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BIM: PROMISES AND REALITY

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The building information modeling – BIM is a technology developed toward creation of computer based information model that encompasses whole building lifecycle. Toward that goal a number of information technology standards have been developed that enable different professions in AEC to cooperatively develop electronic building model. The paper gives overview of essential technologies, discusses their intended purpose, and gives outline of the currently achieved functionality.

Key words: Building information modeling, BIM, Open Standards, intelligent parametric elements, building energy simulation.

INTRODUCTION

Building information modeling – BIM is a collection of computer based technologies developed to support creation of electronic building model that contains definitions of all physical and functional features and required performances of building's elements and ensembles. The model includes information describing whole building lifecycle from conception, through design and construction, to facility management. The BIM is not conceived as a single monolith data repository; instead, it includes variety of programs and associated data representations relating to different disciplines, comprising architectural, engineering and construction (AEC) industry. The buildingSMART international alliance was conceived as a driving force in the development and proliferation of open interoperability standards that will provide seamless transfer of information among BIM applications. Up to now, three standards have been developed: Industry Foundation Classes – IFC, BuildingSMART Data Dictionary – bSDD (previously International Framework for Dictionaries – IFD), and Information Delivery Manual – IDM. Together with existing commercial BIM applications these technologies aim to replace traditional architectural and construction paper documentation with the computer based information model. The paper gives overview of essential technologies, discusses their intended purpose, and gives outline of the currently achieved functionality.

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BUILDING INFORMATION MODELING

The term Building information modeling (BIM) denotes a process of using information technology (IT) to model and manage data encompassing whole lifecycle of the facility (Lee *et al.*, 2006). The technology is inspired by years of research on a general data model for AEC (Eastman *et al.*, 1991; Björk, 1989), but does not follow established principles rigorously. The BIM design process means to build a facility virtually, prior to constructing it physically, in order to simulate and analyze potential impacts and work out possible problems. It is easier to fix a problem by moving element with a mouse on a computer than to demolish and rebuild elements on a construction site.

On the surface, all BIM applications implement same process. The designer selects building elements from the library of parametric three-dimensional (3D) components. The BIM components are based on principles of parametric geometry modeling (Petruševski *et al.*, 2010) with further advancements beyond mere geometric construction. Each component contains parameters describing its geometry and all intrinsic physical and functional properties. Additionally, each component contains rules that describe constraints, behavior, and relations to other objects. The BIM modeling process starts with the selection of appropriate parameter values that describe actual design situation and continues with the selection of appropriate location of the element in the building model. Finally, according to defined rules, the element is integrated in the model (same materials in the joint elements are merged, parts of the element that become surplus in the model are trimmed, etc.). The reliance on the element libraries is the main characteristic of the BIM software. Before any actual modeling is initiated the designer is forced to think about required elements. Thus, the greatest burden in the process is shifted toward initial design phases and to the preparation of necessary information required to define building elements. That way system prevents inclusion of undefined elements in the model and prevents unforeseen work and costs that in traditional practice can often be detected only during construction phase. The elements also prevent information redundancy in the model. Once an element becomes a part of the building model all future operations refer to that unique data structure. All graphical representations (layouts, sections, perspective view or virtual reality walkthrough), project schedules or simulations use that single data structure to create required representation.

Unfortunately, this basic operation mode is all that is common to commercial BIM applications. The actual functioning depends on the core mechanism that each particular application

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uses. The ArchiCAD is the oldest BIM implementation that appeared in 1987 and proclaimed the 'Virtual Building' concept. The core mechanism of the ArchiCAD is based on procedural modeling language – GDL (Geometric Description Language). Each element is defined as the GDL script that identifies 3D geometry, ways that 3D model maps to 2D representations, user interface display, behavior and listing quantities. The language is flexible and enables definition of any conceivable building element. On the other hand, the language does not provide any constraints, so each element can have its peculiar modeling process and user interface forcing a designer to learn to use each particular element from the library correctly. The Revit is the newer application that has in its core the parametric change management engine. The mechanism updates whole building model on each modification according to inter-element relationships. The elements are classified in predefined families. Each family has user selectable predefined rules that define how the element in the family relates to other elements. According to those rules each change in the element is propagated to other elements, and all related data are updated to appropriate values. A new element in the library can be created only by modifying existing families. That limits the scope of geometric forms that can be used in the model, but provides consistent behavior and user interface to all new elements reducing the need for learning how to use them. The characteristic that each Revit element belongs to a predefined family enables management of data both on element and class levels, enabling the user to change parameters belonging to all elements belonging to the same element class rapidly.

