildings*, under the Information and Communication Technology (ICT) for Sustainable Growth policy framework, has been funded by the European Commission (EC) through instruments like the 7th Framework Programme (FP7) for Research and Technological Development (RTD) and the Competitiveness and Innovation Programme (CIP). Noticeable funded projects include REEB: *The European strategic research Roadmap to ICT enabled Energy Efficiency in Buildings and constructions (2008-2010)*, REViSITE: *Roadmap Enabling Vision and Strategy for ICT-enabled Energy Efficiency (2010-2012)*, HESMOS: *ICT Platform for Holistic Energy Efficiency Simulation and Lifecycle Management of Public Use Facilities (2010-2013)* and others (European Commission Information Society, 2012). A central topic of the *Energy Efficient Buildings* initiative is the development of *energy efficient building data models* (eeBDM). Research in eeBDM has been focusing on building ontologies, energy-efficiency models and standards, interoperability issues and advancement of ICT for building energy modelling, simulation, monitoring and management throughout its life cycle. Noticeably, an open and extensible energy-enhanced BIM framework (eeBIM) was proposed to support the data flows for energy efficient design and lifecycle management. The eeBIM framework, with clearly defined ontology and information delivery manual, when bounded with a SOA-based Integrated Virtual Energy Laboratory, IVEL (as developed in the HESMOS project), would enhance the “energy interoperation” between energy simulation model(s), Building Automation Systems (BAS) and Building Energy Management Systems (BEMS) hosted in a semantic web environment (Katranuschkov et al., 2011, Scherer et al., 2011).

2.2 BIM and LEED integration

LEED challenged the conventional practices in the AEC industry and celebrated sustainability as a most critical criterion of today’s architectural and engineering design. BIM software vendors perceived this as a sales opportunity and started to build functionalities in their packages that aimed specifically at aiding designers in configuring building performance in energy efficiency, indoor air quality and other important environmental benchmarks. Representative products include *Autodesk Green Building Studio* (GBS) for energy simulation, daylighting and water consumption calculation; *Integrated Environmental Solutions – Virtual Environment* (IES) *VE-Navigator* for ASHRAE 90.1 (LEED Energy) analysis; and *Bentley AECOSim* for ASHRAE 90.1 (LEED Energy) baseline simulation. Driven by policies and incentives, and the green codes and standards being formulated, the uptake of sustainability has reached an unprecedented level. Business dedicated to green building and sustainable construction started flourishing, with extensive involvement of stakeholders from all industry sectors. Empirical experience and best practices urge the advancement of green information and communication technology (ICT) to facilitate the transition, which in return necessitates innovations of the business process. Fig. 2 shows the loop of interaction between BIM, LEED and the AEC industry in general.

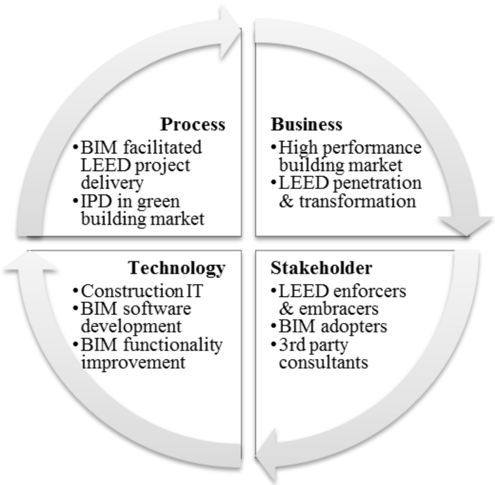

FIG. 2: Integrate BIM and LEED – loop of interaction.

Under specific project circumstances, there are often abundant opportunities for the project team to take advantage of the software package to conduct desired LEED calculations, including energy simulation, lighting analysis, water consumption, material attributes and integrated design, as identified by McGraw-Hill Construction (2010). The practice of matching up particular BIM functionalities and LEED credit requirements represents a primitive stage of BIM/LEED integration, which could be termed as the BIM/LEED *mapping* (Fig. 3). Krygiel and Nies (2008) discussed various exemplary case studies of in-situ BIM application in LEED projects. Wu and Issa (2010), and Azhar et al. (2011) delineated general frameworks and procedures to carry out such mapping in detail. Nevertheless, BIM/LEED mapping tends to encourage ad-hoc solutions that focus on project based LEED calculations using BIM. It seldom goes beyond the project due to the transient composition of the project team, which makes the success difficult to replicate.

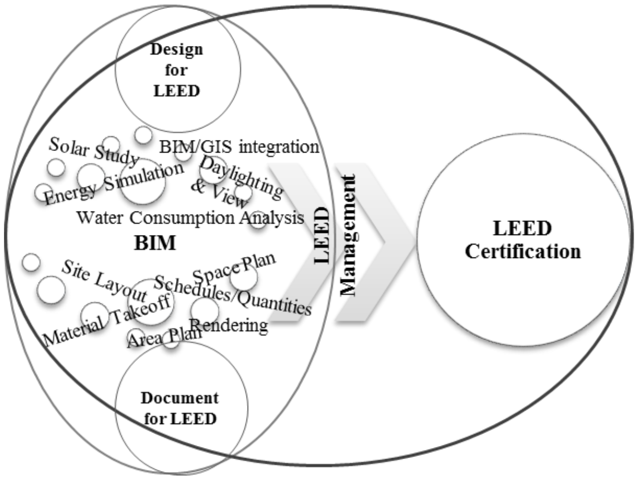

FIG. 3: BIM/LEED mapping for LEED certification.

A major hurdle to BIM/LEED integration is the diversity of software applications and the variety of domain information needed for discipline-specific building simulations and analyses. Although collaboration between software vendors and use of proprietary file formats somehow alleviate the problem, chances are the complexity of LEED projects may eventually cause confusion and miscommunication between project members, should there be no careful planning of model information exchange mechanisms. Level of development (LOD) requirements and the Model View Definition (MVD) are both important concepts in dealing with effective BIM-based project information management. The key is to create an interoperable software environment based on open standards such as IFC to facilitate seamless and bidirectional information flow between individual project members, meeting individual model information needs in real time without compromising the overall design process, the model integrity or the anticipated building performance as prescribed in the LEED rating system. It is quite apparent that this process cannot rely on the traditional desktop applications through simple internet connections with Email or FTP as major data sharing solutions.

