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EXPECTATIONS, REALITY AND PERSPECTIVES IN USING BIM FOR THE GREEN BUILDING DESIGN

OČEKIVANJA, REALNOST I PERSPEKTIVE U KORIŠĆENJU BIM TEHNOLOGIJA U PROJEKTOVANJU ENERGETSKI EFIKASNIH ZGRADA

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Abstract

In the late 1970s when the first programs for building energy consumption simulation appeared, architectural practice was based on paper documentation and 2D drafting programs were considered as state of the art technologies. The requirement for 3D building models for computer-based energy simulation minimized the use of this technology in everyday practice. With the appearance of BIM applications that enable creation of information rich 3D building models, everyone expected that this technology can easily provide all data necessary for energy consumption simulation. Today, the market is full of different BIM related applications that are advertised as solutions for the green building design. The paper gives an overview of energy consumption simulation tools and their connection to two BIM applications – ArchiCAD and Revit and demonstrates that recent development of both technologies does not fully meet expectations. The paper indicates means to avoid overoptimistic expectations from software tools that can help designers to achieve better comprehension of the real merits that BIM can bring to green building design. The paper addresses usability of using BIM for sustainable refurbishment. The paper concludes with the analysis of the Semantic Web technologies which can contribute to a better understanding of simulation results, and can provide more information about energy efficiency of the components used in BIM applications' libraries.

Ključne reči
- Informatičko modeliranje zgrada (BIM)
- simulacija potrošnje energije
- ArchiCAD
- Revit
- Semantic Web

Izvod

Krajem sedamdesetih godina kada su se pojavili prvi programi za simulaciju potrošnje energije, arhitektonska praksa je bila zasnovana na papirnoj dokumentaciji i 2D programima za tehničko crtanje koji su se smatrali najsavremenijom tehnologijom. Zahtev za 3D modelom građevine za izvođenje energetske simulacije na računaru minimizirao je korišćenje ove tehnologije u svakodnevnoj praksi. Sa pojavom BIM aplikacija koje omogućavaju stvaranje 3D modela građevina bogatih informacijama, stvorila su se očekivanja da ova tehnologija može lako obezbediti sve podatke neophodne za simulaciju potrošnje energije. Danas je tržište puno različitih aplikacija vezanih za BIM koje se reklamiraju kao rešenja za projektovanje energetski efikasnih zgrada. Ovaj rad daje pregled alata za simulaciju potrošnje energije i njihovu vezu sa dvema BIM aplikacijama: ArchiCAD i Revit, i pokazuje da nedavni razvoj obe tehnologije ne ispunjava u potpunosti očekivanja. U radu se govori o načinima za izbegavanje preoptimističkih očekivanja od softverskih alata pomoću kojih projektanti mogu da postignu bolje razumijevanje stvarnih vrednosti koje BIM može doneti u projektovanju energetski efikasnih građevina. Rad se bavi upotrebom BIM u oblasti održivog renoviranja. Rad se završava analizom tehnologija semantičkog Web, koje mogu doprineti boljem razumevanju rezultata simulacije i mogu pružiti više informacija o energetskoj efikasnosti komponenti koje se koriste u bibliotekama BIM aplikacija.

INTRODUCTION

The first programs for building energy consumption simulation appeared in the late 1970s. It was the time when the first micro- and personal computers appeared making this technology available to a larger public. Still, the computer performance at that time was limited and 2D drafting programs where considered as state of the art technologies. Since energy consumption simulation applications required 3D computer models of the building, they were rarely used in everyday architectural practice. Despite the development of computer technologies, the situation remained unchanged until the appearance of Building Information Modelling (BIM) applications that enable creation of information rich 3D models of the building. Everyone expected that this technology can provide all data necessary for energy consumption simulation. The software companies developed a lot of external applications, plug-ins, and built-in functions for BIM that are advertised as solutions for green building design. Presumption that BIM will play a central role in the design of sustainable and energy efficient buildings is based on the view that BIM creates information-rich models that contain all data necessary for building design; uses standard data interoperability formats among applications, and that data can be used and updated throughout the life cycle. This position has recently been called into question because the actual operation of the applications does not follow the above assumptions. This paper provides an overview of energy simulation tools and their connection with two BIM applications (ArchiCAD and Revit). The paper points out the means by which overoptimistic expectations can be avoided: (1) the enhanced knowledge of BIM software's core functionality; (2) improved understanding of exact information needs of each particular energy consumption simulation application; (3) knowledge about real abilities of interoperability formats; and (4) attentiveness to the fact that energy consumption simulation applications use simplified building energy models (BEM). Based on these principles, designers can achieve a better understanding of the benefits that can be achieved using information technology in the design of green buildings.