Based on these core mechanisms software manufacturers have developed a range of applications that cover different AEC fields. The MEP Modeler from Graphisoft is the ArchiCAD plug-in that enables model-based MEP networks (ductwork, pipework and cabling) design. The EcoDesigner is the built-in building energy modeling application that calculates building's yearly energy consumption by sources and targets, CO2 emission, and monthly energy balance. The Autodesk offers Revit as the single application that incorporates features for architectural design, MEP, and structural engineering and construction from the version 2013. The range of cloud services offers further analysis of basic Revit models, like Energy Analysis for Revit and Green Building Studio for energy analysis and Structural Analysis for Revit. Both software manufactures offer different partner solutions that cover a broad range of AEC applications compatible with basic modeling applications.

OPEN BIM STANDARDS

The commercial BIM applications use proprietary data formats to represent building models, thus keeping all information locked in distinct software. The proliferation of BIM technologies has raised question of interoperability and public availability of BIM models. This objective is covered by the development of open BIM standards.

The largest open BIM regulatory body is the BuildingSMART, a neutral, international and not-for-profit organization supporting open BIM. Under their supervision three open standards are developed: the Industry Foundation Classes (IFC) data model, the Information Delivery Manual (IDM) data exchange protocols, and the buildingSMART Data Dictionary (bSDD). IFC is an object oriented data model under development since 1996 with the aim to attain highest level of interoperability in AEC industry on the level of data exchange. The currently available version is 4 (IFC, 2013), registered as the ISO 16739:2013 standard (ISO, 2013). The IFC comprises of class definitions representing not only physical components of the building, but also actors and their roles, time, price, approval, etc. The standard provides data interchange without information loss among all AEC applications, unified model-based description of all building components and relationships with other components, information on the graphical representation of components, link to property and classification data, and access to external libraries. Currently, all BIM applications support import and export of their models using the IFC standard format. Since the IFC includes all conceivable building data, and often provides different representations for the same data, it is necessary to define when and what amount of data is necessary to establish effective communication among different participants in the design and construction process. The IDM standard is developed to achieve that goal. It is registered as the ISO 29481-1:2010 standard (ISO, 2010). The IDM provides the reference for process and data requirements in BIM by identifying the distinct procedures undertaken within AEC processes, the information required for their execution, the results of that activity, and how the information should be supported by software solutions. The first result is the IFC2x3 Coordination View Version 2.0 Certification process (buildingSMART, 2010) that strictly defines the scope of IFC data needed to establish seamless exchange of the coordination model among BIM applications. The certification process is accepted by all major BIM software developers and in the 2013 BIM applications received first certifications. The bSDD standard (formerly International Framework for Dictionaries – IFD) is the classification system for all information in the AEC/FM field. It is an object-oriented framework that defines objects, collections and their relationships. The standard is registered as the ISO 12006-3:2007 standard (ISO, 2007). It is intended to work as the overarching structure that will provide support for the development of the unified AEC/FM vocabularies at the national, regional or domain levels. Since all share the same structure it will be possible to translate terms between languages and domains, preferably using automated software agents. The bSDD standard provides the capability to define context within which a concept is going to be used. Each object can have multiple names providing for the definition of synonyms or usage in different languages.

The second type of AEC interoperability formats has been developed based on the free open standards eXtensible Markup Language (XML) (Harold and Means, 2004). The XML enables the structured representation of any kind of information by the insertion of tags in the traditional text, but does not provide any mechanism to infer the meaning of the terms used in tags. One approach to the definition of a tag's meaning is the XML schema. It is a language that provides a description of a type of XML document, usually articulated in terms of constraints on the structure and content of related XML documents. Many schemas have been developed for the AEC/FM field. The gbXML (Green Building XML) schema is used for describing data relating to the building energy efficiency and its impact on the environment. The aecXML schema is used for depicting all building data in design, engineering and construction disciplines, and the CityGML schema is used for geo-spatial data representation. Also, the IFC data can be represented with the ifcXML schema. The commercial BIM applications support most XML schemas, but without strict import/export functionality examination.

