DEMETER - A GREEN BUILDING PLUGIN FOR SKETCHUP

Neil Finlayson[1], Malcolm Murray[1], David Maciver[1], James Morrison[1], Murdo Morrison[1], Donald I. Macdonald[1], Donald Macaskill[1], Donald Macritchie[1] and Ioannis Rizos[2]

[1]Greenspace Research, Lews Castle College UHI, Stornoway, Isle of Lewis, United Kingdom HS2 0TW

[2]BDSP Partnership, Summit House, 27 Sale Place, London United Kingdom W2 1YR

ABSTRACT

Software applications which are hard to use and fail to make full use of Internet components, scaleability, collaboration and interoperability are significant barriers to the widespread adoption of building energy analysis. In this paper we propose a distributed application architecture which addresses some of these challenges. Demeter, the front-end client, is a custom green building plug-in developed for the 3D CAD application SketchUp. A Web-based energy analysis server is used to provide energy analysis reports and gbXML/Web services are used to share building information between client and server.

INTRODUCTION

Demand for scaleable energy modelling solutions is increasing dramatically. The European Union Energy Performance of Buildings Directive came into EU member state law in 2006 and is expected to be fully implemented by 2009. 240,000 Energy Performance Certificates per year are projected for the UK, and the directive is projected to create up to 250,000 jobs in modeling, certification and subsequent remedial work. Ease-of-use, scaleability and a Web –enabled software architecture will be an enabler for this step-change in demand for energy analysis services.

Building information modelling (BIM) and sustainable design are strongly related and complementary concerns. Functionality such as smart 'green building' component libraries, interoperability, distributed work processes and design energy certificates are likely to be enablers for a large-scale move towards a low carbon built environment. Nonetheless there are significant obstacles and complexities to be overcome.

Barriers to adoption

A much-voiced concern is lack of application interoperability, leading to practitioners having to rebuild models in different applications.

Integration of technology is required to streamline businesses and support collaboration between AEC organizations (Laepple, Clayton et al. 2005). Many users of sustainable energy design systems tend to rely on single standalone tools, whereas they may be more productive and gain better results by using a suite of different tools specialising in different aspects of sustainability. (Crawley, Hand et al. 2008) Currently, it is very difficult to do so as different tools have their own file formats and methods of representing data. A common data format that could be understood by a wide variety of tools is desireable.

Efficiency losses in the U.S. capital facilities industry resulting from inadequate interoperability among computer-aided design, engineering, and software systems is estimated to cost $15.8 billion per year in the U.S. capital facilities industry, according to a US National Institute of Standards and Technology report. (Gallaher, O'Connor et al. 2004)

Renee Cheng, AIA, head of the School of Architecture at the University of Minnesota has said:

"There are a lot of urgent issues surrounding BIM, but [interoperability] is one of the most urgent because of the 2010 Imperative and 2030 Challenge and the pursuit of the carbon neutral building." (Livingston 2007)

Difficulties associated with front-end 3D CAD modelling also constitute a significant obstacle to more widespread use of building energy analysis and design-driven approaches to the reduction of building-related carbon emissions. Complexity of the design parameter space inhibits designers from implementing a holistic approach. Lawson has stated that building design has moved from a craft-based approach to a process that involves advanced technologies and inherits endless difficulties. (Lawson 1990)

In a comprehensive and in-depth analysis Macdonald et al identified the barriers to adoption of building simulation. (MacDonald, McElroy et al. 2005) This research indicated that the main barriers are steep learning curves, poor ease of use, fear of user error, the scale and complexity of real projects and demanding input resource requirements. The most significant barrier identified overall was lack of collaborative support networks.

Well-designed XML-based data formats, web services communication layers, 3D CAD/BIM systems, and Rich Internet Applications (RIA) are potential solutions to these problems.

gbXML

Green Building XML (gbXML) is an open XML schema that is emerging as one of the interoperability standards for sharing data between between desktop and web-based tools currently used in the architecture, engineering, and construction industry. A gbXML-based energy analysis system is available as a commercial web service from Green Building Studio (GBS), Inc. (Kennedy 2003) gbXML is also used as a data format by Autodesk Revit, ArchiCAD, IES Virtual Environment and Ecotect.

The gbXML schema facilitates the analysis of building energy and environmental performance, through transfer of building product characteristics and equipment performance data between manufacturer's databases, CAD applications, and energy simulation engines. It promises to greatly reduce the time and cost of designing high performance, energy and resource efficient buildings.