BIM APPLICATIONS

Two most prominent BIM applications on the market are ArchiCAD and Revit. The first developed was ArchiCAD intended primarily for the creation of consistent 2D project documents from the central 3D building model. The core mechanism of ArchiCAD is based on the Geometry Description Language (GDL). It is a BASIC-like programming language that defines parameters, object geometry, user interface, behaviour, and other necessary information of the components. The language is flexible and facilitates description of any geometry, addition of custom parameters, and even creation of custom user interface. Since the GDL supports modification of the component during the process of parameter instantiation and later inclusion and adaptation of the component to fit the whole model, the designer's experience resembles virtual construction or mock-up making.

The Revit is an application designed with the 3D model in mind, intended to provide the solution to the problem of effective revision update. It uses a core mechanism that is based on relations among elements to enable quick propagation of changes from one component to all related components. To achieve that functionality, the components that are part of the application's library are predefined as families. If a component is missing in the library, the designer is free to create a custom building component by choosing a family that suits her/his needs and adapts it. Since the application controls all relations among components each time some modification is done, the modelling is reminiscent of the machine behaviour.

ArchiCAD and Revit applications use two different core mechanisms to accomplish similar tasks and their native models significantly differ. Some of the functionality that exists in the first model is completely lacking in the second model. As a consequence, the designer cannot create building models using the same modelling logic with both applications. That means that instead of having one principle of how to proceed with green building design using a BIM technology in reality, the designer has to face two diverse processes.

ENERGY CONSUMPTION SIMULATION APPLICATIONS

Today, the market has a lot of applications that allow simulation of energy consumption of the building, /1/. They can be classified into three different categories. The first class includes energy simulation engines. Those are the oldest applications developed to provide accurate standardized implementation of computational algorithms for energy consumption calculation. They use specialized input files and require the use of expert knowledge. Two frequently used energy simulation engines are DOE-2 and EnergyPlus. The second class of applications consists of energy simulation systems. Those applications build user-friendly interfaces around energy simulation engines to enable wider adoption of the technology. that enables users to comfortably enter necessary data and to get understandable interpretation of simulation results. These applications include IES-VE, eQUEST, OpenStudio, DesignBuilder, Green Building Studio, IDA ICE, RIUSKA, etc. The third class contains plug-ins and built-in simulation engines specially designed for BIM applications. They are designed to collect necessary data from BIM models without much user intervention and to seamlessly transfer them to the energy simulation mechanism. Most prominent example today is EcoDesigner.

The DOE-2 is a freeware building energy analysis program that is widely used in practice, /2/. The DOE-2 engine simulates thermal behaviour of spaces by calculating solar gain, equipment loads, people loads, lighting loads, and air conditioning systems loads, and then summing them up to determine heat loads in a building. The system bases its calculation on the fairly simplified building geometry. The data entered by the user is combined with the materials, layers and construction library to form Building Description Language (BDL) input file. The input data is then transformed into a computer readable format using BDL processor and that information is later used by the four sequentially executed simulation modules: LOADS, SYSTEMS, PLANT and ECONOMICS. The EnergyPlus is an energy simulation engine that gives more accurate predictions of temperatures in spaces and a better estimate of various resulting parameters, such as thermal comfort. The algorithm relies on the integrated approach that includes both loads and systems simulation, /3/. The application uses text based input files. The load calculations are based on AHSRAE's heat-balanced-based approach. EnergyPlus supports calculation of the inter-zonal airflow, moisture absorption and desorption, and enables definition of more realistic HVAC system controls and radiant heating and cooling systems. The results are more detailed and reliable for most of the simulated buildings and systems compared to older application, like DOE-2.

