

Interactive Three-Dimensional Visualization of Building Envelope Systems Using Infrared Thermography and SketchUp

Alexander C. Schreyer and Simi Hoque

Building Materials and Wood Technology, University of Massachusetts, Amherst, MA

ABSTRACT

Proper insulation, durability, air and moisture tightness are all vital elements for a comfortable and energy-efficient building. As a result, it is important to have a continuous, stable, and integral boundary between the conditioned interior spaces and the unconditioned outdoors spaces. It is common today for many professional home inspectors and energy auditors to use infrared imaging technology to evaluate the performance of this “thermal envelope” in the process of performing energy auditing of homes and buildings.

One drawback of the current application of infrared thermography is that while it provides usable temperature data and renders false-color images, these images are only two-dimensional and in most cases of a very low resolution. In presenting the thermography images to a client, they can be confusing to an untrained eye. Also, the three-dimensionality of a building cannot fully be captured by individual images.

This paper discusses the application of the visualization capabilities of IR in conjunction with three-dimensional models of buildings. Three-dimensional modeling is a powerful tool for visualizing and representing building conditions that is used by architects, builders, and contractors. Also, a three-dimensional model is better understandable than a more abstract two-dimensional representation (like a floor plan or an image).

A method will be presented to apply IR images to simplified exterior and interior models of a building using the freely available 3D modeler Google SketchUp. A variety of common application scenarios will be presented and examples for these will be shown. In addition, the viability of exploring the 3D model interactively and on the web will be discussed.

INTRODUCTION

Infrared thermography also known as thermal imaging can provide accurate, nondestructive information about the thermal envelope performance of any building. This includes validation of structural details, verification of energy performance (conduction and air leakage), location of moisture intrusion, and the identification of structural and system degradation of roofs and facades.

Thermography has been used since the 1960s to detect and diagnose building problems. During the 1970s fuel crisis, it was widely used to visualize the thermal signatures related to many building problems. It is common today for many professional home inspectors and energy auditors to use infrared imaging technology to evaluate the performance of this “thermal envelope” (i.e. the walls, fenestration, foundation, and ceiling or roof) for performing energy auditing of homes and buildings.

Although thermography can be used to measure spot temperatures on a building envelope, it is commonly used to generate false-color images that relate a temperature scale to a color scale. These images (as shown in Figure 1) are very convenient to visually identify thermal leakage in a building. For example, the building’s uninsulated basement walls are clearly visible in Figure 1.

The nature of these images being only two-dimensional and typically of very low resolution offers opportunity for improvement, which the visualization method presented herein attempts to fill.

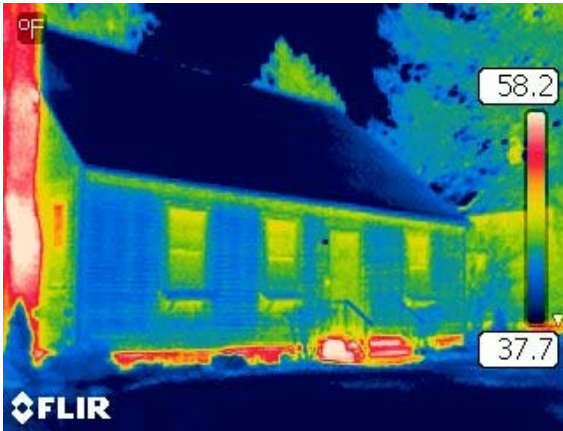


Figure 1 – Two-dimensional image (320x240 resolution) from FLIR camera

The visualization method presented in this paper uses a 3D modeling software called Google SketchUp. This software is a general-purpose 3D polygon-modeler (it considers surfaces only, not volumes), which features dimension-controlled modeling, general editing tools, an easy-to-use texturing workflow and a scripting engine for extensibility. Its main advantages are ease of 3D modeling and a variety of presentation capabilities. The software was originally created by @Last, a company from Boulder, Colorado but is now owned by Google, who purchased it as a modeler for buildings in its GIS viewer, Google Earth. Google is currently supplying a version of this software (with almost complete feature set) as a free download and its use is permitted to include commercial projects. A full version, called “SketchUp Pro” is also available.

