Green2.0: Socio-technical Analytics of Green Buildings

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ABSTRACT Professionals and researchers of the AEC (Architectural, Engineering & Construction) industry, as well as, public policy makers are challenged by the increasing complexity and need to improve our understanding of the social, technical and business dimensions of green building projects. This typically requires close cooperation of the design team, the architects, the engineers, and the rest of the stakeholders at all project stages, but most importantly availability of new methods, tools and strategies that are enabled by emerging technologies. This paper builds around an online platform (*Green2.0*), that tries to leverage advancements in Building Information Models (BIM), energy-efficiency simulation tools and online social network analysis methods to enable a data-driven approach to building design, planning, construction and maintenance. The platform advances the current state of the art by providing an online integrated environment for (a) efficient storage, indexing, querying, 3D visualization and exploration of BIMs, (b) sharing BIMs and enabling online collaboration among the various stakeholders (c) interactive energy efficiency analysis of buildings by automatically linking IFC to external energy simulation libraries, and (d) interactive analysis of patterns of social interactions and collaboration networks of AEC professionals.

1 INTRODUCTION

Increasingly, we are noticing that green building research is a socio-technical process. This is because the decision of selecting energy/water saving measures, ultimately, rests on end-users. The more educated and engaged the users are, the better the chances that they will make informed decisions about greener options. To support this process, we have to match the advanced technical tools with socially-savvy tools that capture end-user needs and at the same time influence their attitude towards water and energy usage. Developing algorithms, tools and work processes that bridge the gulf between social and engineering aspects is therefore a major objective for the green agenda. This is quite a challenge given that the majority of analysis tools were developed by engineers for use by engineers.

In this paper, we introduce *Green2.0*, a web-platform that enables complex interactions between buildings and people, analysis of these interactions, as well as, interactive analysis of energy efficiency of green buildings (Papagelis et al. 2016). Fundamentally, it connects BIM to OpenStudio[1] to allow users to select different products from a catalog and study their green impact. At the same time, it allows participants (end-users or professionals) to comment and share views about design. Social network analysis (SNA) methods are then used to extract trends and visualize insights of these interactions. Green2.0 takes BIM from the realm of a software into the realm of collaborative platform for decision making. We aim to give people the controls of BIM software to study, choose, suggest and innovate new means to design, build and operate their facilities.

2 LITERATURE REVIEW AND NEED

Researchers have developed models to analyze the networked nature of project internal actors (see Di-

[1] https://openstudio.net

Marco et al. 2010; Pryke 2012). Others have considered the impact of project internal networks on the evolution of project scope (see Taylor and Levitt 2007; Wong et al. 2012). The most advanced approach is the proposal by Chinowsky and Galotti (2008) to model construction projects as social networks. Van Herzle (2004) found that inclusion of non-expert knowledge was beneficial to the planning process given that the diversity of perspectives (especially of those who are outside of the professional bubble) can (re)discover creative solutions. In fact, "citizen science" often results in superior solutions (Lakhani et al. 2009; Lakhani and Panetta 2007). Further, such solutions are by default, context-sensitive (Corburn 2003).

BIM technology has been developed and promoted as means to integrate all information of building designs. However, it is overly focused on the traditional design of facilities, i.e. not green-oriented. Designers and operators have to use an increasing set of heterogeneous software systems to complement the missing features in BIM, facing multitude of challenges in relation to interoperability and data integrity. With the increasing size and sophistication of BIM files and the increasingly iterative development cycles, the burdens of transferring data between software and the management of design changes is hindering fuller analysis.

Becerik-Gerber and Rice (2010) found that the top three BIM functions are visualization, clash detection, and creation of as-built models. While most professionals believed that sustainability analysis is of great importance, they didn't consider it to be a priority of the BIM agenda (Bynum et al. 2013). More alarming, researchers in green buildings found that BIM-based energy management is still an immature domain (Wang et al. 2013).

3 OBJECTIVE AND SCOPE

The current models and data structures for green aspects in BIM are lagging. Practitioners have been looking for incorporating green analysis (energy and water consumption) within BIM in an easy-to-use format. The solution is not just to expand BIM data standards to encapsulate all data related to green design, as this would just compound the data management tasks. Our approach and the main contribution of this research is to develop a middleware platform that serves as the bedrock upon which we can study and develop tools to enhance handling of the two challenges: how to engage users (both end-users and professionals) and harness their needs, and how to simplify energy analysis systems within a BIM environment—specifically:

Green-aware BIM: BIM models are large and complex—yet they currently have little focus on green-oriented issues throughout the building lifecycle - on accommodating alternative solutions during design; on the building operations phase; on engaging non-technical end users. Expanding BIM data standards to encapsulate semantics of green design would increase the complexity of existing data management tasks. Rather, our approach consists of establishing a middleware that can loosely integrate BIM and independent green analysis software and libraries, such as OpenStudio, without forcing a full merger.