The IES-VE is based on proprietary Apache dynamic thermal simulation engine (ApacheSim). The system represents a set of integrated analysis tools intended to provide comprehensive energy analysis in all design phases, including program and concept stages. The application provides extensive connectivity to a large number of modelling applications like SketchUP, VectorWorks, Revit, etc., using dedicated plug-ins, IFC, or gbXML files. Dedicated application modules enable the designer to analyse possibility of using day-lighting in the building, investigate the effectiveness of natural ventilation, and conduct either steady-state or dynamic analysis of energy consumption and indoor thermal conditions. To enable better understanding, of the all results are shown graphically, but a meaningful interpretation of the results requires knowledge of building physics. The eQUEST is a freeware building energy analysis tool based on improved building energy simulation algorithm, derived from DOE-2.2. The application combines a building creation wizard, an energy efficiency measure wizard, and a graphical results display module into a single design environment. The eQUEST allows designers to generate multiple simulations and to compare alternative results in side-by-side graphical charts. Using the program, the designer can achieve energy cost estimation, control daylight and lighting systems, and automatically realize the implementation of energy efficiency measures, /4/. OpenStudio is an open source assembly of software tools created to enable the designer to comfortably achieve whole building energy modelling and advanced daylight analysis using EnergyPlus and Radiance applications. The application's graphical interface enables the designer to visualize and edit schedules, edit construction loads and materials, to use drag and drop interface to assign resources to spaces and zones, to use a visual tool to achieve HVAC and service water heating design, and provides the designer with high level results visualization. The results of the electric lighting usage obtained with daylighting simulation can be included in global energy consumption calculation. The system uses the EnergyPlus engine to accomplish energy consumption, carbon emission, and room comfort simulation on different time intervals. Additionally, the system also reports solar gains, surface temperatures and radiant exchanges. The ResultsViewer module enables browsing, plotting, and comparing obtained output time series data. The creation of the building model can be achieved by using the custom DesignBuilder module or by importing existing BIM models. In addition to the energy consumption simulation the designer can use the system to achieve passive performance assessment of the building and can use it for sizing of heating and cooling systems. The Green Building Studio (GBS) is a commercial web-based application designed to provide whole building energy analysis and to forecast resources consumption. All results and estimates are given in tabular report form that enables comparison between different alternatives. All necessary information regarding a building model is imported using a gbXML file format. The application uses DOE-2 core engine to perform whole building energy analysis and calculate carbon footprint. Additionally, by using the software, the designer can consider design alternatives to improve energy efficiency, evaluate correspondence of the solution to the LEED certification requirements, estimate water use, and summarize natural ventilation potential and photovoltaic potentials. All results can be exported from the application to DOE-2 and EnergyPlus custom file formats enabling further analysis using those tools. The IDA Indoor Climate and Energy (IDA ICE) is a commercial application for simulation of building energy consumption, and the estimation of indoor air quality and thermal comfort. The application covers a wide range of phenomena, from the thermal models and integrated airflow network, through CO_2 and moisture calculation, to the vertical temperature gradients. The application uses the Neutral Model Format (NMF), a program-independent language for modelling dynamical systems using differential algebraic equations to provide description of all components that are part of the application's library. The IDA ICE is a general-purpose environment that provides system specific components - translator, solver, and modeller that enable the designer to create the model and perform an energy consumption simulation, /5/. RIUSKA is a tool designed for the dynamic simulation of energy consumption and estimation of comfort in building. It is intended for use in services design and facilities management. The application uses the DOE-2 simulation engine as the core software mechanism. The RIUSKA uses IFC file as the primary format for storing data on the building model. The designer can calculate inside temperatures and heating and cooling loads of individual spaces and to estimate the energy consumption of the whole building. Additionally, the application can be used to dimension and compare HVAC systems. The simulation data generated by RIUSKA can be saved in a database for the use in the lifecycle data management.