Although SketchUp was initially produced for architectural visualization and planning, its versatility makes it useful for a variety of fields – editing digital building models for energy modeling, landscape planning, factory planning, general illustration, movie-set pre-visualization to name a few. It should be noted here, however, that this method can be accomplished with other 3D modeling software as well (Autodesk’s 3ds max, Maya, Blender and others) but SketchUp is freely available and lends itself well to the texturing method used herein.

Despite the variety of uses for SketchUp, it has not been employed as much for scientific data visualization. Due to its scriptability (using the programming language Ruby), it is well suited for custom visualization applications. One of these previously reported applications has been presented on Google.org and illustrated soil fracture events for use in siting oil drilling platforms. Another example connected SketchUp with the online real-time data storage website pachube.com and used it for visualizing real-time data.

SketchUp currently plays an increasing role in the analysis of energetic performance of buildings. Several of the relevant software developers have created plug-ins for SketchUp that use it as 3D modeler and for property entry. The prepared model is then typically exported to the analysis software for calculation and presentation of results. Examples of this kind of energy analysis software are USDOE’s EnergyPlus and IES-VE. Others import SketchUp models directly (e.g. Autodesk Ecotect).

The combination of SketchUp with thermography images is fitting since thermography records surface temperatures. These are stored in images like Figure 1, which give false-color temperature references. Since SketchUp building models consist of surface polygons, thermography images can easily be applied to exterior building surfaces as textures to realistically represent surface temperatures for an entire building.

Figure 2 is a still image from an animation that depicts surface temperatures of a single-family residence. The 3D digital building model shown in this image was created using the method presented in this paper.

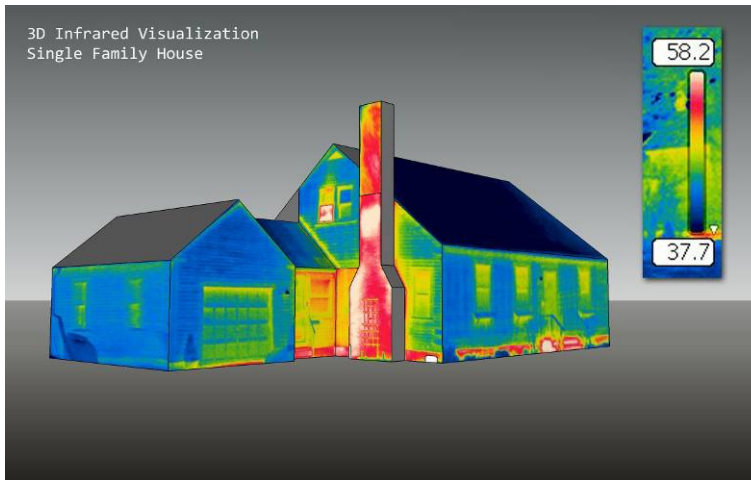


Figure 2. Image from three-dimensional SketchUp visualization of a single-family residence

As can be seen in Figure 2, the result is a visually clear and easily understandable representation of thermography data. Multiple surfaces can be viewed at the same time and the view range is not restricted by the camera angle of a single image. In addition, resolution of the thermography result is increased since multiple images are used to construct the full model.

This method of presentation can aid in the ability to fully comprehend surface temperature variations over the building as a whole. Furthermore, it is better possible to compare portions of a building that are otherwise inaccessible. Due to the clarity of presentation, this method should also allow for a better comprehension of data for the untrained eye.

Figure 3 shows a detail of the same model (garden-side of the house). It illustrates how this method can present multiple surfaces and illustrate thermal effects that span multiple surfaces.

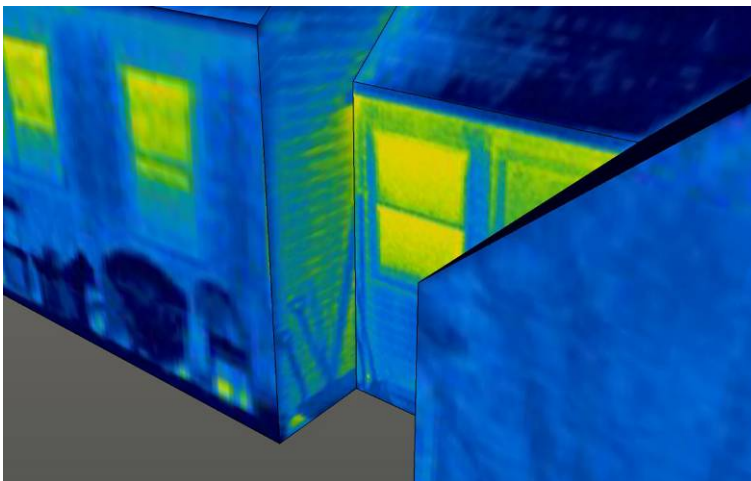


Figure 3. Corner effects and overall temperature distribution can be visualized well using this technique

With limitless space available in a 3D modeling application, it is also possible to archive thermography snapshots of a building (e.g. before renovation and after renovation) and present them side-by-side later.

