

# INTERACTIVE VISUALISATION OF HEAT LOSS AND GAIN FOR EARLY-STAGE ENERGY APPRAISAL OF THE BUILT ENVIRONMENT

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Integration of Building Information Modelling (BIM) within the scope of commercial operations of Small to Medium Enterprises (SMEs) is becoming more important as the deadline for the 2016 UK government guidelines for collaborative information sharing approaches. Until recently, open source and more affordable BIM software tools were almost non-existent. Instead potential users of BIM tools invested time and money in expensive and complex BIM software solutions. Energy appraisal modelling and visualisation is now becoming possible to implement using BIM methodology. However, even top end BIM software tools do not necessarily meet the requirements of SMEs as they are either too complex, too expensive or lack the necessary features for energy appraisal and visualisation. A custom 3D software tool was developed for an SME specialising in low carbon housing, with the aim of influencing early design choices maximising energy efficiency. The software tool is designed to be a quick calculation tool that uses BIM principals for visualisation and limited data exchange. The software tool, based on computation models from the Passive House Planning Package (PHPP), appropriate for early energy appraisal, is able to compute both numerically and visually the estimated energy usage and solar gain for early stage building designs (corresponding to the Level of Detail (LOD) 100 BIM maturity levels specification). We will describe the design and development process of the software tool, software validation and testing results. We conclude that the software tool can offer a beneficial alternative or used in addition with more complex and expensive 3D BIM tools and features a less steep learning curve.

Keywords: BIM, games technology, stakeholder engagement, energy appraisal.

## INTRODUCTION

Building Information Modelling (BIM) is now prevalent within the architectural, civil engineering and construction management professions. The BIM standard is set to become a standard within these industries by 2016 in the UK. At the moment, a significant drawback for small to medium enterprises (SMEs) is investing time and money in purchasing and learning to use high end BIM software packages. As previous research has suggested (Friese *et al* 2008), games based technology has the potential to provide an affordable and flexible alternative when it comes to developing low-cost, fully interactive, robust and flexible software (Isaacs *et al* 2010). BIM can

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also be applied at the early design stage of a building project in order to facilitate sustainability assessment and stakeholder engagement, thus reducing the additional costs of doing this later in the project (Hope and Alwan 2013). We applied games technology to develop a custom interactive 3D modelling and visualisation tool, based on PHPP calculations directed by the needs of two SMEs and with additional input from an academic. The software tool is based in terms of its visualisation and computational functionality on BIM principals, but is limited in terms of its focus only to early stage energy appraisal. 3D PHPP is not a pure BIM software tool, but rather an accessible visual and numerical computation tool that extends the PHPP calculations to include interactive visualisation components. Early stage energy appraisal was deemed important by the clients as it could potentially decrease the carbon footprint of buildings using the Passive House standard by 50% to 65% (Joosten *et al* 2005). Based from initial discussion with the clients it was decided that the primary requirement should focus on early design stage energy appraisal.

## SUPPORTING LITERATURE

Interactive visualisation of early stage energy appraisal is a distinct lacking feature of the PHPP software package. While PHPP is able to approximate the numerical results of energy indicators for building designs, the visualisation of such indicators and their associated components is lacking. Previous research aimed at providing involved stakeholders with clear and concise data about energy performance of building designs has been discussed by (Charalambides and Wright 2013). Software such as Autodesk Ecotect is able to tie the numerical data with an interactive 3D visualisation, but requires extensive parameter input and recalculation if any changes to the 3D building envelope are made. An add-on for the Google Sketchup software to visualise PHPP scenarios (Malzer and Edwards 2013), has been released in December 2013 - but at present only a commercial version of the software is available. Interactive visualisation and modelling have been proved to be one of the key requirements for utilizing BIM concepts and putting them in practice (Baker and Garret 2011). (Whyte *et al* 2000) highlighted the benefits of interactive 3D visualisation for CAD applications. The fact that it was published over 14 years ago shows the recognition of importance for interactive 3D visualisation by the CAD community before BIM became a mainstream and standard. The paper also describes the potential benefits of a collaborative data sharing approach within the virtual environment. The concept of collaborative design is also mentioned by (Whyte *et al* 2000) as one of the key strengths of interactive visualisation. (Plume *et al* 2007) describes how the use of the IFC file format for collaborative data exchange was tested within an educational context. The paper describes the benefits as well as the disadvantages of using the IFC file format within a collaborative educational environment. This paper describes the benefits as well as the disadvantages of using the IFC file format within a collaborative educational environment. This is important as the paper describes user group tests that were carried out in 2004 and 2005, where students collaborated and exchanged building model data using the IFC file format. This is especially important as BIM methodologies are for example being integrated into the academic curriculum worldwide and the need to present and assess building designs at various BIM stages is crucial in order to communicate with the involved stakeholders (Glick *et al* 2012). Using BIM methodology for early stage sustainable building designs has the advantage of providing transparent involvement for all engaged stakeholders and providing a framework for collaboration (Bryde *et al* 2013). In terms of visualisation,