The EcoDesigner came into existence as the ‘one click’ plug-in for the ArchiCAD application enabling instant energy evaluation directly from the BIM model. Starting with the version 16, it was branched in two parts, the built-in Energy Evaluation service and external EcoDesigner STAR plug-in. This version required from the user to allocate all spaces in the project to the specific zones, and from version 17 additional requirements are introduced, that all zones need to be allocated to appropriate ‘thermal blocks’, enabling vertical grouping of spaces. The application uses the VIPCore calculation engine as the core mechanism. The application takes information about spaces, openings and materials from the ArchiCAD model and information about the project, like: location; MEP system; energy type; and availability of green energy systems must be manually provided. Using provided structural and opening lists, the designer can assign new values for all components that are automatically retrieved from the building model. If the U-values inferred from the model are incorrect, proper heat transmission coefficient values can be established using the built-in U-value calculator. From version 17 of the application, additional functionality is introduced, enabling the designer to calculate solar irradiation for each individual opening in the building envelope. The algorithm also takes into account elements from the environment, like adjacent buildings and trees, even making distinction between evergreen and deciduous plants when calculating solar gains during winter. All results from the simulation are represented as charts or tables that can be saved as XLS or PDF file and include data on yearly energy consumption by sources and targets, CO_2 emission, and monthly energy balance.

BIM AND BEM: MODELS, INTEROPERABILITY AND LIFECYCLE

For a long time researchers in the field of computer application in architectural design reflected on the unique information building model, /6/. With the advent of BIM technology and the IFC standard that enumerates all information necessary for computer-based building information model it appeared that *dream become true*, /7/. The BIM models contain all necessary information to describe a building-like geometry of all components, materials from which they are composed, spaces and zones formed inside the building components, their occupancy type and daily schedules. The first BIM applications and related models were conceived to help designers to create construction documentation, not to perform energy simulation. Consequently, BIM models contain a large amount of information that is either too complex or not necessary for the building energy consumption simulation applications. Detailed 3D building models that lie at the core of each BIM model were scarce at the time when most energy simulation algorithms were developed. For that reason, simulation algorithms were developed to use simplified models based on extruded prismatic building volumes. Through time, algorithms based on simple geometry models were refined and had achieved a level of high-quality forecasting. Consequently, simplified geometry models became standard models for energy consumption analysis and, coupled with other information-like weather data, location data, occupation data, etc. represent the Building Energy Model (BEM).