BUILDING MODELING

The current BIM technology is based on implementations that use diverse core mechanisms and intrinsic element libraries. The ArchiCAD uses mechanism oriented toward geometry, while Revit is built around change management engine. Despite some differences in the basic geometry modeling algorithms it is possible to transfer any geometry between applications. But since two applications differ in the ways geometric relations are implemented, elements often lose some of the modeling capabilities when exported to another application. Also, ArchiCAD lacks most of the inter-element relations that Revit implements. For that reason, the ArchiCAD and Revit element libraries are incompatible. This fact causes many discrepancies in the basic modeling process when using different BIM applications.

Because ArchiCAD uses GDL scripts to represent library elements it is easy to generate object's geometry on the fly and to illustrate each change of the object's parameters. That makes ArchiCAD's interface user friendly and supports effortless learning how parameter's change affects object's shape. The drawback is that object's level of modeling detail and amount of supporting information depends on the effort that programmer put in the development of the GDL script. On the other hand, the objects in the Revit are completely constructed only after their location in the model and propagation of all inter-object dependencies. For that reason, the Revit's user interface shows only basic object's representation and the designer can understand how parameter's change affects whole object only after actual location in the model. That makes Revit difficult to learn and requires experience with objects and their parameters for masterful modeling. But once learned, the same principles apply to all new objects.

The Revit has predetermined modeling sequence that depends on predefined relations among families of elements. For example, floor can not be constructed before surrounding walls are created. That means that the designer should learn the whole modeling process before starting actual modeling. The ArchiCAD does not impose any modeling sequence enabling learning by doing and facilitates experimentation in the modeling process. The modeling rigidity of the Revit has its advantages in the design modification. All relations established during model creation will be preserved during modification. For example, if the wall is moved, all connected walls will adjust their lengths to preserve established connections, and all appliances connected to the wall will be moved together with the wall. The staircase will automatically change number of steps and their dimensions to suit new floor height. The ArchiCAD will move only imbedded objects, like doors and windows, together with walls, while all other necessary modifications require user intervention (Figure 1).

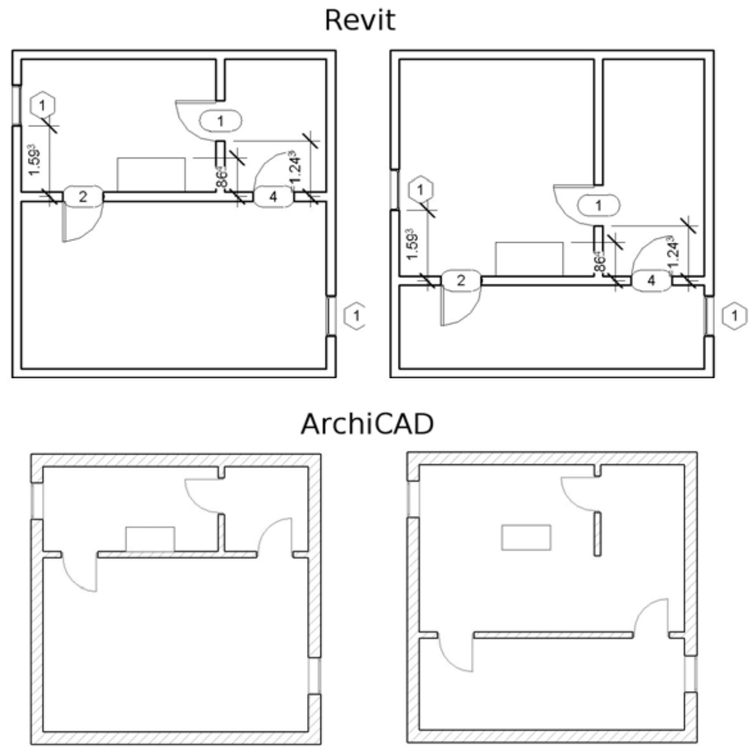

Figure 1. Example of automatic preservation of relationships among building objects in Revit and ArchiCAD

BUILDING SIMULATION

Prior to the development of BIM technology, the building simulation was considered as extremely information demanding and time consuming process reserved for outstanding buildings. Today, when models created with BIM applications contain geometric and parameter representation necessary for simulations, it looks like BIM technology is natural companion to building simulation applications. Among different simulation disciplines the design of sustainable buildings and building energy simulation gain most interest.