2.3 Cloud computing and BIM

As defined by the U.S. National Institute of Standards and Technology (NIST), "*Cloud Computing* is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" (Mell and Grance, 2011). The recent boom of cloud computing is associated with drastic escalation of information generation and consumption in all industry sectors as well as people's daily life. Essential characteristics of cloud computing such as self-provisioning, rapid elasticity/ scalability, multitenant support and measured service make it a superior option for low risk/cost yet high performance computing in handling large, complex virtualized resources. It is deemed as a disruptive computing and business paradigm that poises to change traditional organizational IT infrastructure management and business practices, and to dramatically improve productivity and cost effectiveness of software solutions (Iorio and Snowdon, 2011). There are three cloud computing service models, *Software as a Service* (SaaS), *Platform as a Service* (PaaS) and *Infrastructure as a Service* (IaaS); and four deployment models, *Private Cloud, Community Cloud, Public Cloud and Hybrid Cloud* (Mell and Grance, 2011).

AEC projects require a vast array of software solutions that range from Product Lifecycle Management (PLM) to CAD systems, logistics, and energy usage simulation to environmental impact analysis (Iorio and Snowdon, 2011). It has been widely reported that some of the intrinsic characteristics (e.g. strong regulation, fragmentation, data intensity, majority of the sector comprising of micro to SMEs, project based activity etc.) of the construction industry hinder the adoption of IT by the industry as a whole and this sector is generally behind other sectors in IT uptake (Kumar et al, 2010; Anumba et al, 2008). Cost burden in upgrading IT infrastructures has become overwhelming yet it is an inevitable investment to stay in business. Oversizing in traditional organizational IT deployment is a long time bottleneck to efficient usage of corporate IT resources, which is exacerbated by the adoption of BIM when the intensity and complexity of computing needs have increased exponentially. As noted by Jardim-Goncalves and Grilo (2010) the building industry had its ICT fragmented yet the interfacing with BIM brought another layer of complexity, mostly due to the heterogeneity of the systems and applications that need to interface with it. They believed that the implementation of BIM under the cloud computing paradigm held the promise to the industry and they proposed a SOA4BIM framework as a cloud service to enable universal access to the BIM paradigm by any system, application, or end user on the web. The AEC software market also indicates that BIM has or will soon steadily move to the cloud, featuring cloud based BIM *apps* and the BIM server technology.

2.3.1 Benchmark cloud solutions for BIM

Selecting a cloud solution for BIM involves not only the general considerations (e.g. service model type, deployment model type, data security, user management, resilience and cost), but more importantly, the unique factors that matter most in BIM implementation. From the end-user perspective, there are four fundamentally different approaches to cloud computing: 1) *Data in the cloud*, such as Dropbox; 2) *Software virtualization*, such as VMware and Citrix; 3) *Web applications*, such as Google Docs; and 4) *Business logic*, such as Apple iCloud. The *Business logic* approach seems to be the only one that syndicates the benefits of a live collaboration environment of web-apps with full offline access and functionality (Várkonyi, 2011). When applying cloud computing in the context of BIM, there are two major factors that can influence the effectiveness of the BIM workflow, especially for large projects that will typically be the focus of a cloud-based solution:

- *Accessibility of the BIM model:* BIM models are large, complex and highly integrated databases. It is essential to provide concurrent access to models while maintaining their highly integrated nature but not introducing unnecessary limitations. Depending on the project progression and model users, there are three distinct model accessibility issues, including *concurrent "real-time" access, purpose-built "lightweight" access* and *offline access.* Concurrent, real-time, remote access to a central model hosted on a BIM server has gradually become a dominant approach for cloud deployment of BIM.
- *System performance of the BIM model:* this refers to the fact that how the highly integrated BIM project performs with a growing model and a growing team and with growing geographical distances will ultimately depend on scalability, including BIM project scaling with hardware and with software. Multiprocessor and 64-bit processing are mission critical to hardware scalability, while multitenant environment support is the prerequisite to optimized cloud setup/budget.

In order to exploit the true potential of the cloud, an integrated, network-based collaborative BIM model instead of a collection of standalone files is desired. This integrated model requires an active BIM server component that enables the real-time collaboration of "professionals" and provides direct bidirectional access to the live BIM model for any stakeholders through purpose-built tools running on various mobile devices. Such an active BIM server requires a multitenant software architecture in order to be able to scale with the "cloud" and utilize its infinite data storage and computing capacity to provide the best return of investment (ROI) on the IT infrastructure (Várkonyi, 2011).

2.3.2 Development of BIM apps and BIM server

Development of cloud computing in the area of BIM technology comes in two major directions: 1) cloud based BIM applications (*apps),* and 2) BIM server. BIM apps provide purpose-built lightweight access to model information to facilitate run-time response and minor model configuration and update on the fly, while BIM server proposes fundamental strategic transition in organizational BIM deployment.

Autodesk and Graphisoft have been taking the leadership in the cloud-BIM initiative. Graphisoft's *BIM Explorer* (BIMx) was the No.1 construction and productivity app in 2011 as ranked by Engineering News-Record (ENR). Working through mobile devices, BIMx provides an interactive environment with game-like navigation allowing anyone to explore full BIM models without having a copy of the original software in which the model was created (Khemlani, 2011). *AutoCAD WS* is another influential BIM app from Autodesk. It is a web and mobile application for AutoCAD software that enables customers to view, edit, and share DWG files through a web browser or mobile device without the need to install or maintain specialized software. It supports both the online and offline working mode (Fig. 4). Table 1 provides a summary of current popular BIM apps.

FIG. 4: User interfaces of BIMx (left) and AutoCAD WS (right) in mobile devices (Source: Khemlani, 2011).