The GBS web service automatically generates geometrically accurate, detailed input files for major energy simulation programs through translation from gbXML. The DOE-2.2 simulation engine is used to calculate energy performance.

Such services are particularly suitable for use at the outline design stage when most energy savings can be achieved. This is because decisions made at the early stages of design can fundamentally affect the performance of the building. (Morbitzer 2003) For example, a well designed ventilation strategy can supplant the need for air conditioning in a building, significantly affecting the design in terms of energy and environmental performance. In addition, early-stage decisions made regarding orientation, glazing area and materials can also affect design and environmental performance.

Design complexity is addressed by implementing default values for simulation parameters. The default values are based on building practices, weather sets and codes for a specific area of the globe. These defaults together with a gbXML component based approach to design alternatives make it easy for the end-user to identify the impact of early decisions upon energy and environmental performance.

Production, transformation and consumption of gbXML using a web services platform supports integration and communication between different software tools and users, bringing advantages of global scale, richer functionality, interoperability and accessibility that are missing in desktop software architectures.

Industry Foundation Classes and ifcXML were alternative approaches considered for this work but there are substantial long-standing questions concerning the real commitment of software vendors to implementing IFCs and to provision of easy to use software implementations. (Howard and Bjork 2008) Behrman has highlighted the difficulties vendors have faced in implementing the large, complex IFC standard (Behrman 2002).

Building Information Modeling

A new generation of easy-to-use 3D/BIM modelling tools such as Revit and ArchiCAD have emerged in recent years. These tools promise to enhance coordination, collaboration, automated drawing production, intelligent objects, detailed performance simulations, and interoperability.

Large property owners are increasingly aware of the benefits of moving towards comprehensive BIM solutions. Representation of all the information needed to describe buildings throughout the whole design, construction and management process is a long-standing goal. (Howard and Bjork 2008) Mandatory building energy certification is likely to accelerate such efforts.

Both Revit and ArchiCAD export gbXML in simplified form. Revit relies on external web services or desktop applications to conduct computational energy analysis and to populate the full gbXML data model.

Direct manipulation of gbXML from within Revit is not currently possible, yet there are often requirements during the design process to inspect and modify gbXML, whilst presenting a 3D CAD view of the underlying geometry. One important requirement identified therefore for Demeter was to act as a helper application supporting import, view and edit of all elements in the gbXML data model.

SketchUp

The 3D CAD tool SketchUp is highly popular due to its short learning curve, high ease of use and low cost. The key innovation in SketchUp (Schell, Esch et al. 2003) is a push/pull tool that easily extrudes two-dimensional surfaces into three dimensions.

In 2006 Greenspace Research conducted a survey among UK architectural firms. 124 UK respondents selected the applications they used most frequently for

3D models or Building Information Models (BIM). Of these SketchUp scored 38.3% ArchiCAD 6.1% and Revit 4.3%.

Rich Internet Applications

SketchUp does not currently support gbXML but exposes a full-featured application programming interface suitable for extending the application. Designers in our scenario will require ready access to rich design alternatives based on gbXML component libraries.

The SketchUp user interface can be extended using a WebDialog class which enables communication with a Web browser window. Traditionally, browsers have offered relatively simple stateless user interfaces. A tree control to represent the complete gbXML tree, for example, is difficult to render in the traditional browser, as is support for the Model-View-Controller software design pattern.

Rich Internet applications (RIA) based on emerging technologies such as Ajax, Silverlight and Flex enable Web browsers to support much richer constructs such as user interface tree controls, transitions and application state.

Strong reasons for incorporating RIA technologies include the abilities to (Rogowski 2007)

- Visualize data
- Showcase key product features
- Allow users to configure a product or service
- Streamline a multistep process
- Sort large, multivariable data sets
- Allow users to perform complex calculations with multiple variables
- Enable quick edits and revisions to product selections

The primary context for the designer will continue to be the 3D CAD model. Fortunately an additional capability supported by RIA software vendors is Internet-enabling of standard desktop applications. eBay Desktop for example uses Flex technology to enable a desktop application to connect with the eBay web services platform and backend systems. (Lewis 2007)

In this paper, an RIA, XML and Web services approach is outlined which renders the highly popular 3D CAD modeler SketchUp interoperable with gbXML and commercial energy analysis web services using Demeter our SketchUp green building plugin. Demeter is a custom plugin which converts SketchUp models to gbXML. Advanced BIM functionality such as online energy analysis, smart gbXML components and distributed work process support is thereby extended to the SketchUp system.