Social-aware Analytics: Green2.0 embeds social commenting into BIM technology. This is coupled with analysis of the resulting discussion networks, which allows to understand the social dynamics between participating stakeholders and the semantics of their comments. In the era of the knowledge economy, these interaction networks constitute a rich source of data and can provide meaningful insights regarding design and operations plans. Indeed, this could provide the spark for a new realm in innovation democratization and bottom-up decision making.

4 HIGH-LEVEL ARCHITECTURE

In this section we describe the high-level architecture of our platform. Figure 1 illustrates the three components of the architecture and how they relate to each other, namely *Green2.0 MVC*, *Green2.0 BIM Management, and Green2.0 Modules.*

4.1 Green2.0 MVC

The main part of the Green2.0 core infrastructure is a web service that is based on a *Model-View-Controller* (MVC) web architecture. MVC is a popular software architectural pattern for implementing user interfaces. It divides a given software application into three interconnected parts, so as to separate internal representations of information from the ways that information is presented to or accepted from the users. This component is therefore responsible for

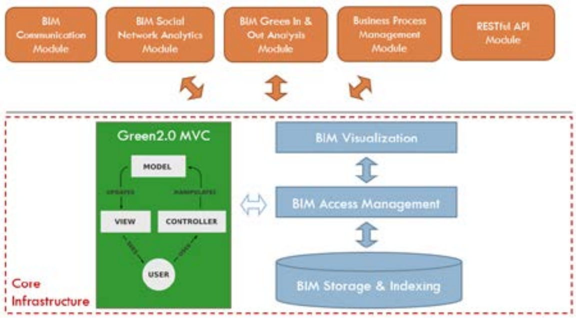


Figure 1. Green2.0 High-level architecture

managing all user interactions and domain-specific functionality. It is also responsible for integrating the BIM open source technologies, and facilitating the communication with various independent modules.

4.2 Green2.0 BIM Management

The most critical functionality of the Green2.0 platform's core infrastructure is the efficient management and visualization of BIM models. Towards this end, Green2.0 relies on a number of tightly-knit open source technologies:

BIM Storage & Indexing (*BIMServer*): The BIMServer (Beetz et al. 2010) enables to centralize the information of a building design project. The core of the software is based on the open standard IFC (Industry Foundation Classes) and therefore knows how to handle IFC data. The BIMserver is not a fileserver, but uses the model-driven architecture approach. This means that IFC data are interpreted by a core-object and stored in an underlying database (i.e., BerkeleyDB). The main advantage of this approach is the possibility to query, merge and filter the BIM-model and generate IFC files on the fly.

BIM Access Management (*Service Interfaces*): The *Service Interfaces* is a set of defined interfaces for interaction with BIMserver. These interfaces are defined as (heavily annotated) Java interfaces. All interfaces with namespace `org.buildingsmart.bimsie1` are implementations of the *BIM Service Interface Exchange* standard (BIMsie[2]). All calls in the `org.bimserver` namespace are BIMServer specific calls. Green2.0 uses a JavaScript Object Notation (JSON) interface to access the methods of the Service Interfaces. The JSON interface is mainly there to facilitate connecting to the BIMserver from web applications/web sites.

BIM Visualization (*BIMSurfer*): BIMSurfer[3] is an open source web-based viewer for the visualization of BIM models described as IFC models. It is based on WebGL (Web Graphics Library), a JavaScript API for rendering interactive 3D and 2D computer graphics within any compatible web browser without the use of plug-ins.

4.3 Green2.0 Modules

The Green2.0 high-level system architecture emphasizes separating the functionality of the system into independent, interchangeable modules, such that each contains everything necessary to execute only one aspect of the desired functionality. With modular programming, concerns are separated such that modules perform logically discrete functions, interacting through well-defined interfaces with the core architecture. Currently, Green2.0 consists of five modules.

4.3.1 BIM Communication Module

One of the main functionalities of the system is to provide means of online communication and collaboration of the various actors (engineers, owners, contractors, etc.,) around building design elements. These actors are coming from an Ontology that describe roles in AEC industry (see Zhang and El-Diraby 2012). Green2.0 supports online communication and collaboration through shared BIM models. In order to share a BIM online, it first needs to be uploaded by its owner in the system, typically as an IFC file. Then, the owner can share it by sending email invitations to known actors or by browsing the user database seeking for experts to join the project.

