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BIM-based collaborative design and socio-technical analytics of green buildings

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ABSTRACT

As Building Information Modeling evolves into becoming the central mean for coordinating project design and planning activities, we notice a few limitations/opportunities in the way current BIM tools address the needs for integrated design, collaboration and analysis (the initial objective of BIM). First, substantial communications and interactions about the design exist outside the BIM environment — typically in e-mail formats. This may cause distractions, delays to the project, and could waste valuable knowledge (contained in these interactions). Second, the need of engaging end-users and their keen interest in selecting "green" features. Professionals can develop different designs that achieve varying levels of energy conservation, but these will always require changes based on usage patterns. So, it is important that end-users are involved in the design process early on to make sure that they receive adequate information/ education before they make decisions. This is the nature of limitations that we try to address in this research. This paper builds around the design and development of an online system, named *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 planning, construction and maintenance. Fundamentally, it allows participants (end-users or professionals) to comment and share views about building designs. Social network analysis and semantic modeling tools are then used to extract information from these interactions. At the same time, it connects BIM to energy analysis software to allow users to select different products from a catalog and assess the impact of each on energy consumption. The platform aims to advance the current state of the art by bringing about a fundamental shift in the way that AEC professionals, end-users and public policy makers work together throughout a building's lifecycle. Designed as an open platform, it provides access to information that enables researchers and practitioners to build new, more efficient theories and methods of building design. The premise of our work is that by providing new insights into the building design process it is likely to have a profound beneficial effect for both AEC professionals and the society at large.

1. Introduction

As the world is experiencing a period of extreme urbanization, 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 design. Green building design (or sustainable building design) refers to the process of designing buildings (or other facilities) that are environmentally responsible and resource-efficient throughout a building's life-cycle [23]. This typically requires close cooperation of the design team, the architects, the engineers, and the rest of the stakeholders (clients, manufacturers, contractors) at all project stages. However, current common practice assumes that semantic building model information is typically not existing or not available online (i.e., it lies in local repositories and is typically accessible through proprietary stand-alone desktop software). Moreover, sharing of building project information is either not feasible or done in a way or at a level that is considered inadequate and inefficient, such as through email, paper printouts or other traditional channels of information exchange [2]. Therefore, the scope of collaboration and analysis is typically still limited to single projects in isolation and valuable knowledge about functioning of the various teams is lost in ad-hoc decentralized and traditional forms of communication.

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Furthermore, green building design emphasizes the increasing role of end-users in selecting green features. While the role of end-users is especially important, their early engagement and education is required to overcome adoption barriers [30,64]. As an example, professionals might develop alternative designs that achieve varying levels of energy conservation [24]. But, since these designs always require changes in usage patterns, it is essential that end-users are engaged in the design process early on and they receive adequate information/ education before making decisions [19]. However, current common practice is to perform energy efficiency simulations after the design stage. As such, design-simulation iterations are slow and operate on disjoint models, hampering sustainable design. Therefore, there is need for collaborative design of BIM in an integrated environment — one that can engage not only the professionals, but also non-expert end-users [27].

At the same time, the changing trends in the use of Web technologies that aim to enhance interconnectivity, interoperability and information sharing are transforming the way in which information is accessed and disseminated online [15]. Most importantly, availability of new standards, methods, tools and strategies that are enabled by emerging technologies in the domain of AEC suggest new ways of sharing and working with Building Information Models (BIM). Designing and developing services that provide a data-driven approach to operate on building projects, is therefore, a global imperative and defines a number of research and engineering challenges and opportunities [9].

1.1. Aim and objectives

Our research aims to alleviate the aforementioned limitations of building project design by advancing the state-of-the-art in two dimensions.