REQUIREMENTS AND USE CASES

Geometry

A challenging requirement is to create new gbXML models from SketchUp while preserving high ease-of-use. An intuitive and minimal set of user gestures to support space creation, selection and attribution of building surface properties is a design goal.

Geometry is one of the most essential parts of a simulation model. The development of the building's shape should be only limited by the designer's imagination. SketchUp is a faceted modeler which provides the designer with the flexibility required within the conceptual design. The basic structure of a 3D geometry model consists of three coordinates (xyz) that form vertices. Vertices form edges and faces. Surfaces form spaces and spaces form the functional structure of the building.

Ideally the plug-in should incorporate a generic algorithm to automatically identify spaces. Thus, the designer-user will not have to spend time to specify the surfaces a space consists of. The algorithm to support this feature should be based on geometric facts typically checked using Euler-Poincare rules (for example, if two surfaces are adjacent to each other, then they share an edge, etc.). Also, while spaces are created, there is a need to ensure that the particular space is contiguous. Algorithms to perform these tasks have been incorporated into Demeter..

Surface and space attribution

The model created in the sketching environment consists of many surfaces which form spaces. Each surface has its own identity (ID) so that it can be referenced whenever necessary. Surface attribution is also an essential part of building simulation modelling. By attributing surfaces the user can specify whether the specific surface is an external or an internal wall, underground or roof slab, etc. In terms of openings attribution, the tool should be able to identify whether a sub-surface is attached to another so that the opening (sub-surface) can be referenced with regards to the surface attached. Then the attribution of the openings could be established by specifying the opening type (fixed window, air, skylight. sliding door, etc.)

Interoperability and Energy Analysis

Web services interoperability with the analysis engine was one of the key requirements of the project, to ensure that users could store building models and energy reports in a globally accessible repository.

The overall requirements for the plugin are summarized in Table 1.

Table 1 Demeter use-cases

USECASE ID	DESCRIPTION
UC1	Import gbXML from file
UC2	View/Edit gbXML
UC3	Create gbXML spaces/surfaces from new model
UC4	Assign surface and opening attributes
UC5	Submit energy analysis run to web service
UC6	Share and collaborate on project
UC7	Import gbXML from web service

SOFTWARE SYSTEM ARCHITECTURE

The SketchUp API

SketchUp is a faceted modeler. A fully featured API is provided for plug-in development based on the Ruby language. Classes include Entity, Face, Edge, Drawingelement, Material as shown in Fig. 1. as well as Observer classes to support an event driven programming model. In addition, the attributes supported by SketchUp entitties can be extended using AttributeDictionaries.

EdgeUse class

The EdgeUse class defines how an Edge is used in the definition of a Face.

Material class

The Material class is used to access the materials used in a model.

AttributeDictionary class

The AttributeDictionary class allows arbitrary collections of attributes to be attached to a SketchUp entity.

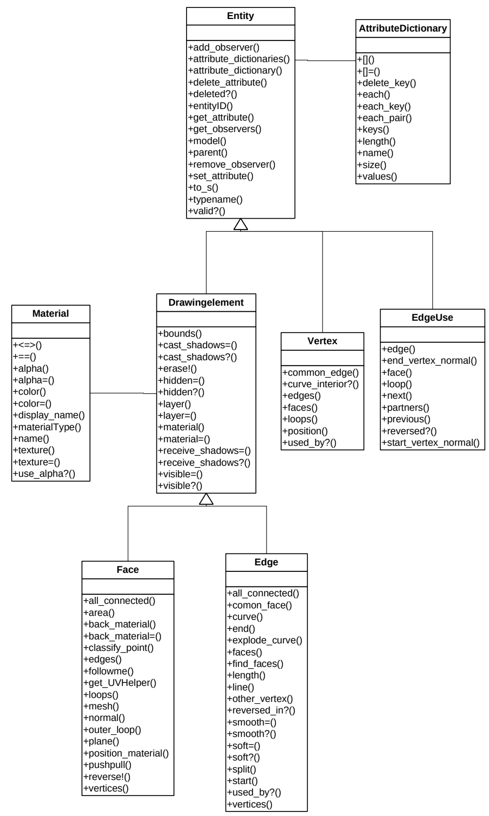

Figure 1 SketchUp application programming interface

SketchUp- gbXML Transformation

The Face entity is the starting point for translation from SketchUp to gbXML, matching quite closely to the gbXML Surface element. A Face has 3D geometry defined by its Vertices, and face normals are also supplied which can be useful for inferencing purposes.