Once users have access to a shared BIM model, they can use the 3D building model visualization tool to navigate, explore, and select specific elements of the model (see Figure 2). Once an element is selected in the Tree View, the various element properties are listed that provide useful information to the expert. The collaboration is facilitated by means of a rich comment management tool that allows to submit, edit, delete, and filter comments about selected BIM elements. The functionality is similar to that found in

[2] https://buildingsmart.github.io/BIMSie/

[3] http://bimsurfer.org

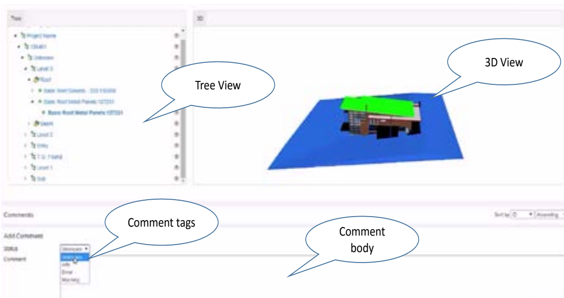


Figure 2. Snapshot of the Communication Module

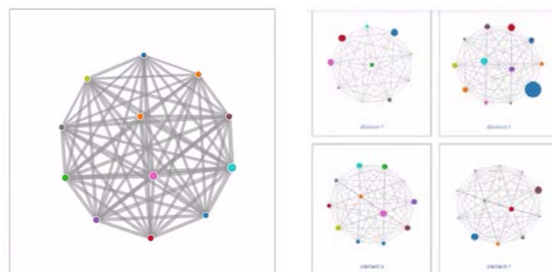
an online discussion forum, with the exception that the discussion is domain-specific and thus domain-specific features are supported. For example, comments can only be of a specific type (info, error, warning, other). A user can navigate comments in chronological order or other semantic properties. Notifications are also available that inform actors for new dialogues or updated conversations.

4.3.2 BIM Social Network Analytics Module

Social interactions that occur among the various actors and BIM elements during collaboration processes consist valuable information for analysis. This module is responsible for the collection, storage, analysis and visualization of such data in a meaningful way. Revealing interesting patterns of communication can further enrich user experience and support decision making. The approach we follow is to define *discussion networks* based on interactions of actors and building elements and perform analysis on the underlying networks. These networks can be defined at many different levels of granularity. Aiming for a more flexible platform, we made the decision to define networks at three different levels of operation:

- Element-level Networks (*EN*)
- Project-level Networks (*PN*)
- Cross-project Networks (*CN*)

For each of the operational level above, a graph *G(V, E)* is defined comprising of a set of vertices *V* and a set of edges *E*. In the case of *EN*, each node represents a user and each edge represents that two users have contributed in a discussion thread about a specific building element. Accordingly, in the case of *PN*, each node represents a user and each edge represents that two users have contributed in discussion threads of at least one common building element of a BIM project. Finally, in the case of *CN*, each node represents a user, and each edge represents that two users have contributed in at least one discussion thread of a shared project. It is easy to see that a user always represents a node in the network, while the type of interaction between two users defines the exact semantics of an edge in that network. For the various definitions of a network (*EN*, *PN*, *CN*), a number of network insights are possible, based on network analysis. For each network, Green2.0 reports a number of important network structure measures, such as *network size*, *diameter*, *density* and *characteristic path length*. Note that due to the system's architecture, it is easy to plug-in more network measures in the future.



(a) (b)

Figure 3: Green2.0 SNA. (a) Example project-level network (*PN*), (b) Visualization of trending discussions (element-level networks)

This module is also responsible for the visualization of the various networks. Figure 3(a) shows an example *PN* network, while Figure 3(b) illustrates a number of *EN* networks about various elements of a specific project. Note that a user can easily depict trending discussions and navigate there directly by means of selecting the network.

4.3.3 BIM Green In & Out Analysis Module

The aim of the Green In & Out Module is to provide a comparative energy analysis of building models. For example, an engineer or an end-user might want to assess alternative window systems for the same building. In order to facilitate this, a product substitution functionality was developed. It allows to locally replace building products, such as a window, with a comparable product (from the product catalog).

To conduct the energy analysis (of each model being compared), OpenStudio is used. It is a cross-platform (Windows, Mac, and Linux) collection of software tools to support whole building energy modeling using EnergyPlus and advanced daylight analysis using Radiance. OpenStudio is an open source project which includes graphical interfaces along with a Software Development Kit (SDK). In addition, OpenStudio provides a rapid development mode and open application programming interface (API), which makes it highly extensible and customizable. It is rather simple for developers to either build on existing applications or create completely new ones to conduct customized building energy analysis. All of these aspects suggest OpenStudio as a suitable platform for initial targeting to support the data exchange needs of building energy modeling.