Once the 3D model has been created, it can be used in various ways. Exporting static images – as shown in Figures 2 and 3 – is an obvious possibility. The understanding and analysis of the thermography data can be significantly improved, though, by exporting the model as an animation (walkaround, walkthrough), or as a

web-viewable Virtual-Reality (VRML) file. The latter then also provides the ability for the viewer to study the model and to interactively zoom and tilt it. Figure 4 shows a VRML model of this house in a browser window.

Since the 3D modeler – SketchUp – is available for free, another possible presentation method is using its graphics. Using a 2D (“classic” wheel) or a 3D (e.g. Logitech’s 3dconnexion) mouse, the model can be interactively explored either by studying it (orbiting around) or as a walkthrough. To physically remove the user from the computer during this exploration (during large-screen presentations, for example), another option to interactively navigate through SketchUp’s space is using a Wiimote (the remote of a Wii game console). This method has been described by Schreyer (see reference).

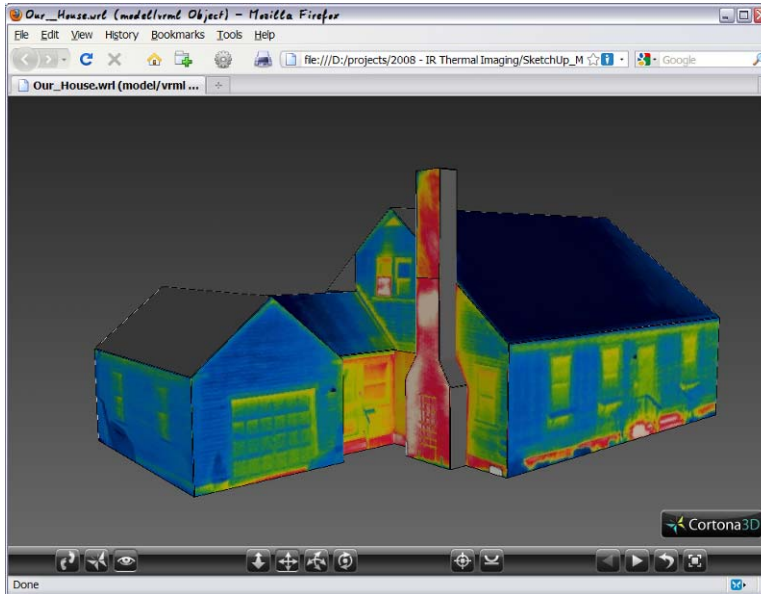


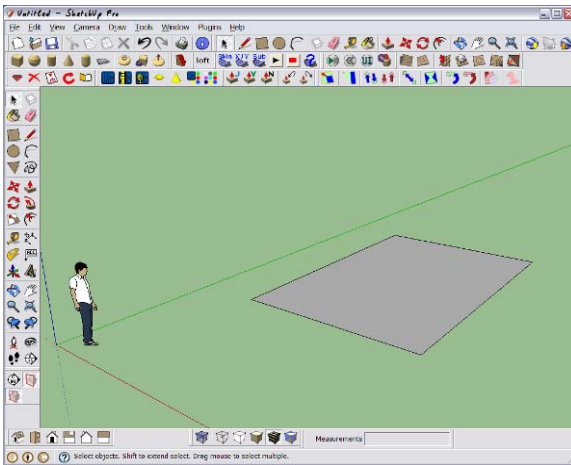
Figure 4. 3D model embedded as VRML object on a website (shown in Firefox browser)

Although this visualization technique has only been shown in this paper for the exterior of a house, it is possible to use it for interiors where the viewer’s location would be inside a box-type space that then would receive the thermography images as textures on its interior walls. This space can then be explored simply by looking around.