A gbXML Surface element has the essential structure shown in Fig 2. Attributes include id to provide a unique identifier for the surface, a surfaceType and a constructionIdRef. A Surface contains a mandatory PlanarGeometry and optional AdjacentSpaceId and Opening elements.

The constructionIdRef attribute points to a Construction element, and its value is not typically populated until after the geometry and surfaceTypes have been defined. A trip to the web service is required before constructionIdRef is assigned a default value.

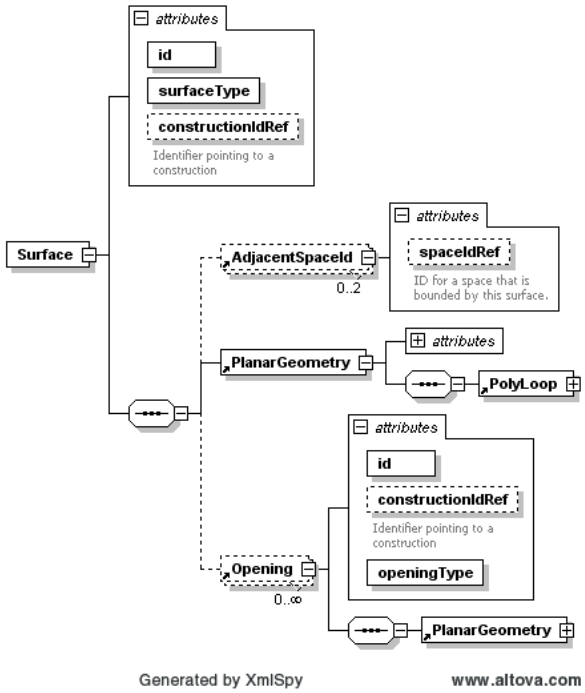

Figure 2 gbXML schema – Surface element

The surfaceType attribute takes one of the values from Table 2.

Table 2 gbXML Surface.surfaceType options

SURFACE TYPE OPTIONS
InteriorWall
ExteriorWall
Roof
InteriorFloor
Shade
UndergroundWall
UndergroundSlab
Ceiling
Air
UndergroundCeiling
RaisedFloor
SlabOnGrade

Surfaces can optionally have Openings with openingType attributes drawn from the list shown in Table 3.

Table 3 gbXML Opening.openingType options

OPENING TYPE OPTIONS
FixedWindow
OperableWindow
FixedSkylight
OperableSkylight
SlidingDoor
NonSlidingDoor
Air

SketchUp entities, unlike Revit entities, are not object-oriented: a Face entity does not know whether it's a wall or a ceiling for example. The potential consequences are a heavy level of user interaction with the model for gbXML markup purposes. Material and AttributeDictionary classes can be used to address this challenge. In Demeter a palette of custom Materials is assigned to gbXML surfaceTypes and openingTypes. As each Face is painted with its corresponding Material by the user an onMaterialRefChange event is generated which leads to a new gbXML Surface element being created in the Demeter plugin. Sustainable design entities such as Shades are readily incorporated as a result.

The gbXML PlanarGeometry.PolyLoop element maps straightforwardly onto the SketchUp Face geometry attributes. The AdjacentSpaceId attribute is used to connect the Surface to a gbXML Space, whose structure is shown in Fig 3.

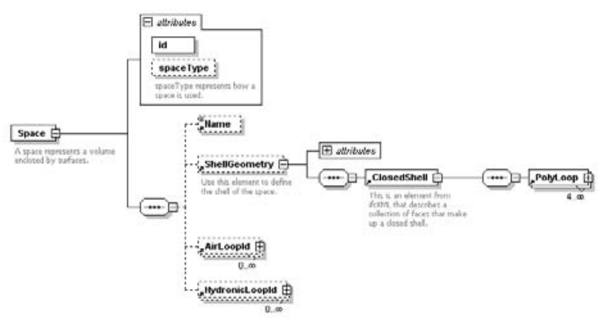

Figure 3 gbXML schema – Space element(partial representation)

Collections of SketchUp Face/gbXML Surface pairs emerging from the user's model can be tested for OpenShell/ClosedShell properties using eg Euler-Poincare rules.