A lot of commercial and free energy simulation applications are available on the market (Jarić *et al.*, 2013). They can be divided in three groups: energy analysis engines, energy analysis environments, and built-in analysis applications. The energy analysis engines are oldest developed applications and contain basic computer implementations of the energy analysis algorithms. They read input information and write results in the form of the custom formatted text files. The main concern in their development is the accuracy of the implemented algorithms. The prominent engines are DOE-2 and EnergyPlus, both freeware applications. The energy analysis environments are developed to offer user friendly interface to the energy analysis engines. They enable the designer to graphically construct building model or to use standard interoperability formats to import models from BIM applications. Some also enable export of files for further analysis. The well-known free energy analysis environment is eQUEST and among commercial applications the notable are Green Building Studio, Ecotect Analysis, Virtual Environment (IES-VE), IDA Indoor Climate and Energy, RIUSKA, etc. The built-in analysis applications are developed for the use inside the existing BIM applications with the intention to provide instant energy analysis. The whole process of transferring data from the BIM model to the energy simulation is hidden from the user and only final results are provided. Two existing built-in applications are Energy Evaluation in ArchiCAD and Conceptual Energy Analysis Tool in Revit.

The major weakness of the current energy simulation applications is that they were developed before BIM technology, when computer based information about building was scarce. Each simulation has developed simplified building representation to cope with the lack of data and whole computation algorithms are based on those energy models. Today, when BIM applications offer detailed computer based building information, it is necessary to translate this detailed model to the simplified energy model. Often, dimensional accuracy required in the BIM model for construction purposes is too complex for analytical purposes, and adjustments are necessary to produce simplified analytical model. Also, terms of nomenclature and the definition of various parameters differ among BIM applications and analytical software. Neutral file formats like IFC and gbXML enable transfer of the data between applications but the content of the data depends on the actual simulation applications. Each application requires distinct set of data, and still there are no attempts to define standard set of data for all simulation applications. Also, there are no predefined criteria on the material and section profile names in the BIM libraries, and in the case of ArchiCAD they can vary between different implementations of the same building elements.

The results of building energy simulation applications include yearly energy consumption by sources and targets, CO_2 emission, monthly energy balance, etc. Often, simulation results are represented as charts or tables (Figure 2). Most applications aim to provide precise prediction of energy consumption and building's environmental impact in accordance with recent regulations (Pucar and Nenković-Riznić, 2007). This information is valuable for investors and regulation bodies, but has little impact on design process. The information how to build sustainable building is still based on the designer's knowledge, not on the results of the simulation software.

CONCLUSIONS

Most commercial brochures and a lot of research papers describe BIM technology as the compact activity with common practices. The research and educational communities recognized potential of BIM technologies to unite AEC stakeholders around unified building information model (Aranda-Mena *et al.*, 2008). Based on this recognition, researchers attempted to define how the IFC can be used as the unified nonproprietary format that provides seamless interchange of the building model among AEC professions and to define what kind of paradigm shift is needed in the AEC business processes for the full BIM adoption among practitioners (Arayici and Aouad, 2010). But AEC industry remained insensitive to BIM promises mainly because neither IFC nor other BIM formats provided mechanism for the identification of information authorship, and consequently responsibility for validity of information in BIM models.

The still dominant view of the BIM as the cohesive technology gives the idea that choice between competing commercial applications is the only concern of the future BIM user. This may be true in some distant future, but recently the BIM technology is a set of diverse and sometimes even incompatible software solutions. Also, on the current level of development, BIM is more appropriate for large companies that have architectural, engineering and construction teams, and internal IT departments. Medium and small architectural companies have more difficulties in adopting BIM technology (Coates *et al.*, 2010) and since they don't represent majority of BIM technology users, the new BIM development is directed toward large AEC companies and professional BIM services.