TABLE 1: Summary of popular BIM apps

Name	Company	Platform	Functionality
goBIM	goBuild Inc.	iPhone/iPad	BIM model viewer
BIMx	Graphisoft	iPhone/iPad/Mac/Win	BIM model viewer
AutoCAD WS	Autodesk	iPhone/iPad/Android/ Mac/Win	DWG view/edit/sharing
Buzzsaw Mobile	Autodesk	iPhone/iPad	Document transfer/sharing
Bluestreak Mobile	Autodesk	iPhone/iPad	Project management/collaboration
Constructware Field	Autodesk	iPhone/iPad	Project management/collaboration
Design Review Mobile	Autodesk	iPhone/iPad	DWF share/view/mark-up
Vela Mobile	Vela Systems, Inc.	iPad	Construction field management

Autodesk also formally unveiled its cloud strategy – *Autodesk Cloud* and *Autodesk 360 for BIM* in Autodesk University (AU) 2011 and Revit Technology Conference (RTC) 2011. Essentially, Autodesk Cloud provides free cloud storage for drawings, models, and other documents for its users, which can be used to access these files from any platform (e.g. regular computer, smartphone and iPad) and for sharing and collaboration. It also institutes *BIM-as-a-service* (BaaS) solutions including cloud-based rendering and energy analysis. The technology at the heart of Autodesk 360 for BIM is the *Autodesk Vault* data management solution. As a new business model, it represents the cutting edge cloud BIM solution that ensures security, accountability and reliability needed by AEC professionals in the following key areas (Autodesk, 2011):

- *Direct integration with AEC workflows:* this refers to Vault's natural integration with 35 existing AEC BIM applications (e.g. Revit, Navisworks) and project management/collaboration software (e.g. Buzzsaw) for more secure external information exchange and mobile access.
- *Scalability across globally distributed networks:* this refers to Vault's support for direct and remote file access/replication, full database replication over wide area network (WAN), and synchronization between enterprise network and the cloud by team members outside the firewall
- *Connection to the cloud:* this refers to the selectively and automatically mirroring data between network-based Vault and Buzzsaw cloud to securely share information and better maintain acc-ountability beyond the enterprise.

Before the advent of BIM server technology, most work sharing in BIM workflow was file-based, meaning full synchronization of a monolithic model file under editing across the project team. Full size model synchronization takes considerable time and bandwidth and thus becomes a serious performance and productivity bottleneck to the overall workflow, especially when Wide Area Network (WAN) instead of Local Area Network (LAN) collaboration is desired. BIM server takes a drastically different approach. It is database driven and only the changed model elements/information will be synchronized, which largely solves the WAN latency issue. Fig. 5 illustrates the transition of the work sharing infrastructure. The central model on the Central Server is not one monolithic model but a directory that lists individual data streams in the model managed by the server. A database structure makes it easier to set up permissions for access, and facilitates information exchange between central and local servers. It thus maintains better the model integrity. Both Graphisoft's BIM Server and Autodesk's Revit Server can be easily deployed over the cloud.

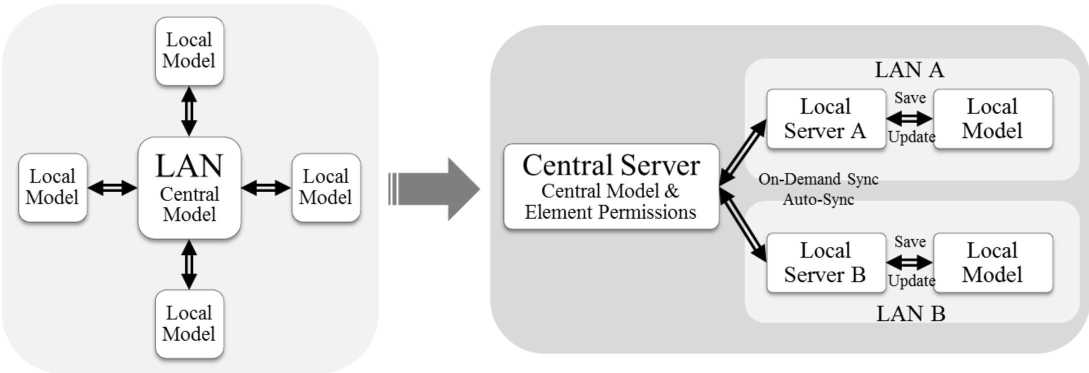

FIG. 5: File-based work sharing to server-based collaboration (Source: adapted from Khemlani, 2010).

In parallel to proprietary BIM server technology, initiatives to establish an open source BIM server are highlighted by the *BIMServer* project led by TNO and the University of Eindhoven (Beetz et al, 2011). This project explored the concept of BIM-as-a-service through open source server technologies. The BIMserver centralizes the information of a construction (or other building related) project internally and exposes its information to client applications through a series of well controlled and documented interfaces (Fig. 6). The core of the software is based on IFC. The BIMServer itself is not a file server, but uses the model-driven architecture approach. This means that IFC data is interpreted by a core object system and stored in an underlying database. The main advantage of this approach is the possibility to query, merge and filter the BIM-model and generate IFC files on the fly. By centralizing the flow of data the BIMServer is able to preserve the complete history of a project over time while allowing model users to retrieve and update models or model components without intervening with each other through a unique model versioning mechanism (Beetz et al, 2010). The major challenges of the BIMServer are similar to those confronted by cloud computing: scalability, robustness and information exchange protocols.

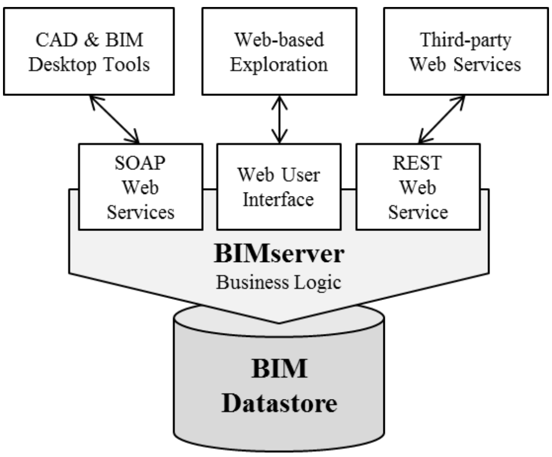

FIG. 6: Functional overview of a BIM server ecosystem (Source: adapted from Harrison, 2009).

2.4 LEED Online and LEED Automation

The USGBC launched *LEED Online* in 2006 and the Green Building Certification Institute (GBCI) took over its administration in 2008. LEED Online is the primary resource for managing the LEED documentation process. Through LEED Online, project teams can manage project details, complete documentation requirements for LEED credits and prerequisites, upload supporting files, submit applications for review, receive reviewer feedback, and ultimately earn LEED certification. LEED Online provides a common space where members of a project team can work together to document compliance with the LEED rating system (GBCI, 2011).