The Space.spaceType attribute has an important bearing on energy analysis results. It can take string values such as:

- OfficeEnclosed
- OfficeOpenPlan
- OfficeCommonActivityAreasInactiveStorage

which eventually get mapped onto occupancy attributes for the underlying energy analysis engine.

AirLoopIDs and HydronicLoopIDs are assigned to Space elements by a gbXML round-trip from Demeter to the web service in a manner analogous to the Construction assignments.

RESULTS

After logging in to the web service, the user is able to select from a portfolio of stored projects, and to then create or import models for energy analysis purposes.

Once the model is constructed to the user's initial requirements, it is zipped and submitted via a Web services call. Before submission the gbXML model is in a simplified state containing essentially Campus.Building and Campus.Space and child elements. The round-trip populates the gbXML model fully with intelligent design defaults.

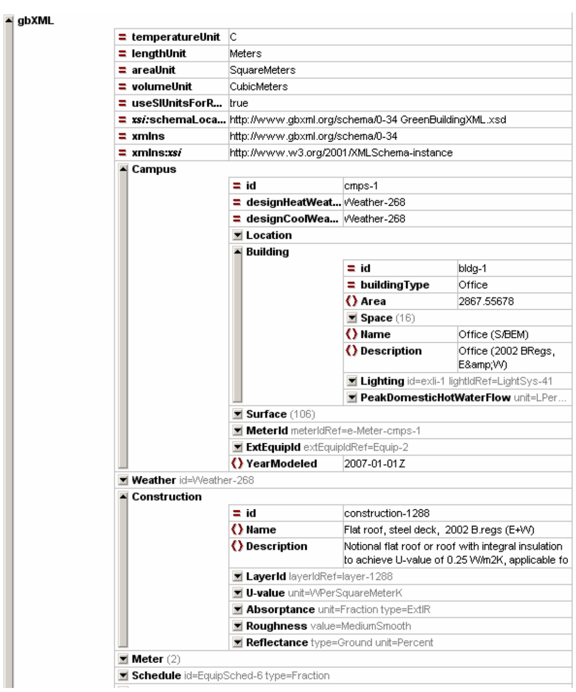

Figure 4 gbXML model

The model state following the round-trip is shown in Fig. 4. At this point the model has been imported, modified by the user, uploaded to the web service and returned to the client with a fully populated gbXML model. Elements such as Schedule, Construction and AirLoop are now available to the user for further exploration of design alternatives.

An AirLoop gbXML component with systemType attribute "PackagedVariableAirVolume" for example can rapidly be exchanged for one with systemType set to "PackagedSingleZone". All equipment child elements and attributes needed to configure the component are thereby neatly packaged into component libraries as shown in the truncated gbXML fragments below.

<AirLoop
systemType="PackagedVariableAirVolume">
<AirLoopEquipment equipmentType="UnitaryAC"/>
<AirLoopEquipment equipmentType="Duct"/>
<AirLoopEquipment equipmentType="Fan"/>
<AirLoopEquipment equipmentType="Economizer"/>
<AirLoopEquipment equipmentType="Coil"/>
<AirLoopEquipment
equipmentType="VAVBox"/></AirLoop>

<AirLoop systemType="PackagedSingleZone">
<AirLoopEquipment equipmentType="SplitAC"/>
<AirLoopEquipment equipmentType="Duct"/>
<AirLoopEquipment equipmentType="Fan"/>
<AirLoopEquipment
equipmentType="Economizer"/></AirLoop>

Intelligent design defaults, together with component-based XML libraries for exploring design alternatives, make it easy for a user with minimal building services expertise to get a starting point for energy analysis at the conceptual design stage which can be progressively refined with successive round-trips to the server for energy reports.

A sample report obtained using the Demeter plugin for SketchUp is shown in Fig. 5. Owing to the Internet architecture, the model, project and reports are easily shared with other stakeholders.

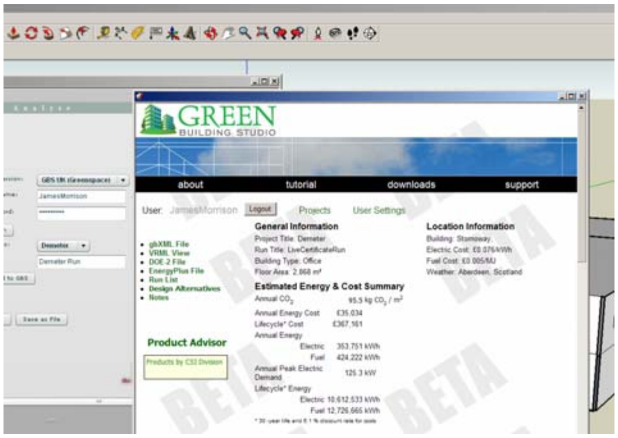

Figure 5 Demeter plugin – energy analysis report retrieved from the web service

DISCUSSION

This paper has described the software architecture for a plugin which links SketchUp, an easy to use 3D CAD system, with a commercially available energy analysis web service. Ease-of-use, high levels of interoperability and a Net-centric design philosophy is used in the system to achieve results well-suited to the needs of a building modeling effort which is expected to grow to a global scale owing to climate change and energy certification efforts.

