Green 2.0: Socio-Technical Analytics of Green Buildings

Tamer El-Diraby[1], Thomas Krijnen[2], and Manos Papagelis[3]

1. Associate Professor, Dept. of Civil Engineering, University of Toronto, Canada. 35 St. George St., Toronto ON M5S 1A4. Email: tamer@ecf.utoronto.ca
2. PhD Student, Eindhoven University of Technology, Netherlands. t.f.krijnen@tue.nl
3. Post-Doctoral Fellow, University of California, Berkeley, United State. papaggel@berkeley.com

ABSTRACT:

Green 2.0 is a BIM-based platform that support integrated analysis of green features through linking files that use ifc (industry foundation classes) with energy analysis systems. Through this, a user can study the energy performance of a variety of design elements. Green 2.0 also incorporate commenting abilities into BIM models. This allows users to question decisions, or share ideas. Social network analysis algorithms are then used to profile the collaborating team and their discussions.

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 select greener options. To support this, we have to match the advanced technical tools with socially-savvy tools that captures end-users 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.

Green 2.0 is a BIM-based platform that integrates user interactions with green energy analysis abilities. Fundamentally, it connects BIM to EnergyPlus to allow users to select different products from a catalog and study the green impacts of each. At the same time, it allows participants (end-users or professionals) to comment and share views about design. Social network analysis (SNA) tools are then used to extract trends/needs form these interactions. Green 2.0 takes BIM from the realm of a software into the realm of socially-based collaborative platform for decision making. We aim to give people the controls of BIM software to suggest, choose, study and innovate new means to design, build and operate their facilities.

LITERATURE REVIEW AND NEED

Researchers have developed models to analyze the networked nature of project internal actors (see DiMarco 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/operators have to use an increasing set of heterogeneous software systems to complement the missing features in BIM, facing multitude of problems in relation to interoperability and data fidelity. With the increasing size/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 sustainable analysis is of great importance, most still believed that sustainability was not a primary application of BIM (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).

OBJECTIVES & 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 will just compound the data management tasks.

The contribution of this project is to develop a middleware platform as the bedrock upon which we can study and develop tools to enhance handling of the two challenges: how to engage users (end-users or professionals) and harness their needs, and how to simplify energy analysis systems within a BIM environment—specifically:

- *Green-Savvy BIM:* BIM models are large and complex—yet they currently have little focus on green-oriented issues; on accommodating high numbers of alternative solutions during design; on the building operations phase; and on non-technical end users. 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. Rather, establish a middleware that can loosely couple BIM and independent green analysis software such as Energy Plus without forcing a full merger.

- *Social-semantic Analytics:* the project embeds social commenting into BIM technology. This is coupled with a full analysis of the resulting social networks, which allows us to understand the social connections between participating stakeholders and the semantics of their comments. In the era of the knowledge economy, these networks are a rich source of creative ideas regarding design/operations plans. Indeed, this could provide the spark for a new realm in innovation democratization and bottom-up decision making.

MAIN ARCHITECTURE

The architecture of Green 2.0 includes two main layers. The first a core infrastructure that houses BIM files and manages their manipulation. The second is a set of applications that enables commenting, supports analysis of comments, and links BIM to Energy Plus (see Figure 1).