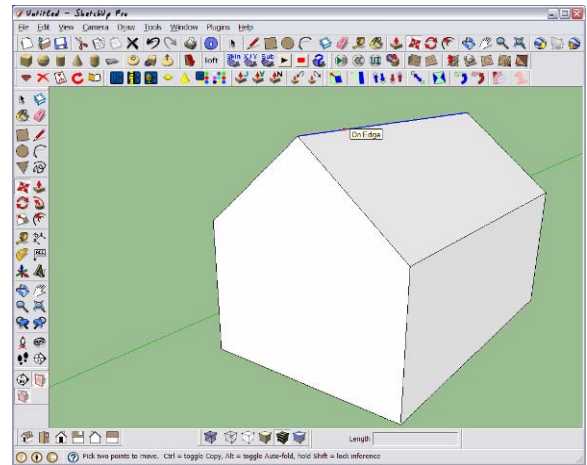
METHODOLOGY

The series of images in Figures 5 and 6 illustrate two methods that yield a thermography-textured 3D model of a building. Both have advantages and disadvantages, which will be discussed below. In both cases, a complete set of thermography images must exist for the exterior of the building, showing all surfaces. For this method to work best it is important that the following points are considered:

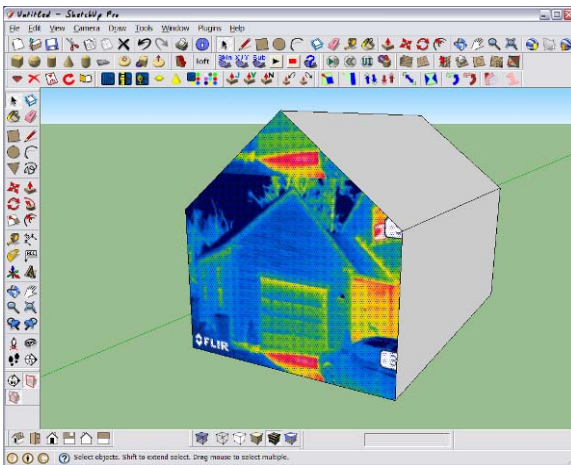
- All images must have a fixed temperature-color reference. For this to be the case, the IR camera must be switched to manual mode. It may also be desirable to manually set the minimum and maximum temperatures to convenient values.
- Perspective distortion is minimized if images are taken perpendicular to all surfaces (i.e. head-on). This is not always possible and is mainly influenced by accessibility of building perimeter and building obstructions (e.g. trees). If the images have significant distortion, then a lower-quality surface texture must be accepted.
- As with all thermography imaging, it is best to take these images at night when visible light is at a minimum. This increases consistency of the temperature-color reference.



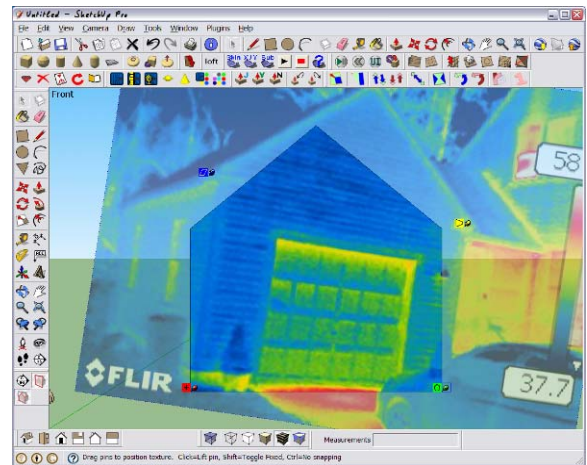
Start a building – from footprint



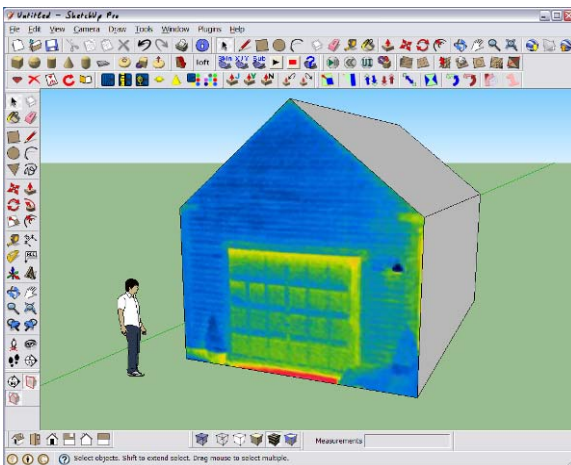
Use 3D editing tools to model building volume