Building Information Modelling for sustainability purposes is likely to evolve on a software-as-a-service model. The gbXML standard is likely to be a key driver of such services owing to its increasingly wide adoption by industry.

NREL EnergyPlus Plugin

Related work in this field includes a National Renewable Energy Laboratory initiative to integrate SketchUp with EnergyPlus. (Ellis 2007) The release of the NREL plugin is eagerly awaited. However EnergyPlus is prone to long simulation times, is difficult to use with the Internet to share projects, and the focus of the plugin does not appear to address interoperability issues greatly. Lack of application interoperability is extremely costly (Gallaher, O'Connor et al. 2004) and represents a significant barrier to widespread adoption of building simulation.

Energy Performance Certificates

Our group is currently working on XML-based interoperability between gbXML and UK Simplified Building Energy Model (SBEM) input files used to generate Energy Performance of Buildings (EPBD) energy performance certificates. Native SBEM has significant geometric modeling weaknesses and a path to generate SBEM compliant building models from BIM tools such as Revit and SketchUp will greatly improve the ability of industry to scale up to the EU EPBD energy certification challenge.

CONCLUSION

An energy analysis plugin for SketchUp has been described which uses rich internet application technologies and the gbXML file format to render SketchUp models compatible with server-side energy analysis engines. Significant advantages accrue to end-users as a result, the most important of which are Internet-level interoperability and collaboration, together with high ease of use.

ACKNOWLEDGMENT

This work was carried out with support from the European Regional Development Fund, Comhairle nan Eilean Siar and Highlands and Islands Enterprise. We gratefully acknowledge support and technical assistance from Green Building Studio and John Kennedy. The paper is based in part on research work presented in an M.Sc. Thesis written by one of the authors.

REFERENCES

Behrman, W. (2002). Best Practices for the Development and Use of XML Data Interchange Standards. Technical Report #131, Center for Integrated Facilities Engineering, Stanford University, USA.

Crawley, D. B., J. W. Hand, et al. (2008). "Contrasting the capabilities of building energy performance simulation programs." Building and Environment **43**(4): 661-673.

Ellis, P. (2007). EnergyPlus Plugin for Google SketchUp. Energy Codes 2007. Pittsburg, PA.

Gallaher, M. P., A. C. O'Connor, et al. (2004). Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry, National Institute of Standards and Technology.

Howard, R. and B.-C. Bjork (2008). "Building information modelling - Experts' views on standardisation and industry deployment." Advanced Engineering Informatics **In Press, Corrected Proof**.

Kennedy, J. F. (2003). "gbXML Schema." from http://www.gbxml.org/schema.htm.

Laepple, E., M. Clayton, et al. (2005). Content Analysis Of Web-based Collaborative Design: Empirical Evidence of Design Process. AIA Report on University Research, edited by D. Friedman and F. Hoermann. Bloomington, IN: Original Smith Printing.

Lawson, B. (1990). How Designers Think – The Design Process Demystified, Butterworth Architecture.

Lewis, A. (2007). "Building eBay Desktop on Adobe AIR."

Livingston, H. (2007). "BIM and Sustainable Design." from http://aec.cadalyst.com/aec/article/articleDetail.jsp?id=436385.

MacDonald, I., L. B. McElroy, et al. (2005). Transferring simulation from specialists into design practice, Montreal, Canada.

Morbitzer, C. A. (2003). Towards the Integration of Simulation into the Building Design Process. Energy System Research Unit, Department of Mechanical Engineering. Glasgow, University of Strathclyde. **Ph. D. Thesis**.

Rogowski, R. (2007). The Business Case For Rich Internet Applications, Forrester Research, Inc.

Schell, B., J. L. Esch, et al. (2003). System and Method for Three-dimensional Modeling. U.S.A. **US Patent 6,628,279 B1**.