The problem of coordinated and seamless transition of information between AEC software applications has long preoccupied experts and as a result, appropriate interoperability formats have been developed. Industry Foundation Classes (IFC) is an object-oriented data model developed to attain highest level of interoperability in AEC, /8/. The IFC defines classes necessary to represent all concepts related to the building during its lifecycle. At the moment IFC is the international standard for data exchange in the whole AEC industry. The Green Building XML schema – gbXML, /9/, is developed to facilitate data exchange between digital building models and energy analysis tools. It is a language based on Extensible Markup Language (XML) that contains specific sets of definitions and data requirements focusing on sustainability analysis. Contrary to IFC that supports complex geometry description, gbXML deals only with spatial volumes and thermal zones with simple boundary surfaces. For that reason, BIM application supporting gbXML must transform its complex geometry models to a required simplified form. The process of transforming BIM model to a BEM model is not straightforward and requires many specific operations. The first step is the transformation of the BIM's complex geometry to simple BEM geometry. This task can be achieved by using BIM objects like spaces and zones. In order to achieve exact BEM model, the spaces and zones must be precisely defined within the BIM application, a task that is not supported as default BIM behaviour and requires many modifications, depending on the energy simulation application to which data is exported. The process of BEM model creation is further complicated by the fact that both interoperability formats define only standard structures for data interchange, but do not define what information is necessary to include in the file. The experts developing the IFC standard have recognized this problem and a solution is given in the form of Model View Definitions (MVD) but MVD for BIM to BEM transfer is still not defined, partially because the IFC format does not support climate data, material data, and prefabricated components. Because neither one interoperability format defines the necessary information content, once the model is successfully imported into the energy consumption simulation application, it is necessary to find what information is missing or misinterpreted and to provide proper values. The energy efficient building design by using BIM and BEM models is additionally complicated with the fact that information flow between BIM and BEM is unidirectional from BIM applications toward energy simulation applications, and that the results remain connected to the BEM model. Most often the designer gets only the numerical results and charts, and if the energy simulation application provides mapping of the results on the building model, that mapping is performed against simplified BEM geometry. The designer who wishes to design energy efficient building is forced to base her/his decisions on the interpretation of the BEM model while he is performing design decisions in the BIM environment. The interpretation of the obtained results requires expert knowledge of particular energy simulation application. Additionally, since the results are tied to the BEM model, the designer working in the BIM environment does not receive any feedback on how to improve her/his design to achieve more energy efficient building. She/he cannot get any response on how to improve the building's form, select more appropriate building components, or choose efficient building systems. All these decisions are still based on the designer's experience and intuition.

The problem with complex BIM models can be avoided by using applications that generate simple geometric designs, by sketching building form and connecting them to energy analysis tools. A most notable example is the SketchUP application that provides many energy analysis extensions. Recently, a cloud-based application Formit 360 appeared on the market that enables connection of sketching tool to EnergyPlus engine. Unfortunately, since sketching tools do not provide sufficient data, applications make many assumptions about the building model which are not often consistent with the designer's assumptions. In essence, on the current level of development, it is not possible to perform free object modelling and verification of its energy efficiency using these applications, but the object must be modelled in accordance with the assumptions of software producers.

The rarely considered problem associated with the use of BIM technology in energy efficient design is the consistency of results during a particular period of time. Results obtained with different versions of the same application show considerable variation, /10/. Also, to achieve greater efficiency and to support new functionality, BIM models are changing every year with each new version of a BIM application. This trend characteristic of the software industry does not comply with the AEC industry. The duration of an AEC project can spread for several years and during that time several new software versions can appear. Often models from earlier version are not fully compatible with the new version, and in the course of few years the old models can become unusable. The problem of obtaining the same simulation results over several years is aggravated by the fact that during a time some plug-ins or applications can be discontinued. This poses a problem how to reuse the older models, and how to obtain again the same results which were previously used to obtain certifications. It is clear that the issue of sustainability and lifecycle management should be extended to the digital building models.

DESIGNING NEW BUILDINGS AND BUILDING REFURBISHMENT IN BIM

The assumption that BIM brings consistency in the green building design process is further weakened by the fact that different core mechanisms of BIM applications dictate special mutually incompatible element libraries for each application. Building component manufacturers that recognise BIM importance are developing libraries of their components for each BIM application. That way, when designing new buildings in BIM applications, the designer can expect to find accurate information relevant for energy consumption simulation already included in BIM components. Contrary, when creating BIM models of already built facilities, the designer has to use generic building components and later to provide all information related to the energy consumption simulation. That way, it is hard to guarantee that the calculated energy consumption of the old building is precise, and that the calculated savings after refurbishment correspond to actual values. Concluding, using a BIM only to calculate energy savings after refurbishment is not effective at this level of BIM development.

The energy efficiency of modern buildings increasingly depends on active saving technologies and complex installations designed to realize those savings. Unfortunately, import routines of most current energy consumption simulation applications do not take into account any information about installations designed using current BIM applications. That way, all precisely modelled information about active energy saving technologies created in BIM application must be reinterpreted and manually entered into an energy consumption simulation application which greatly reduces the accuracy of calculation and reduced usability of BIM technology in green building design.