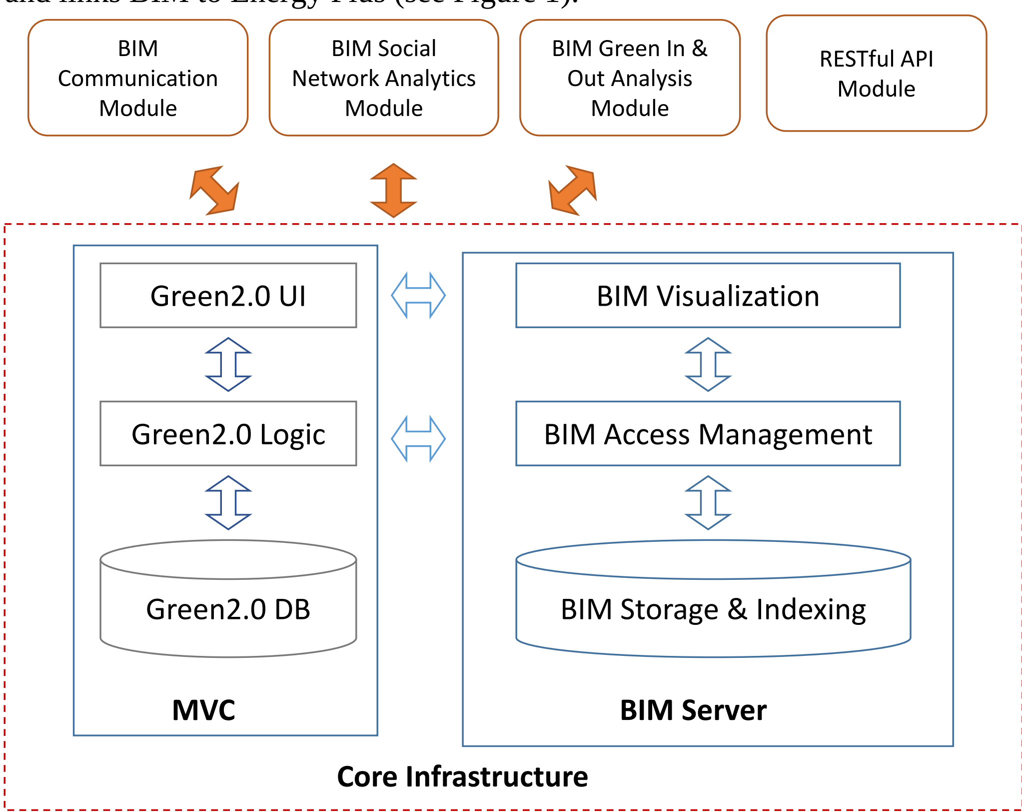


Figure 1: Main Architecture

Core Infrastructure:

This includes the following elements:

- BIM Storage & Indexing (BIMServer): IFC data are interpreted and stored in an underlying database (based on the BerkeleyDB format). The main advantage of this approach is the ability to query, merge and filter the BIM models and generate IFC files on the fly.

- BIM Access Management (Service Interfaces): These interfaces are defined as (heavily annotated) Java interfaces. All interfaces are implementations of the BIMsie standard (BIM Service Interface Exchange). a JSON (JavaScript Object Notation) interface is used to facilitate connecting to the BIMserver from web applications/web sites. Green 2.0 has also a plug in for BimQL (Building Information Model Query Language). It can be used for selecting and updating data stored in IFC models and it is currently implemented on top of the BIMServer.
- BIM Visualization (BIMSurfer): The BIMSurfer (Building Information Model Surfer) is an open source WebGL viewer for BIM models based on open standards (for now only IFC). It allows for easy web-based viewing and manipulation of IFC models.

Green2.0 MVC Architecture

The second part of the Green2.0 core infrastructure is based on a Model View Controller (MVC) web architecture. MVC is a software architectural pattern for implementing user interfaces. It divides a given software application into interconnected parts, so as to separate internal representations of information from the ways that information is presented to or accepted from the users. The web development of Green2.0 is supported by the Symfony web application framework. It alleviates the overhead associated with common activities such database access, webpage templates and session management. In particular, Symfony consists of three levels:

- The *model*: represents the information on which the application operates its business logic
- The *view*: renders the model into a web page suitable for interaction with the user
- The *controller*: responds to user actions and invokes changes on the model or view as appropriate

The MVC architecture separates the business logic (model) and the presentation (view), resulting in greater maintainability.

Module 1: BIM Communication Module

One of the main components of the Green2.0 project is to provide means of online communication and collaboration of the various stakeholders (engineers, owners, contractors, etc.) around building design elements. The online communication and collaboration is supported through (see Figure 2 below):

<u>Sharing BIM models with other users (by email invitation)</u>: this is the main entry point to the platform. Users can register and profile themselves. They can also start a project (by uploading an IFC file). Green2.0 distinguishes between two types of projects: “owned” and “shared”. A user can be the owner of a project that he/she creates. Alternatively, a user can be invited to join a project (owned by another user). When the invitation is sent, a user role is also assigned to the invited user

(e.g., Architect, Engineer, etc.). There are two types of “roles” supported in Green2.0:

- Predefined roles: these are extracted from an Ontology that describes the roles in the ACE industry (Zhang and El-Diraby 2012).
- User-defined roles: these are free text tags provided by the owner of the project.

The two types of roles are flexible enough to accommodate needs of the ACE industry.

<u>A comment management tool</u>: any user can view the ifc file of the project as a set of 3D-objectes or as a hierarchy of ifc products. By clicking on any object, a user can submit/edit/delete comments about this element of the design (similar to a discussion forum). Comments can be of a specific type (four initial types are supported: Info, Error, Warning, Other). Comments can be sorted by time or other properties in an ascending or descending order.