Despite its intention of streamlining the LEED certification process, some intrinsic drawbacks of LEED Online undermine the overall productivity of the project team:

- *Interoperability:* LEED Online does not provide any interface with mainstream BIM software regardless of the fact that quite a few LEED credits heavily rely on software simulation results. The project team has to manually type the information into LEED Online templates even if it is possible to extract the exact information from the software applications.
- *Database support:* As a web service, LEED Online was developed without database support, but built upon a file-based framework. Information submitted to LEED Online is hard-coded, relying on manual modification and excludes support for dynamic/real-time database queries.
- *Knowledge management:* When a company has several on-going projects, or has done projects pursuing the same LEED credits, no active cross-reference between projects on the same credits will be available for the company to take advantage of previous knowledge.
- *User comfort:* LEED Online supports only Internet Explorer (IE), while Firefox and Chrome have become much more preferred options.

The fact that the use of BIM applications in sustainable design and building simulations have become common practice and LEED rating systems are constantly evolving has pushed the USGBC to rethink the technology and infrastructure of administering the LEED certification process. This rethinking was clearly reflected in the tenet of *LEED Automation*, a brand new business paradigm of LEED certification inaugurated by USGBC in *Greenbuild 2010*. LEED Automation works similarly to an app. It performs three key functions for LEED project teams and users of LEED Online by seamlessly integrating third-party applications to: 1) provide automation of various LEED documentation processes; 2) deliver customers a unified view of their LEED projects; and 3) standardize LEED content and distribute it consistently across multiple technology platforms (USGBC, 2010). LEED Automation also conveys the following important messages to the AEC industry:

- USGBC will disclose the Application Programming Interface (API) of LEED Online to selected partners, for the first time, to facilitate direct information exchange between software platforms;
- LEED Online will rely on 3rd party applications to provide database support for LEED project teams in documentation and knowledge management.
- LEED Automation by nature is a cloud-friendly solution, and works best with applications deployed in the cloud as well, for instance, cloud-BIM.

2.5 Bringing sustainability/LEED, BIM and cloud computing together

As major trends in the global AEC industry, the interactions and synergies among BIM, sustainability and cloud computing are conceivable. An important driver is that the regulatory environment for the building industry is getting more stringent. Sustainability has been and will eventually be written as mandatory clauses into contracts and enforced by jurisdictions. The first international green model code – the 2012 *International Green Construction Code* (IgCC) promulgated by the International Code Council (ICC) conveyed a clear and firm message on this matter. While sustainable design and construction have long been and will continue to count on ICT advancement, the integration between BIM and sustainability has barely started. McGraw-Hill Construction (2010) pointed out that there was a significant increase of BIM tools being utilized to achieve project goals specifically related to sustainability, e.g. LEED certifications, and the perfect tools were yet to be developed.

Not only has the technology been evolving amid the market transformation, but also the business process and the relationship between project stakeholders. Collaboration and communication have become key factors in project success especially when the project entails ambitious expectations in sustainability and highly sophisticated implementation of ICT. The cloud infrastructure has been driving the shift of both the technological and business paradigms. From a project delivery perspective, the cloud approach emancipates the project team from limited and low performance computing resources so that they can utilize more powerful BIM tools to perform and communicate comprehensive and rigorous analyses of LEED design options, which used to be too laborious and expensive to conduct. Quality assurance (QA)/quality control (QC) would be enhanced with a robust field-compliance validation mechanism enabled by 3D laser-scanning and BIM integration. A digital asset of as-built BIM model(s) instead of piles of tedious documents could be handed over to the owner to facilitate the facility management, for instance, the energy performance monitoring that has been required by LEED. Eventually, the project team will be able to deliver to the owner a better-value project with a much higher ROI.

3. SUGGESTED CLOUD-BIM FRAMEWORK FOR LEED AUTOMATION

3.1 Development approach

The suggested framework of Cloud-BIM facilitated LEED Automation is a working concept based on the following assumptions:

- The project stakeholders have a set of explicit goals on achieving the LEED certification, and supportive strategies in regard to achieving those goals.
- The project stakeholders have a consensus on the risks, benefits and responsibilities in creating a commonly accessible project information portal through the centralized, cloud deployed project BIM model(s).
- The LEED Automation mechanism provides robust interfacing with BIM applications, especially in the sense of allowing information flow between the project IT infrastructure and the USGBC IT infrastructure.
- The project stakeholders have a set of well-defined, standard guidelines that streamlines information exchange among project stakeholders during the multiple BIM model creation, manipulation, extraction, confederation and analysis along with the project delivery process.

The development of the framework used a *reverse-engineering approach*. With achieving LEED certification as the default project goal, a set of sublevel tasks – *LEED tasks* – were identified based on project delivery milestones. Each LEED task was described using four parameters: 1) the responsible party, 2) the deliverables, 3) the information source, and 4) the computing needs. The LEED tasks were clustered by similarity according to certain criteria, for instance, disciplines and project stages. BIM applications and their functionalities were among the major criteria that categorized these LEED tasks. This process was usually referred to as LEED Strategizing. A few most widely adopted BIM tools were used as examples to help the audience understand the framework. With the LEED tasks and BIM applications being confirmed, the cloud strategies were analysed and selected. This was the most challenging part of the framework, considering that the selected cloud strategies needed to meet the following expectations:

- The cloud strategy should reconcile the possible heterogeneity of the selected BIM solutions.
- The cloud strategy should provide the appropriate mechanisms for model versioning, extraction and confederation to handle domain specific computing needs and yet sustain a dynamically evolving, common model database that ensures the integrity of information shared by the project team.
- The cloud strategy should have secured and easily defined access levels to enhance the confidentiality yet maintain the flexibility of project information management.
- The cloud strategy should have a friendly user interface.
- The cloud strategy should have data traffic enabled with LEED Online.

Quite a few successful business cloud strategies were reviewed and analysed, despite the fact that none of them could be immediately used in the LEED context. It should also be noted that cost-effectiveness of the cloud strategy was not considered in developing the framework, simply because there was not enough hard data on this matter yet (except for very few industry case studies – e.g. France, 2011). This research only intended to investigate the feasibility of this framework in theory. The assessment and validation of the proposed framework are beyond the scope of this research and will probably be conducted in the future. The overall workflow for the framework development is illustrated in Fig. 7.