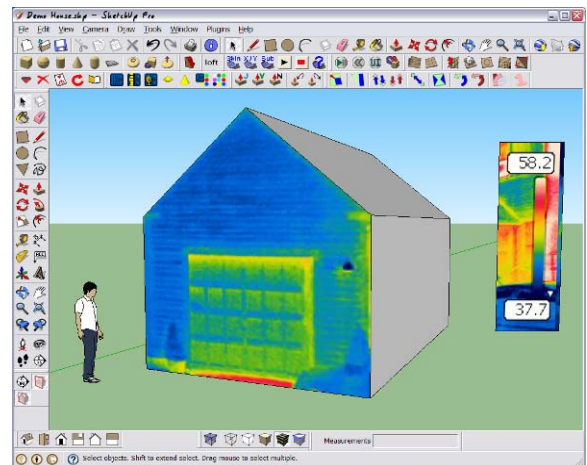
Apply thermography image as surface texture



Straighten surface texture using SketchUp's built-in tools



Thermal image in position and with perspective distortion removed



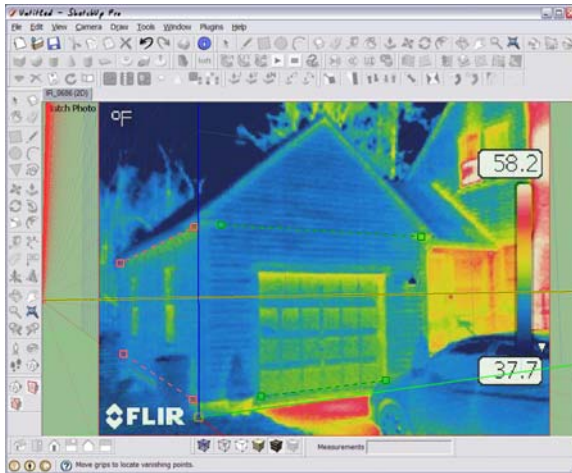
Temperature reference added

Figure 5. Creating a building model and applying thermography images

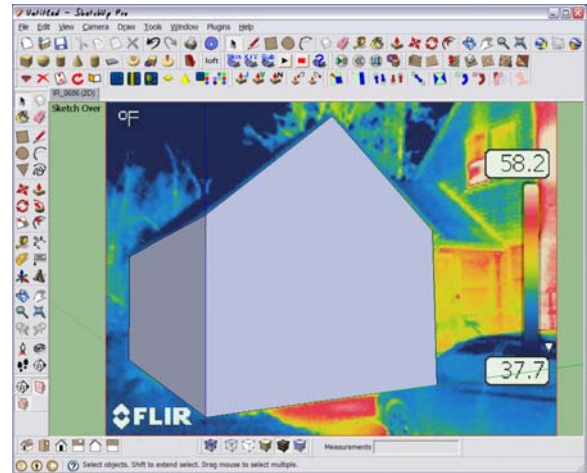
This first method works best if at least the building's footprint dimensions are known. It is also important that most of the images should be taken as perpendicular to the respective surfaces as possible.

The main drawback of this method is that sometimes it may be impossible to precisely align the image textures with the exact building geometry. This can be due to wrongly assumed geometry dimensions, overly distorted images or obstructions of building portions. This may then lead to the use of too much “artistic license” in deciding which part of the image should be shown. In most cases – and with clean imagery – the end-result will be appropriate, though.

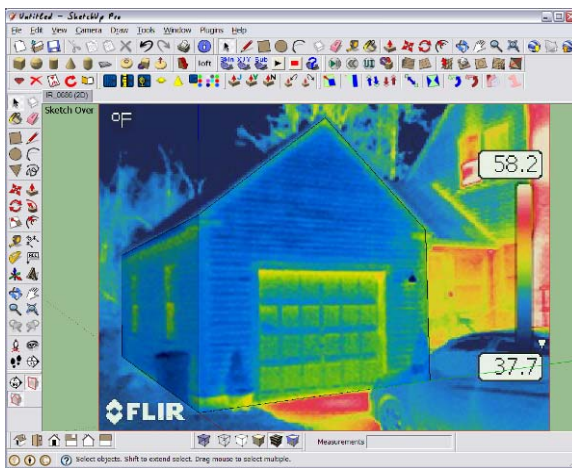
SketchUp’s second method (illustrated below) for modeling and texturing geometry uses the image itself to model geometry. This method is especially applicable where more than one surface is shown in an image (e.g. when a building corner is photographed). It is then easy to texture multiple surfaces at the same time.