Recall that Green2.0 represents BIM models using the IFC standard. On the other hand, the OpenStudio API requires a specific file format, Open Studio Model (OSM), as input in order to run energy analysis of a model using tools such as Radiance (advanced daylight analysis tool) and EnergyPlus (whole building energy modeling). The first challenge therefore is to map the information represented in an IFC file to information that can be represented in an OSM file. A crucial difference between the two formats is that IFC files describe a building as a decomposition of individual components, which have one or more solid-volume geometrical representations and are enriched with semantic and relational information. An OSM file describes the building from the viewpoint of thermal zones and thin-walled space boundaries. Therefore, not only does the information need to be encoded differently, the geometrical information needs to undergo a translation process that flattens the solid-volume geometry for space bounding elements (such as walls, roof and floor slabs) into thin-walled thermal zone boundaries (see Krijnen et al. 2015). The geometrical conversion process sketched above requires a programming environment to efficiently and effectively manipulate IFC files and geometry in the Green In & Out Module. The choice has been made to develop this system in the Python programming language using the IfcOpenShell[4] and pythonOCC[5] modules. The former allows to efficiently parse IFC files and return geometrical definitions as Open Cascade[6] Boundary

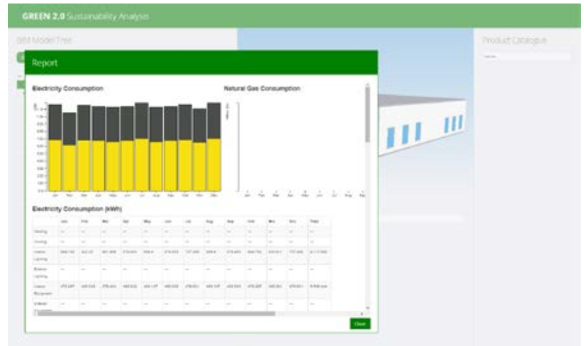


Figure 4. Green In & Out Module: Energy analysis results

Representations (BReps). The latter allows BReps to be further manipulated so as to conform to the thin-walled thermal zone boundaries expected in OSM file. In addition to the geometrical definition, OpenStudio expects semantic information that pertains to the use of the building to deduce heating, cooling loads and functional constraints. These are to be defined by the user. In summary, the steps of conducting comparative energy analysis in Green2.0 are as follows:

- User can select any *targeted product* to study
- The user can choose a *replacement product* for the *targeted product*, from a predefined catalog
- The user must define the usage scenario of the facility (if not already done)
- IFC data of alternative designs are transliterated to OSM data
- OpenStudio is then invoked for energy analysis
- Results of the analysis are returned to user (see Figure 4)

4.3.4 Business Process Management Module

One of the objectives of the Green2.0 project is to improve corporate performance by optimizing business processes related to the building projects. To this end, we designed and developed a Business Process Management (BPM) module that operates on processes that become available in the Green2.0 platform and supports:

- Monitoring and exploration of business processes that evolve in Green2.0
- Offline analysis of BIM business processes

[4] http://ifcopenshell.org
[5] http://www.pythonocc.org
[6] http://www.opencascade.com

The above functionality becomes feasible by integrating Green2.0 with Activiti[7], an open source lightweight workflow and Business Process Management (BPM) platform. Processes are designed in Activiti and are instantiated in Green2.0. As users perform tasks and interact with each other in Green2.0, Activiti RESTful calls are automatically invoked that inform and update the BPM engine.

4.3.5 RESTful API Module

One of the major design decisions in Green2.0 is to allow third-party services to access Green2.0 resources. This is enabled through a RESTful API that is accessible via standard HTTP methods by a variety of HTTP clients, including browsers and mobile devices. Figure 5 illustrates a typical architecture for supporting RESTful APIs in Green2.0. Third-parties are accessing the Green2.0 REST API by submitting URL requests; the platform performs the necessary computation and compiles a REST answer to the request formatted as a JSON file. Through the API a number of resources become available to third-party services, clients and applications, such as, BIM users, projects, IFC elements, comments, information about the discussion networks, business processes.

5 CONCLUSIONS

We introduced Green2.0, a platform for enabling online socio-technical analytics of green buildings. The platform has been successfully deployed at the University of Toronto and as a Canarie[8] research platform - a collection of platform services to be used by multiple independent research teams. Early phase users of the system include research and industry collaborators. Designing and developing Green2.0, we had to identify the scope of the system, investigate alternative system design and architecture concepts, explore data collection methods and assess the relevant emerging technologies. The premise of our work is that by engaging users in early design phases and by simplifying energy analysis within BIM environment it is likely to have a profound beneficial effect for both the AEC industry and the society at large. Our research describes a significant improvement over current practice and tries to advance the current state of the art in green building design towards sustainable development of cities.

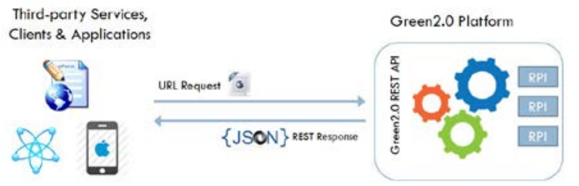


Figure 5. RESTful API Module Architecture

[7] http://activiti.org/
[8] www.canarie.ca

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