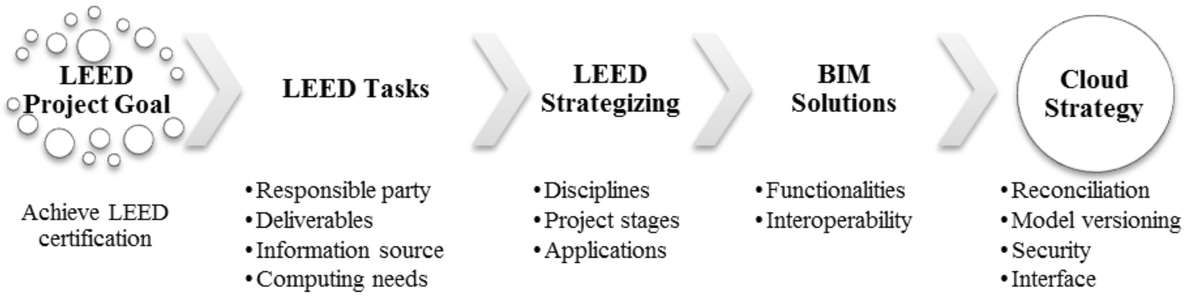

FIG. 7: Workflow for developing the proposed framework.

3.2 LEED project delivery and documentation

LEED certification is the ultimate goal of a LEED project. In comparison with conventional projects, a LEED project entails a series of unique tasks according to the rating system requirements at each stage of the project delivery, as illustrated in Fig. 8. In general, the project team has to meet the performance prescription meanwhile submit appropriate project documentation to GBCI for review on the process of the compliance. Accordingly, the challenges reside not only in the highly specialized LEED oriented design, but also in the construction and documentation management. As a rule of thumb, an integrated project delivery method is desirable, especially when BIM is implemented as a facilitator. The generation, collection, compilation, dissemination and submission of LEED documentation are usually shared responsibilities that are quite clearly allocated to individual team members according to their expertise. Major LEED documentation includes 1) the *LEED Online templates*, which are mandatory Portable Document Format (PDF) files created using *Adobe LifeCycle Designer*; and 2) the optional documentation that contribute to verifying the compliance. With BIM becoming the project's essential information reservoir, it will typically store *model data*, *field data* and *inventory data* relevant to the LEED documentation.

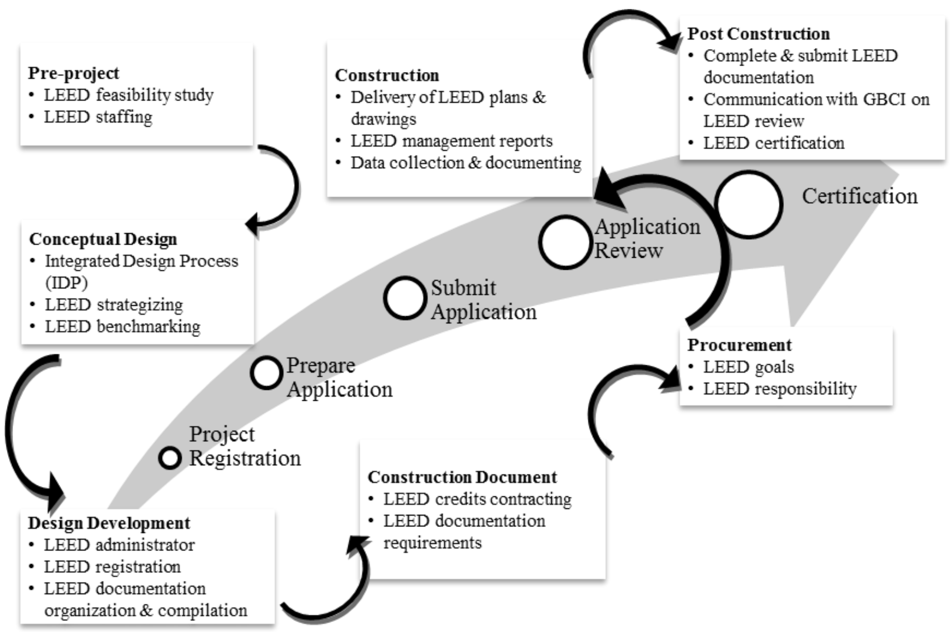

FIG. 8: LEED tasks and milestones in LEED project delivery.

Model data refers to the use of the BIM model to extract quantities, schedules, floor plans and simulation reports, and so on. Manipulation of model-embedded data usually entails interoperability issues, which can be resolved using common information exchange protocols and mechanisms including IFC, Extensible Markup Language (XML), Open Database Connectivity (ODBC) as well as proprietary formats agreed upon by software vendors. The focus is to ensure the accomplishment of the following two goals:

- BIM model(s) can be accessed and shared by individual team members at anytime and anywhere as long as pertinent access levels are authorized. Concurrent, real-time, on-demand model access will greatly reduce the duration of project design, configuration and pre-construction services without compromising owner's project requirements (OPR). Rather, it is likely to improve the building performance and overall project outcome due to the holistic design approach adopted. The team can perceive the dynamics of building systems better and thus have the opportunity to experiment different options and optimize the overall LEED oriented design.
- BIM model(s) allow bi-directional information exchange across software platforms. Model information can be extracted, calculated and rearranged to meet specific formatting requirements of LEED Online templates. Bi-directional information exchange between special software applications and BIM model(s) promotes the utilization of BIM as the ultimate project information repository, and often involves partnership of software vendors at programming level. Such a partnership also applies between BIM applications and LEED Online.

Field data mainly refers to the construction process and when the design model evolves into the construction model, and the project team starts to garner information of project progress. Field data validates the model data, which is typically required as submission to LEED Online. Challenges posed by field data management dwell on the subcontractor management and archive of temporary project information. It is not unusual that quite a few subcontractors cannot afford the IT infrastructure as general contractors (GC) and architects/engineers (A/E) do, which often causes data gaps and information inconsistency. Possible solutions include but are not limited to owner controlled IT resources sharing, GC or A/E invited IT resources sharing, or data re-entering by GC.

Inventory data refers to materials and equipment management. Inventory data is closely related to field data, thus they are usually collected, processed and managed by the same group of people. There are mature theories and instruments for inventory management, yet how to link the inventory data with the other two data groups as well as LEED Online remains challenging. Fig. 9 shows the overall LEED project data acquisition needs, and the possible interactions and management issues in submitting the desirable project data to LEED Online.