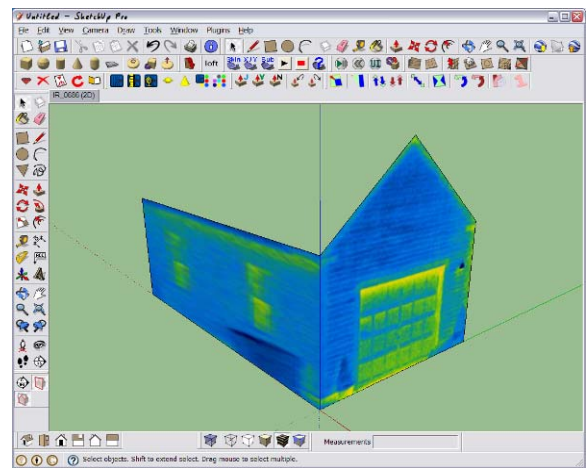
Set up the photo-match – align the axes



Draw geometry in perspective and without knowledge of the exact dimensions



Project image onto created surfaces as textures



Textured portion of building – ready to continue modeling

Figure 6. Using SketchUp’s built-in photo-matching tool to create geometry

In some cases, geometry and image alignment can be improved using this method. However, the main drawback is that when more than one surface is to be textured at a time, image distortion is inevitable. The least amount of distortion occurs when using only perpendicular images and single-face texturing.

Independent of the method chosen to model and texture the geometry, some overall issues must be taken into consideration: The quality of the result is largely dependent on the quality of the texture images (i.e. the

thermography images). Often, perspective distortion cannot be avoided because a straight view of a surface is not available – leading to grainy and distorted textures.

Also, depending on the point of view and the accessibility of the site, portions of a building may be out of view or obstructed (e.g. a flat roof). A method must be devised to consistently label these surfaces as containing no data. Fig. 7 shows areas on the back of the chimney and portions of a side roof that were out of view. In this example, those areas were simply grayed out.

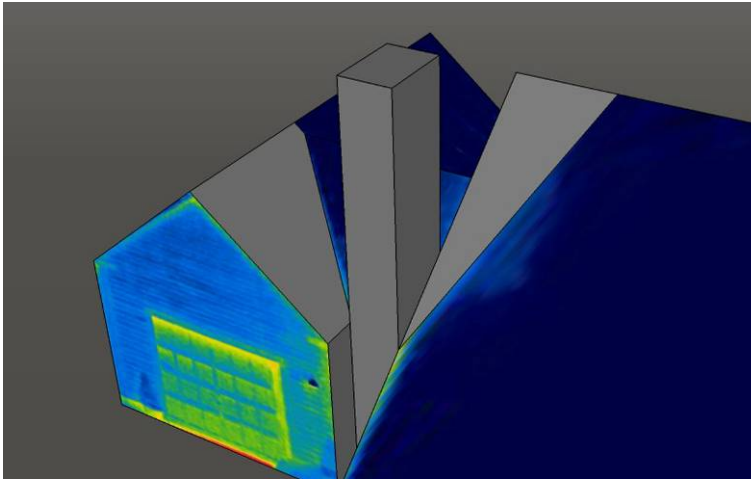


Figure 7. Inaccessible areas of the 3D model for which no image data is available.

It should also be noted that it is currently not easy in SketchUp to apply textures to curved objects (e.g. curved walls). These may be simplified and approximated by planar elements where feasible. If a highly curved building is to be modeled, then it may be advisable to use a different 3D modeling software.

COMMERCIAL EXAMPLE

The visualization method described in this paper is applicable to any polygonal object. Figure 8 shows the example of its use for a commercial office building.