To use BIM technology properly on the current level of development, the designer needs to have good knowledge how the functioning of commercial BIM application fits actual design processes in the bureau (Arayici *et al.*, 2011). It is necessary to test how libraries of building elements and procedures for the creation of new elements fit actual components used in the everyday design. Furthermore, it is important to establish if the design process involves more creation of the new building components, or the modification of the existing ones. The best way is by conducting pilot projects with actual designs and different BIM applications. The

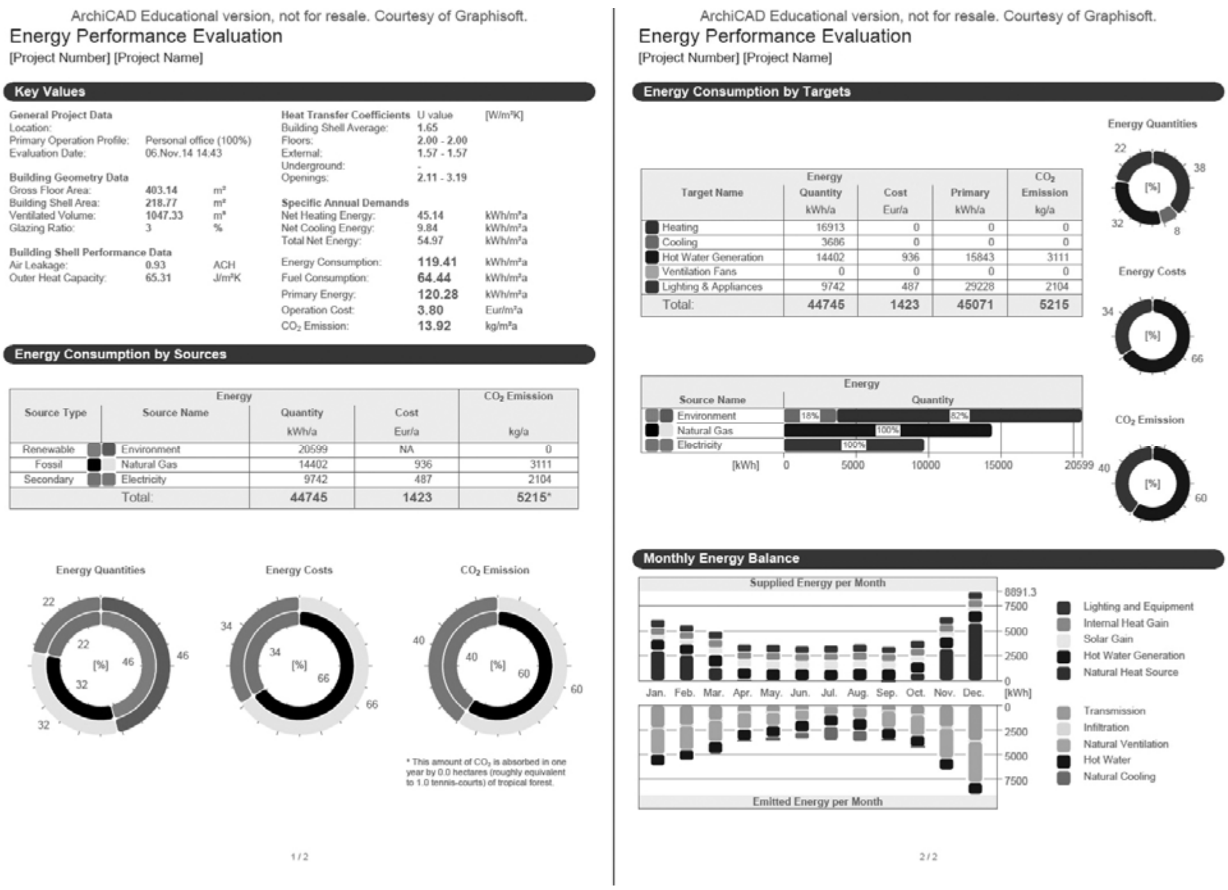

Figure 2. Example of typical results obtained by building energy simulation applications

decision on proper BIM technology also depends on other stakeholders in the design, engineering and construction process, and the tools they use in their business. It is not enough to determine that different applications import and export same data formats, but to understand the actual implementations.