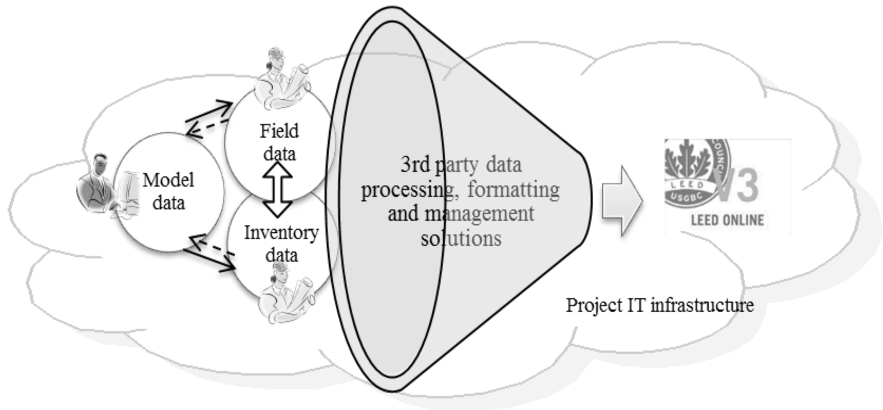

FIG. 9: Data acquisition and management in LEED documentation and submission.

3.3 Cloud-BIM implementation strategies

Selecting an appropriate cloud-BIM strategy is of ultimate importance to the proposed framework, as discussed in *Section 3*. The following case studies summarize some of the best practices of cloud-BIM implementation in the industry. They were not necessarily purposefully-built for LEED project delivery. Nevertheless, lessons learned from the cloud strategies and the data acquisition techniques could be possibly applied to the framework.

3.3.1 STRATUS

STRATUS is a private cloud server technology for Autodesk Revit developed by Des Pudney, CIO for *Stephenson & Turner* (S&T) in New Zealand. The ultimate goal of STRATUS is to deliver Revit as a remote, online service (BIM-as-a-Service) through a private cloud, and achieve distributed Revit modelling. Fig. 10 depicts the architecture and the user interface of the STRATUS cloud.

With the STRATUS Cloud, the Revit application and the Revit files both reside in the STRATUS Cloud data center. Remote Revit users connect to the STRATUS Cloud to access their Revit applications and Revit files, irrespective of their physical location, assuming the minimum requirements for WAN bandwidth and latency are met. The STRATUS-based Revit applications consume the system resource of the STRATUS Cloud servers, which far exceed those of any typical personal computing hardware. The Revit files remain secure in one location, supported by a comprehensive disaster recovery plan with fully redundant failover systems. In contrast, Autodesk's Revit Server uses Revit applications installed on the Revit user's personal computer, consuming the relatively finite system resources of the user's local machine. The Revit model files do not reside on one file server; rather, with Revit Server, several offices are connected together with Revit Server responsible for replicating the central files to each office and keeping them coordinated (Pudney, 2011). An obvious advantage of STRATUS is the multitenant and concurrent modeling achieved with relatively simple cloud typography, which fits nicely into the integrated design process that is usually adopted in a LEED project.

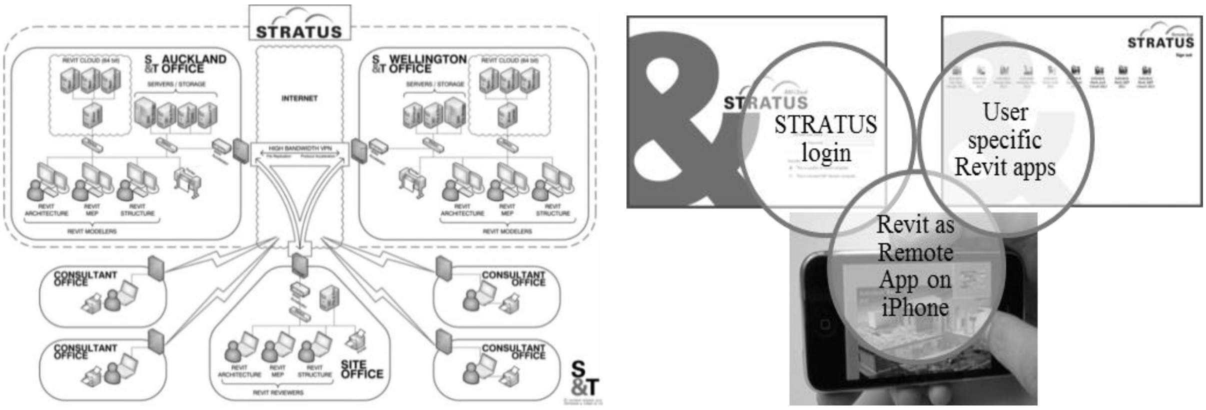

FIG. 10: The architecture and user interface of the STRATUS cloud (Source: Pudney, 2011).

Furthermore, the *Revit apps* concept applied by STRATUS, if administered by the software company directly, might become a relatively cheap IT procurement option for AEC small and medium enterprises (SMEs), similar to the idea of the iTunes and Android apps market. With Autodesk's cloud infrastructure and IT resources, project teams may finally be able to celebrate a homogeneous software environment, and avoid possible inefficiencies, errors and omissions in typical information exchange between software applications.

3.3.2 Balfour Beatty and Vela Systems

Balfour Beatty Construction approved enterprise-wide license of *Vela Systems*, a comprehensive construction field management software application, for all U.S.-based projects. The decision was made based on pilot project findings that the company was able to recoup a ROI of 300% and cut people hours almost in half (Vela Systems, 2011).

Vela Systems is offered as SaaS through iPad to the company, called *Vela Mobile*, with the server running the software in the cloud. Vela conducts business mainly in four areas: *Quality Program*, *Safety Programs*, *Document Management and Field BIM*. The *Field BIM* service essentially integrates with BIM to enable end users to leverage model objects (e.g. equipment) and their attributes (e.g. name, type and manufacturer) in specific Vela Field Management workflows (e.g. commissioning). Data is passed from the model to Vela, then back again, creating an as-built BIM that has new attributes from the field that are dynamically updated as work and operations progress. End users do not even need to see the BIM while in the field - the data are a part of the workflow in Vela Systems (Fig. 11). However, not all information will be stored in the BIM nor should it be - Vela Systems' cloud computing-based software extends BIM so its objects can be used to access other data, documents and more stored in the cloud (Vela Systems, 2011).

Field data and QA/QC information are among the most challenging parts in preparing LEED documentation, as discussed previously. Applications like Vela can significantly cut the overhead in documenting the LEED project, and improve the efficiency and integrity of the documentation due to its capacity for real-time data acquisition and validation against model data and inventory data. Since building commissioning is an essential part of building energy performance in the LEED rating system, the benefits of implementing a *Field BIM* approach are quite palpable.

FIG. 11: Field BIM ties BIM models to the field for data and document exchange (Source: Vela Systems, 2011).