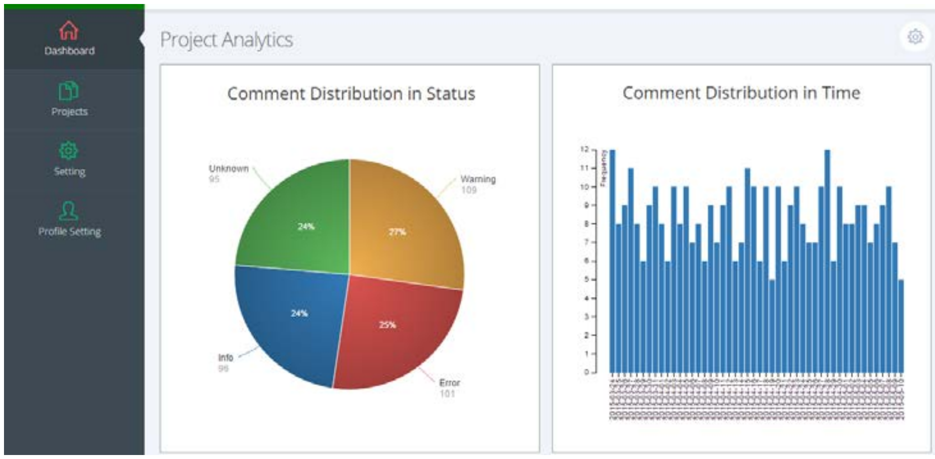
Figure 2: Snapshot of the Communication Module

Module 2: BIM Social Network Analytics Module

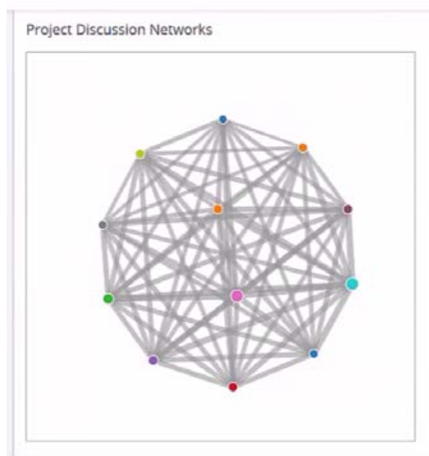
One of the main objectives of the Green2.0 project is the study of the networks that can be performed through analysis of the discussions occurring among the various stakeholders (engineers, owners, contractors, etc.) around building design elements.

In such a domain, there are many different levels of abstraction where a network analysis can be performed. For the needs of our research and to provide a platform as agile and flexible as possible for supporting diverse network analysis studies we define networks on three levels of abstraction/ operation:

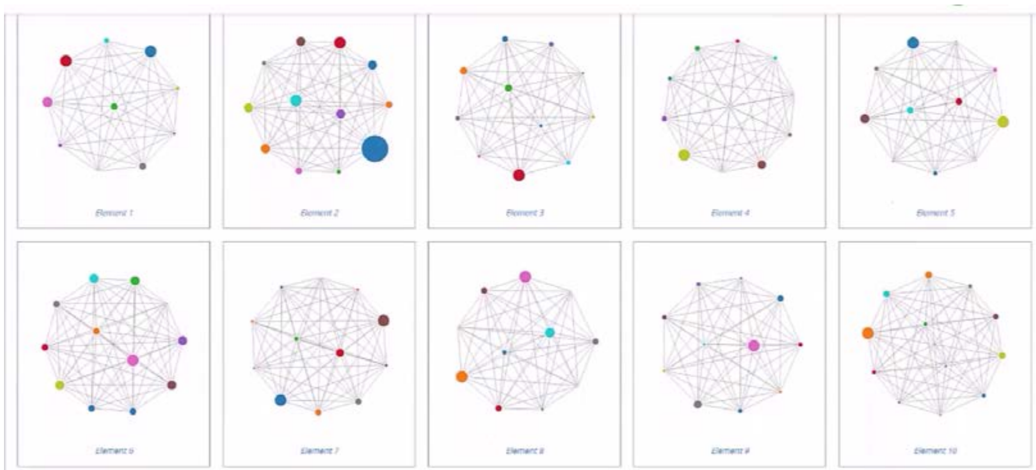
- Element-level Networks (EN)
- Project-level Networks (PN)
- Cross-project Networks (CN)



a: Comment Statistics and Trends



b: the social network of the overall project



c: social networks for individual elements

Figure 3: Augmented Snapshots of social and comment networks.