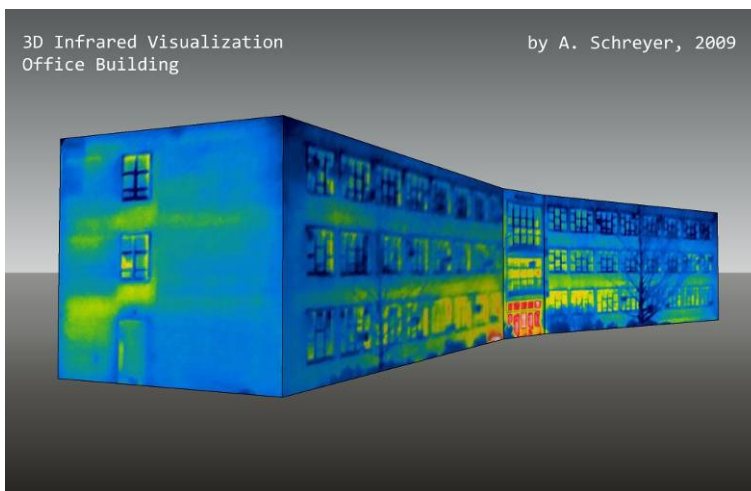


Figure 8. Office building visualization.

SUMMARY

This paper presents two methods to create thermography-textured three-dimensional digital models of buildings using the freely available 3D-modeler Google SketchUp. This method of presentation of thermography data has a variety of benefits. The resulting model is clean and shows only relevant data. Furthermore, overall resolution is increased. A building can also be viewed as an animation or explored interactively – as a virtual-reality (VRML) 3D model in a web browser, for example.

REFERENCES

Google; “SketchUp software download”; <<http://sketchup.google.com/>>; 2009

Go-2-School; “Google.org Case Study: Visualizing Spreadsheet Data in SketchUp”; <<http://www.go-2-school.com/media/view/5>>; 2009

Pachube.com; “Tutorial: Connecting SketchUp to Pachube v0.2”; <<http://community.pachube.com/sketchup>>; 2009

Ellis, P.G., Torcellini, P.A. and Crawley, D.B.; “Energy Design Plugin: An EnergyPlus Plugin for SketchUp”; IBPSA-USA SimBuild 2008 Conference Berkeley, California; 2008

IES; “IES-VE Sketchup-plugin”; <<http://www.iesve.com/Software/Model-Building/SketchUp-plug-in>>; 2009

USDOE; “EnergyPlus Energy Simulation Software – OpenStudio SketchUp plugin”; <<http://apps1.eere.energy.gov/buildings/energyplus/openstudio.cfm>>; 2009

Schreyer, A.; “When Wii Met SketchUp”; <<http://www.alexschreyer.net/cad/when-wii-met-sketchup/>>; 2009

ABOUT THE AUTHORS

Alexander C. Schreyer, M.A.Sc., Dipl.-Ing.
Lecturer, University of Massachusetts

Combining backgrounds in structural engineering as well as wood science, Mr. Schreyer's interests span the entire range of structural engineering, building design and performance analysis. This is complemented by a strong interest in computer applications, particularly CAD and web applications. Mr. Schreyer teaches classes in CAD (Computer-Aided Design), BIM (Building Information Modeling), wood properties as well as building materials and construction methods.

In his research, Mr. Schreyer focuses on the behavior of wood-based structural systems with a particular interest in innovative connection systems for wooden structures. In addition, his research encompasses computer applications in building design as well as structural optimization.

Simi Hoque, Ph.D., M.S.Eng., B.A., LEED AP
Assistant Professor, University of Massachusetts

Dr. Hoque teaches environmental systems and sustainable design principles. Her research is focused around the application and development of energy efficient buildings. She specializes in energy modeling, resource efficiency, and systems design and is seeking to improve the way buildings use the earth's resources. Hoque is the co-founder of Floodspace, a research and design collaborative, whose mission is to develop strategies for improved housing, infrastructure, and livelihood in communities subject to climate change-related flooding.

Dr. Hoque is a member of the American Society of Heating, Cooling, and Air Conditioning Engineers and the Boston chapter of Engineers Without Borders. Before her appointment to the NRC faculty in 2008, Hoque was a lecturer in the Department of Architecture at the Massachusetts Institute of Technology. At that time she was a consulting mechanical engineer at Norian/Siani Engineering, Inc. in Waltham, MA.