3.3.3 Lessons learned

The above case studies demonstrate the possibility of cloud-BIM implementation across the design, construction, commissioning and handover stages of a project delivery. It was quite apparent from the case studies that the design stage is simulation-intensive, while the construction, commissioning and handover stages are documentation-intensive. As a result, these distinct computing power and data exchange requirements necessitate the thoughtful treatment of deployment strategy catering to the unique needs at each stage. For instance, it might be beneficial to modularize the proposed framework and dedicate each module to a particular group of tasks, yet reserve the organic relationship between these modules should there be data exchange needs. This is feasible considering the scalability of the cloud infrastructure and the availability of appropriate information exchange protocols.

3.4 Cloud-BIM for LEED Automation: Framework of a new business paradigm

Essentially, the proposed framework intends to establish a new business paradigm in delivering LEED projects. This paradigm should provide the desired capacity and business agility to accomplish the goals of LEED Automation (Fig. 12). The framework is general in nature, considering the scope and complexity of the issues being addressed.

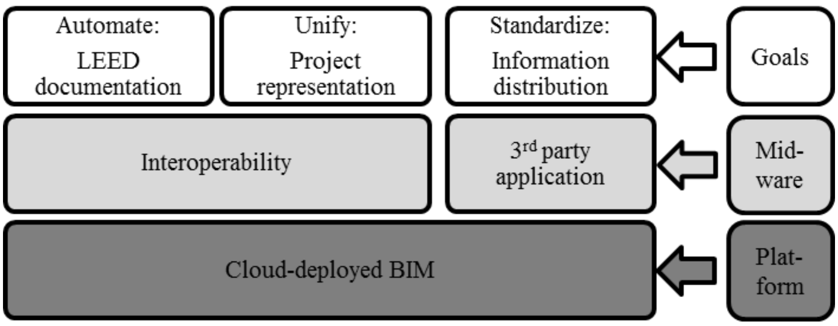

Fig. 12: Intended new business paradigm for LEED project delivery.

Fig. 13 gives an overview of the realised prototype of the proposed framework of *cloud-BIM leveraged LEED Automation* providing bottom-up proof of the developed overall concept. The framework is built upon BIM server technologies, AEC cloud infrastructures, dedicated AEC SaaS solutions that are available in the market, and standard information exchange mechanisms/protocols (it should be noted that it is not the intention of this paper to give any preferences to products used as examples in this framework). The overall *LEED project cloud* of the framework comprises a cluster of modularized sub-clouds. Each sub-cloud was focused on a particular business process and a set of project tasks championed by pertinent project individuals, and yet was able to communicate efficiently with the rest of the team with carefully designed information exchange criteria.

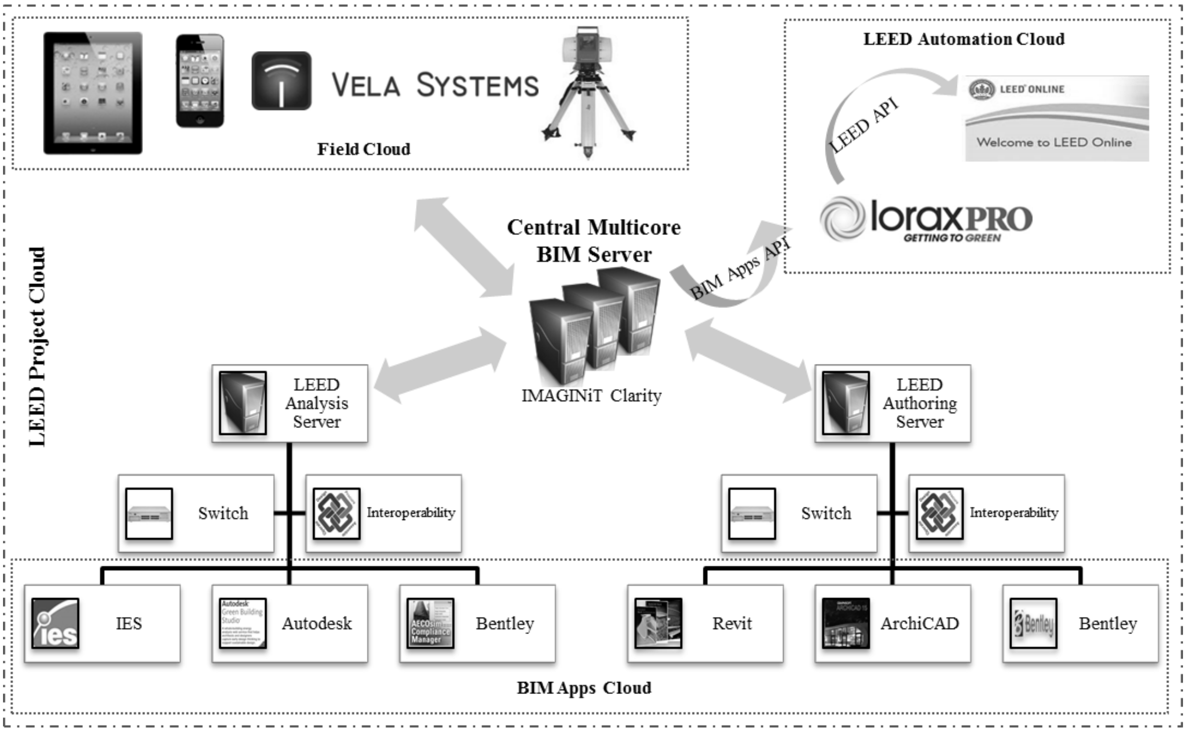

FIG. 13: Framework of cloud-BIM leveraged LEED Automation.

The *Central Multicore BIM Server* could be administered using the *IMAGINiT Clarity* solution which was built upon the Autodesk Revit Server platform. Clarity was able to efficiently manage central BIM model(s) and host project data and documentation generated, updated, and consolidated along with the LEED project delivery. The advantage of using a server stewardship solution like Clarity resides in the fact that it can support multiple central servers and enable information exchange between servers in popular data formats such as DWG and IFC (IMAGINiT Technologies, 2012), which is critical to the sub-cloud layout of the proposed framework.

The *BIM Authoring Server* and *Analysis Server* handle the model creation and configuration respectively. Model based collaboration and communication were enabled through the Clarity between designers, consultants, contractors, and other stakeholders, or even with non-BIM users through reports of real-time information. The *BIM Apps Cloud* emulated the strategy adopted by the STRATUS case study, and it constructed a scenario when major software vendors eventually release fully functional BIM applications in the cloud, like the apps that could be purchased from the iTunes store and the Android market.