For each of the operational levels above, a graph is defined comprising of a set of vertices and a set of edges (links). In the case of EN, each node represents a user and each edge represents that two users have contributed in a discussion about a specific building element. In the case of PN, each node represents a user and each edge represents that two users have submitted a comment for at least one common building element of a specific project. Finally, in the case of CN, each node represents a user, and each edge represents that two users have contributed in a discussion about some (at least one) building elements of a common project. It is easy to see that a user of the service always represents a node of a network, while the type of interaction between two users defines what exactly an edge in the network represents.

For the various definitions of a network (EN, PN, CN) we can provide a number of network insights, based on standard social network metrics.

Module 3: Green In and Out Module

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

The Green In and Out Module requires a programming environment to efficiently and effectively manipulate IFC files and geometry. The choice has been made to develop this system in the Python programming language using the IfcOpenShell and pythonOCC modules. The former allows to efficiently parse IFC files and return geometrical definitions as Open Cascade BReps, which can be further manipulated using the Python bindings for Open Cascade, called pythonOCC. The Python programming language further enables the rapid development of such a system.

The functionality in this module is exposed to the end-user by providing an internal REST API. In order to provide a seamlessly integrated experience to the end-user the building model data is automatically replicated between the two environments using a mirroring script.

To further facilitate easily selecting multiple products for substitution, an IFC-based product catalog is available to users. The end-user can pick an element from this set of types when replacing products from another model. Upon synchronizing the data with the main platform, the IFC files are scanned for such instances and recorded in the local database.

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 System. OpenStudio is an open source project which includes graphical interfaces along with a Software Development Kit (SDK).

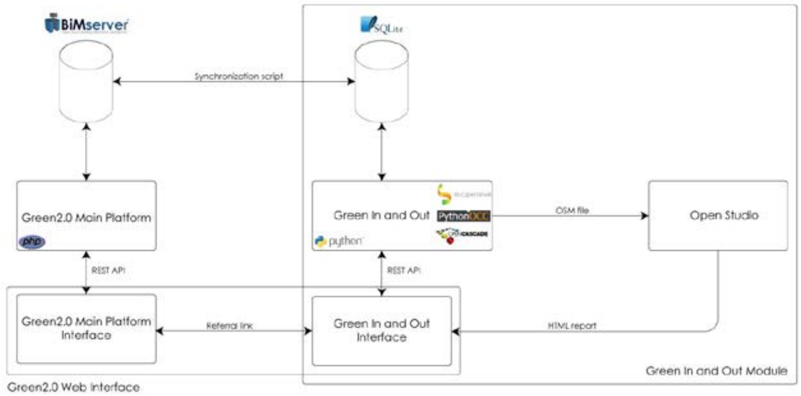


Figure 4: the Energy Analysis Module

The OpenStudio includes visualization and editing of schedules, editing of loads constructions and materials, a drag and drop interface to apply resources to spaces and zones, a visual HVAC and service water heating design tool, and high level results visualization. Radiance can also be integrated into the simulation workflow. This is accomplished by using an annual Radiance simulation to measure daylighting, and then creating an electric lighting usage schedule for EnergyPlus. OpenStudio also gives the modeler integrated access to data from the Building Component Library. The ParametricAnalysisTool lets users modify a baseline OpenStudio model using OpenStudio measures to produce design alternatives. OpenStudio measures are specially formatted Ruby scripts and accompanying files for modifying energy models in OpenStudio or EnergyPlus format. RunManager facilitates queuing and running simultaneous EnergyPlus simulations, and ResultsViewer enables browsing, plotting, and comparing EnergyPlus output time series data.

The BIMServer handles IFC files and can export information in that format (**IFC** files). On the other hand, 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 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.

The geometrical conversion process is executed by a routine in the Green In and Out Module. The module is written in the Python programming language and heavily relies on IfcOpenShell and pythonOCC, for respectively, interpreting the implicit geometry in IFC files as explicit Boundary Representations (BRep), and for manipulating these BReps to conform to the thin-walled thermal zone boundaries expected in OSM file.

In addition to the geometrical definition, Open Studio expects semantical 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 Green 2.0 are as follows:
The administrator should develop a catalog of products
User can select any product to study.
The user can choose any replacement from the catalog for the targeted product
The user must define the usage scenario of the facility (if not already done)
IFC data is then transferred to OSM data
EnergyPlus is then invoked for energy analysis
Results are returned to user.