SEMANTIC WEB TECHNOLOGY

The Semantic Web is technology created to provide universal knowledge representation for information available on the Web, /11/. The technology uses layered structure of representation standards. Upper layers exploit functionality of lower layers and provide greater semantic expressiveness. The whole technology is based on XML language, and regular XML expressions constitute the lowest level. Meaning is expressed in the next layer using Resource Description Framework (RDF) that represents information about entities (resources) on the web using triples to define that a particular thing has a property with a particular value. Subjects, predicates, and their values are identified using the Universal Resource Identifier (URI), ensuring that concepts are not just bare terms, but are connected to unique items on the Web. When multiple triples point to the same resource, they start to form a network of information. The next level of semantic expressiveness is achieved with the ontology. Ontology is identified as the formal representation that defines relationships among terms. The lower level of ontological functionality is achieved with the RDF Schema (RDFS). RDFS allows declaration of classes, subclasses, property, and subproperty relationships among resources using RDF triples. The Web Ontology Language (OWL) provides the highest level of ontological functionality at the current level of technology development. It is a family of languages based on two semantics. The first one is based on Description Logic semantics that guarantees completeness of reasoning and is implemented as the OWL Lite and OWL DL languages. The second, OWL Full, does not support complete or efficient reasoning but provides maximum expressiveness and the syntactic freedom of RDF. The language supports constructs like class, property, property restrictions, Boolean combinations, enumerations and instances. OWL users can express and test knowledge using a wide range of services like reasoners and editing tools developed in connection to this formalism.

The lack of ability to link information into useful aggregates is recognized by researchers and the extension of IFC format with Semantic Web technologies is under development in the form of ifcOWL ontology, /12/. The ifcOWL is designed to enable creation of Linked Data structures about buildings. That way, information from existing IFC models can be connected with information from diverse external sources like climate data or information about building products. The HESMOS project, /13/, takes a similar approach by associating the BIM model with external resources with the help of a dedicated RDF-based Link Model. That way, a multi-model framework is created enabling holistic building's energy efficiency simulation and lifecycle management.

The recognition of components appropriate for energy efficient design before the modelling process starts is another promising terrain for the application of Semantic Web technology. At this time the designer searching BIM object libraries can find filters based on software platforms, types of component, component brands, but cannot find any indication of the component's energy efficiency behaviour. By linking BIM libraries with product catalogues and results of energy consumption simulations, the information on component's energy efficiency can be obtained prior to modelling and the simulation process.

CONCLUSIONS

The connection between BIM technologies and energy consumption simulation tools is not seamless and efficient at this moment. The assumption that BIM is a technology that automatically supports green building design can lead to disappointment and rejection of technology. At the present level of development, a good knowledge about particular BIM application and energy consumption simulation tool is necessary to define accurate design workflow. The designer need to take active interest in the development of software applications and to follow all advances in BIM standards and their implementation in applications to ensure prolonged validity of BIM model and obtained simulation. Following these principles, designer can merit from using BIM for green building design.

BIM technologies coupled with energy consumption simulation tools at the current level of development support linear design progression from model toward simulation results. This way the designer lacks feedback information from simulation which could help her/him to improve the design. The Semantic Web technology is the prime candidate for modelling a feedback flow of information. The fact that all interoperability formats are either based on XML language or have XML-based variants like ifcXML, makes this assumption more credible. The knowledge about how to use individual BIM components for the design of energy efficient buildings can be achieved by linking results of simulations to BIM components used to create the building model. Also, information from built buildings could be linked to BIM models. This could be achieved by tagging all physical building components using some technology (e.g. RFID) and by equipping all building spaces with monitoring equipment. That way a real building's energy performance could be linked to the building's information model using Semantic Web technology. This will establish a continuum between the design phase, construction and building maintenance, by creating a comprehensive knowledge about how particular building components, IT building models and energy consumption simulation tools can be used to achieve real energy efficiency.

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