The *Field Cloud* was another sub-cloud dedicated to manage the field data and inventory data. During the construction, commissioning and handover stages, an intensive bulk of data needed to be captured in the field and compiled into project documentation that were eventually formatted into the LEED submittals. These data were fed back to the office staff through the BIM server to validate and update the model data as the design model(s) gradually progressed into the construction model(s) and eventually the as-built model(s) when the project was handed over to the owner.

The *LEED Automation Cloud* specialized in the LEED certification process with emphasis on streamlining the automated LEED documentation generation, managing LEED Online templates submission, and tracking the certification status. This sub-cloud needed support of specially designed 3rd party solutions like *LoraxPRO* (a business partner of USGBC specializing in LEED Automation management, see http://www.loraxpro.com) to enable data exchange between the project team and LEED Online, using customized information exchange formats such as XMLs through the API provided by USGBC.

As a summary, the proposed cloud-BIM based framework could provide the LEED project team with the following benefits:

- Unified central model(s) and a multitenant working environment that allowed remote real-time access and concurrent LEED authoring/analysing.
- Scalable/elastic model information exchange and communication across platforms enabled by standard or customized information exchange protocols such as IFCs and XMLs.
- Integrated data acquisition, processing and management along the project life cycle with enhanced collaboration between the office and field operation.
- Natural interface with LEED Online with auxiliary web services supporting automated LEED submission, and cloud based longer term document and knowledge management.

The demonstrated realization of the proposed framework addresses a most comprehensive scenario of the LEED project delivery process. Nevertheless, it is possible that in real world applications, only part of the framework would be utilized. For instances, a certain amount of LEED credits only required design information, and submittals pertinent to these credits could be submitted to USGBC right after the design was finished. In this case, a modularized cloud infrastructure as adopted by the proposed framework would be able to increase the business agility and efficiency in computing resource consumption of the project team.

3.5 Brief demonstration

Cloud-BIM leveraged LEED Automation is a working concept but the prototypes have been seen already in the industry. The following is a brief use case using *Bentley AECOsim Energy Simulator* and *LoraxPRO* to automate the *LEED for New Construction - Energy and Atmosphere Prerequisite 2: Minimum Energy Performance* (LEED-NC: EAp2).

After designers finished configuring the building model and performed the ASHRAE 90.1 energy simulation using the *AECOsim Energy Simulator,* the simulation report was exported into an XML file using a schema created by *LoraxPRO*. The schema was a straightforward interpretation of the PDF LEED Online template. Then with *LoraxPRO*'s cloud based application, the user could import the data contained in the XML file and automatically extract data to fill up the corresponding PDF LEED Online template for LEED-NC: EAp2. If desired, all project team members could get access to the generated template to check whether accurate and completed information was used to populate the template. Once confirmed, the template could be submitted to LEED Online directly within the *LoraxPRO* application. During this process, no manual data input was needed at all (Fig. 14). *LoraxPRO* also provided a LEED information reservoir that could be shared and cross-referenced by the project team to monitor and track the status of the LEED submittals and the LEED certification.

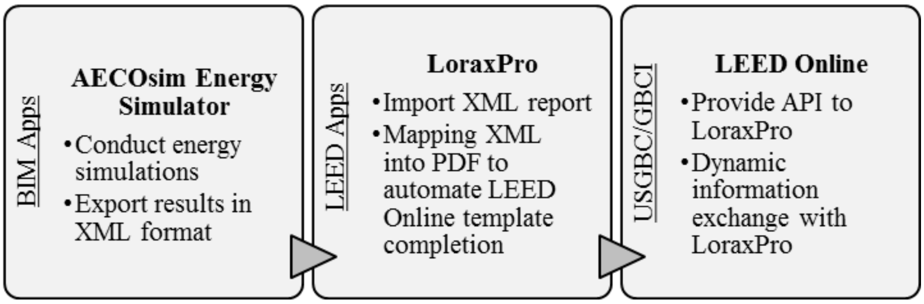

FIG. 14: Workflow of automating LEED NC: EAp2.

4. CONCLUSION

This research discussed a possible new business paradigm for delivering LEED projects, LEED Automation facilitated by cloud deployed BIM applications. It reviewed the literature of synergies between BIM and sustainability applied in the AEC industry, and the cloud approach of BIM software development and implementation. The research then proposed a framework intended to leverage the cloud-BIM technology for LEED Automation. With a brief demonstration, the paper also showcased the possibility to implement the proposed framework using cutting-edge technology and best practices. The framework was limited by the fact that no validation was possible to make due to the lack of applicable case studies. The performance and efficacy of the framework in comparison with current approaches could not be assessed either. Nevertheless, the research demonstrated that the technology core of the *cloud-BIM leveraged LEED Automation* framework can be considered well developed and widely adopted in the AEC industry.

As BIM gets even more sophisticated in modelling and configuring building life cycle performance, it will eventually be able to address concerns in sustainability and high performance, as advocated by green building rating systems including LEED, and building codes such as the International Green Construction Code (IGCC). Advancement of BIM based on a cloud-computing infrastructure has significant impacts on IT planning and strategizing of AEC companies. SMEs as a major constituent of the industry typically cannot afford the costs of intensive IT upgrading. Cheaper yet robust enough cloud solutions will become their preferences to stay in business. AEC software vendors have recognized this emerging market and have started a marketing campaign to take advantage of it. Unlike individual-entity focused initiatives, the cloud-BIM leveraged LEED Automation framework necessitates strong partnership and enhanced collaboration among all project stakeholders. Just as digital social-networking is revolutionizing the human society, socialization of ICT is gradually gaining acceptance in the AEC industry. Business today is increasingly relationship and collaboration oriented. Success of AEC companies now depends heavily on organization's flexibility and interoperability performance when working on a project team, especially in complex, high performance projects such as LEED. A cloud-based IT infrastructure is a critical investment to enhance a company's social capacities.

Future research on this topic should look more in-depth at the details of the proposed general framework. For instance, it will be beneficial to conduct a business process modelling analysis to take a closer look at the implications of the cloud-BIM facilitated LEED project delivery on different project stakeholders, especially the information flow and information exchange requirements during this process. Interoperability issues have not been sufficiently discussed in this paper either. Furthermore, before the framework is actually implemented on broader scale, its validation and assessment against real-case scenarios should be conducted.

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