Module 4: RESTful API Module

One of the benefits of the Software as a Service (SaaS) delivery model is that part of the service's functionality can become available to third-party applications and services through a web application programming interface (web API) and in particular as a more cohesive collection of RESTful web resources. These RESTful web API will be accessible via standard HTTP methods by a variety of HTTP clients including browsers and mobile devices.

The following Figure demonstrates a typical architecture for supporting RESTful APIs in the Green2.0 platform. Third-parties are accessing the Green2.0 REST API by submitting URL requests; our platform performs the necessary computation and compiles a REST answer to the request formatted in a JSON file. Through the API a number of services become available to third-party services, clients and applications.

SUMMARY

We developed a service (SaaS) to support interactions (commenting) by stake-holders of a green facility. All participants (professionals and end-users) can share views. To support testing of different design options, we connected BIM (IFC in particular) and EnergyPlus (through OpenStudio). The proposed algorithms to transfer IFC data into thermal zones represent a novel method to create a link between BIM and energy analysis systems. In combination, the platform allows for iterative and collaborative testing of alternative building design models potentially leading to more informed, more green decisions. At a deeper level, Green2.0 is a manifestation and supportive tool of the opinion that design of green facilities is a socio-technical domain. And that knowledge is an evolutionary social phenomenon: it emerges through interactions between knowledge agents (based on iterative analysis).

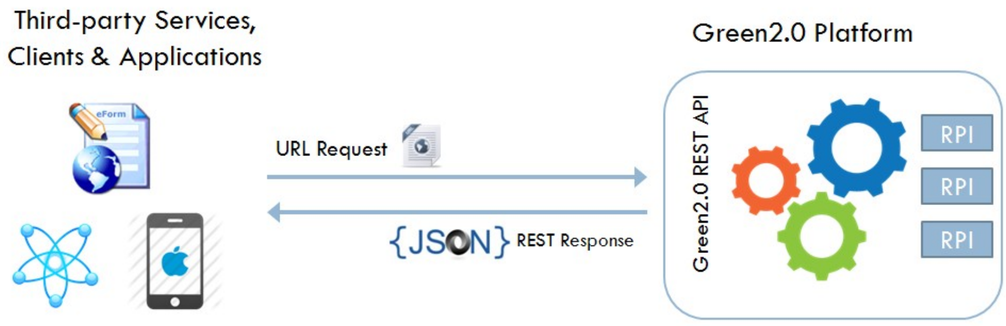


Figure 5: the RESTful API module

REFERENCES

Becerik-Gerber, B., & Rice, S. (2010). The perceived value of building information modeling in the US building industry. ITcon, 15, 185-201.

Bynum, P., Issa, R. R., and Olbina, S. (2013). “Building Information Modeling in Support of Sustainable Design and Construction.” Journal of Construction Engineering and Management, 139(1), 24-34.

Chinowsky, P., Diekmann, J., & Galotti, V. (2008). Social network model of construction. *ASCE Journal of construction engineering & management*.

Corburn, J. 2003. Bringing local knowledge into environmental decision-making: Improving urban planning for communities at risk, journal of planning education and research, vol. 22, pp. 420-433

Di Marco, M. K., Taylor, J. E., & Alin, P. (2010). Emergence and role of cultural boundary spanners in global engineering project networks. *Journal of Management in engineering*, *26*(3), 123-132.

Lakhani, K. R., L. B. Jeppesen, P. A. Lohse, and J. A. Panetta (2007). “The Value of Openness in Scientific Problem Solving. Harvard Business School Working Paper No. 07-050, 2007.

Lakhani, K. R., and J. A. Panetta. (2007). “The Principles of Distributed Innovation. Innovations: Technology, Governance, Globalization, Vol. 2, No. 3.

Pryke, S. (2012). Social network analysis in construction. Wiley-Blackwell

Taylor , J., & Levitt , R. (2007). Innovation alignment and project network dynamics: an integrative model for change. Project management journal.

Van Herzele, A. (2004). “Local Knowledge in Action: Valuing Nonprofessional Reasoning in the Planning Process. Journal of Planning Education and Research, Vol. 24, No. 2,

Wong, K., Unsal, H., Taylor, J. E., & Levitt, R. E. (2010). Global dimension of robust project network design. Journal of construction engineering and management, 136(4), 442-451.

Zhang, J. and El-Diraby, T. E. (2012). “Social semantic portal for coordinating construction communication”, J. of Computing in Civil Engineering, ASCE, Vol 26, No 1.