3D PHPP focuses on the ‘envelope’ or schematic visualisation model of the building – showing only the shell of the building and the key exterior structural support. In this paper we use the Level of Detail (LOD) 100 BIM maturity level terminology to describe conceptual building geometry (BSI 2013). The use of BIM visualisation in order to visualise energy appraisal within the building design constraints of a given standard such as the Passive House Standard can cut down costs at the initial stages and increase building performance through out its life cycle (Morrissey *et al* 2005).

## METHODOLOGY OVERVIEW

### Games based technology used for development

Having access to a simple, robust and reliable tool for the computation and visualisation of early stage energy appraisal (3D PHPP) was the core requirement for this project set by the SMEs and academics involved with the project. Specifically the requirements of 3D PHPP were to implement heat loss and gain calculations as in PHPP, with the additional benefit of interactive visualisation, navigation and ease of use. Given our previous research and development in the games technology for sustainability assessment and visualisation, this approach was adopted to meet the clients requirements. The 3D PHPP software tool was developed using Unity 3D. Unity 3D is a leading games engine (Lee 2013) and allows for rapid application development of games prototypes. The need to incorporate BIM software principals exposed the need to handle different file formats for importing and exporting geometry and associated building information data. This required the use of a file system and it was decided to create 3D PHPP as an extension to the Unity 3D editor. This would allow the software tool to make use of the existing file system functionality tied to the Unity 3D editor, as well as to allow use of the Unity 3D

“prefab” objects library - which can be thought of as similar to a BIM server component library, thus enabling easy sharing of building models created within Unity (see Figure 1). We additionally implemented the feature of being able to import LOD 100 geometry from IFC files into 3D PHPP. This enables users to create their building designs using their preferred BIM software and export the LOD 100 geometry into 3D PHPP for energy appraisal testing. This makes the design of 3D PHPP conform to the core BIM concept of accessible and collaborative data sharing.

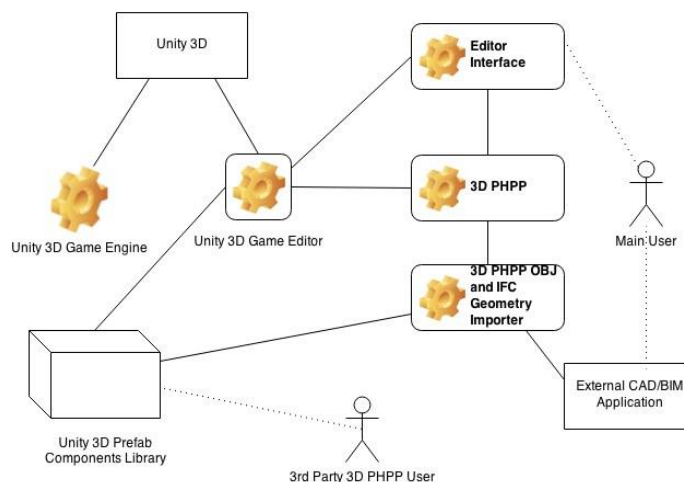


Figure 1: Relationship diagram showing the integration of the 3D PHPP tool with the Unity 3D editor, the Unity 3D Game Engine and the Unity 3D Prefab Components library.

Another important reason for creating the 3D PHPP software tool as an extension to the Unity 3D editor is that it allows 3D PHPP to use most of the existing editor

features, such as real-time interactive object selection and manipulation, different camera projection models for viewing the scene in different ways - as well as both standard and non-standard camera control schemes. Most of these editor features align with 3D editor features found in commercial CAD software packages (Autodesk 2003). The version of Unity 3D that was used to develop the 3D PHPP is free for academic and non-commercial use (and even limited commercial use), and allows potential users to use 3D PHPP for free (provided they have access to the free version of Unity 3D). The current version of the 3D PHPP is tied to the Unity 3D editor and is designed to work on modern Microsoft Windows computers. Unity 3D is also able to run Mac OSX, Linux, Web browser and Android platforms, and this provides an interesting opportunity for future versions of the 3D PHPP software tool to be developed to run on these platforms.

## CASE STUDY

3D PHPP was used to assess the effect of building location and orientation on energy appraisal of building designs for a site in Dundee that is currently being developed (see Figure 2). The default concept building model we used is 100 square meters and the height expected to be no more than two storeys in line with the existing buildings. A recommended minimum building floor space for Passive Houses is 70 square meters (Mead and Brylewski 2013). A default model of what would be an open plan office space with a south facing glazed façade (see Figure 3) was selected for 3D PHPP testing.