On the recent level of development, the BIM technology is not a miraculous tool that solves all problems in the AEC industry. This is not the reason to reject this technology and to wait until it reaches levels of greater maturity. It should be adopted with the understanding of current limitations, and only when more designers start to require increased functionality from the existing BIM applications can we expect that developers will provide better software.

References

Aranda-Mena, G., Crawford, J., Chevez, A., Froese, T. (2008) Building information modeling demystified: Does it make business sense to adopt BIM?, in Rischmoller, L. (ed.) *Improving the management of construction projects through IT adoption*, Santiago Chile: Universidad de Talca, pp. 63-76.

Arayici, Y., Aouad, G. (2010) Building information modeling (BIM) for construction lifecycle management, in Doyle, S.G. (ed.) *Construction and Building: Design, Materials, and Techniques*, Hauppauge NY: Nova Science Publishers, pp. 99-118.

Arayici, Y., Coates, P., Koskela, LJ., Kagioglou, M., Usher, C., O'Reilly, K. (2011) Technology adoption in the BIM implementation for lean architectural practice, *Automation in Construction*, Vol. 20, No. 2, pp. 189-195.

Björk, B-C. (1989) Basic structure of a proposed building product model, *Computer-Aided Design*, Vol. 21, No. 2, pp. 71-78.

BuildingSMART (2010) IFC Certification 2.0 procedure, http://www.buildingsmart-tech.org/certification/ifc-certification-2.0, accessed on the 15th Aug 2014.

Coates, P., Arayici, Y., Koskela, LJ., Kagioglou, M., Usher, C., O'Reilly, K. (2010) The limitations of BIM in the architectural process, in Teng, J. G. (ed.) *Proceedings of First International Conference on Sustainable Urbanism*, Hong Kong: Hong Kong Polytechnic University, Faculty of Construction and Land Use, pp. 117-125.

Eastman, C., Bond, A., Chase, S. (1991) A Data Model for Engineering Design Databases, in Gero, J. (ed.) *Artificial Intelligence in Design '91*. Oxford: Butterworth-Heinemann, pp. 339-365.

Harold, E.R., and Means, S. (2004) *XML in a Nutshell, Third Edition.* Sebastopol: O'Reilly Media, Inc.

IFC (2013) Industry Foundation Classes Release 4 (IFC4), http://www.buildingsmart-tech.org/ifc/IFC4/final/html/index.htm, accessed on the 15th Apr 2014.

ISO (2007) Building construction -- Organization of information about construction works -- Part 3: Framework for object-oriented information, http://www.iso.org/iso/iso catalogue/ catalogue_tc/catalogue_detail.htm?csnumber=38706, accessed on the 15th Apr 2014.

ISO (2010) Building information modeling -- Information delivery manual -- Part 1: Methodology and format, http://www.iso.org iso/iso_catalogue/ catalogue_tc/catalogue_detail.htm?csnumber=45501, accessed on the 15th Apr 2014.

ISO (2013) Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries, http://www.iso.org /iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=51622, accessed on the 15th Apr 2014.

Jarić, M., Budimir, N., Pejanović, M., Svetel, I. (2013) A review of energy analysis simulation tools, in Majstorović, V. (ed.) *TQM 2013, Proceedings of 7-th International Working Conference of Total Quality Management-Advanced and Intelligent approaches*. Belgrade: Mechanical Engineering Faculty, pp. 103-110.

Lee, G., Sacks, R., Eastman, C. (2006) Specifying parametric building object behavior (BOB) for a building information modeling system, *Automation in Construction,* Vol. 15, No. 6, pp. 758-776.

Petruševski, L., Dabić, M., Devetaković, M. (2010) Parametric curves and surfaces: Mathematica demonstrations as a tool in exploration of architectural form, *Spatium*, No. 22, pp. 67-72.

Pucar, M., Nenković-Riznić, M. (2007) Legislative and policy in energy efficient designing and renewable energy sources: Application in Serbia, *Spatium*, No. 15-16, pp. 66-71.

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