1.1.1. Managing interactions “around ” BIM.

We provide means to capture user input by integrating a commenting and annotation tool into BIM technology. Unlike existing tools, the communication model proposed benchmarks social and information network systems and is semantically rich. Recording and tracking comments by all users (professional or non-experts) is coupled with a full analysis of the resulting social and information network structure and data, which allows to understand the social connections between participating stakeholders and the dynamics of their communication. In the era of the knowledge economy, these networks and user-generated data constitute 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.

1.1.2. Linking BIM to sustainability analysis.

BIM models are large and complex-yet they currently have little focus on green-oriented features. The solution is not just to expand IFC (Industry Foundation Classes) 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 third-party building energy analysis software and libraries, such as OpenStudio, without forcing a full merger. Such linkage will make consideration of energy usage easy-allowing for an early-stage and iterative consideration. The bridge developed between IFC and third-party energy efficiency software is not meant to provide a 100% accuracy in analysis (more fundamental and substantial rethinking of product models is needed before that). Rather, we present a novel, easy, scalable method to provide automated, fast and highly accurate means to compare the energy performance of alternative designs and model features. The aim is to provide adequate level of analysis with the end-user as a main target (i.e. we want the end-user to be able to test/ compare the approximate energy performance of two or more alternatives to support their educated-input or decision making).

1.2. Methodology and contributions

This paper builds around the design and development of an online system, named *Green2.0*, that tries to leverage recent advancements in building information models, energy-efficiency simulation tools, and social network analysis methods for enabling online socio-technical analysis of green buildings in *an integrated environment*[20,53]. In particular, *Green2.0* brings about a fundamental shift in the way we investigate and assess green buildings at multiple fronts:

- *Efficient BIM Management*: It consists of an online BIM management system that enables the efficient storage, indexing, querying and visualization of BIM elements on the Web.
- *Online Sharing and Collaboration of BIM*: It provides an integrated environment for uploading, sharing and commenting on building information models. That enables meaningful distributed online communication and collaboration of researchers and professionals of the AEC industry, but also non-expert end-users.
- *Real-time Social Network Analytics*: Mining and analysis of the collaboration data and information networks that become available in the system can reveal interesting patterns of communication. Visualization of these patterns in a meaningful way can help researchers and professionals to identify, re-design and optimize business processes, discover synergies, streamline the workflows of different stakeholders, as well as, to optimize information flow between decision makers.
- *On-demand Energy Efficiency Analysis*: It provides an integrated on-demand energy efficiency analysis for buildings that enables researchers and professionals to better study and understand the complexity of building sustainability, suggest alternatives of design options, and develop new more efficient design processes.
- *Monitoring of BIM-enabled Business Processes*: It provides an integrated environment to analyze and improve industry performance by monitoring, storing and visualizing business processes that occur during the building design and collaboration procedures.
- *A Sandbox for BIM Developers & Researchers*: It provides to researchers and third-party developers access (through a RESTful API) to a repository of (i) building information models, (ii) BIM-related communication and social analytics, (iii) Energy efficiency analysis reports, (iv) BIM-related business processes.

Green2.0 takes BIM from the realm of a stand-alone proprietary software into the realm of a socially-aware collaborative service for decision making. We aim to give people (professionals and non-experts) the controls of BIM software in order to suggest, choose, assess and innovate new means to design, build and operate their facilities.

1.3. Paper organization

The rest of the paper is organized as follows. Section 2 discusses background and related work. Section 3 provides an overview of the system's functionality and high-level architecture. Section 4 presents our approach for managing interactions between buildings and people and our methods for analyzing the dynamics of information and collaboration networks. Section 5 presents a novel method for automating the sustainability analysis of buildings within the context of BIM. Finally, a few extensions of this work are discussed in Section 6. We discuss the significance and limitations of our work in Section 7 and conclude in Section 8.

2. Background & related work

The impact of the AEC industry on the environment is substantial. Manufacturing building materials account for 10% of global energy usage; the operation phase produces at least 30% of all greenhouse gas emissions; and, demolishing buildings is responsible for 40% of all solid