## Research and development

The initial challenge faced during the design of the 3D PHPP prototype was concerned with abstracting the “core” Passive House energy appraisal calculations relevant for early design-stage energy appraisal.



Figure 2: The location of the proposed building development on the Dundee Waterfront.

The functions listed below were selected for the initial early-stage energy appraisal after consultation with the clients involved in the project – one of which routinely uses PHPP. Additionally, we made use of the official Passive House Planning Package documentation (Passive House Institute 2014):

- Heat Loss for component (Q-value)
- Overall heat loss for the building (Q-value)

- Treated Floor Area (TFA)
- Insulation value for component (U-Value)
- Insulation value for building (U-value)
- Estimated energy consumption for building (kWh/m<sup>2</sup>)

The heat usage or heat loss, referred to as the Q-value component, is calculated using the standard formula (Weisstein 2012):

$$Q = U * A * \Delta T$$

*Equation 1: The heat usage formula.*

After we implemented and verified the material property calculations (Equation 1), the next major functionality component that was added to the current version of the 3D PHPP has the ability to dynamically calculate basic energy appraisal values based on custom environmental, parametric and spatial properties associated with each building model component. The inside and outside temperature difference is defined as

$\Delta T$  and the total surface area  $A$  in Equation 1 is calculated for each polygon face of the building envelope geometry. Additionally, these values can be recorded and summed for the whole building. As the user modifies the scale of the component, the total surface area value gets automatically updated. This parametric form of control is one of the main current strengths of 3D PHPP – as users can translate, rotate and scale the selected component, the spatial values tied to component get directly updated in any associated numerical calculation models.

The client was interested to see how the rotation and positioning of the building in Figure 3 would affect the solar gain of the glazed façade. The glazing value component of the façade featured in the current building model takes into account the standard glazing material components (thickness, thermal conductivity, U-value), but also includes an additional solar radiance gain calculation component that is calculated using the following custom formula:

$$S_g = (\vec{u} \cdot \vec{v}) * 1.362 * TSA$$

*Equation 2: Approximated solar gain equation.*

Where  $S_g$  is the solar gain variable that is calculated as the dot product between the directional coordinates of the global light (vector  $u$ ), and the current rotational coordinates of the selected glazing components reference frame (vector  $v$ ). This dot product value is then multiplied by a constant of 1.362, which is the approximation of the solar constant variable, calculated in kWh per meter square units (Kopp 2011). This result is then multiplied by the total surface area of the selected model glazing component – which can be dynamically updated by the user in real-time. This provides the user with the advantage of being able to edit the glazing component of the building model in real-time 3D, while simultaneously assessing the energy performance impact.

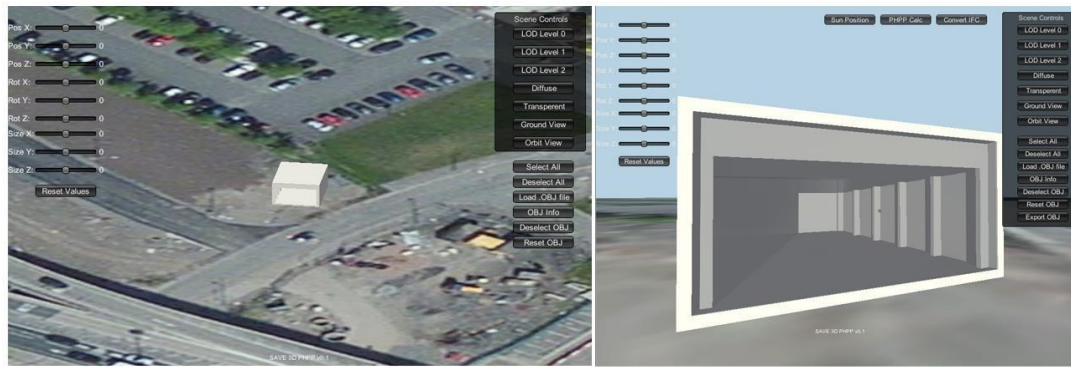


Figure 3: The site visualisation (left) of the default model and the glazing component of the front building (right).

## RESULTS

### Testing: Verification of implementation of heat loss and gain calculations using Ecotect

A verification test was carried out for the direct solar gain computation using Autodesk Ecotect, and the 3D PHPP software tool. The building model that we used for this test was the LOD 100 conceptual model described above (see Figure 3). The results obtained from 3D PHPP closely match the results produced by Ecotect. In the test scenario, we obtained the direct solar gain for the building model for the day of 1<sup>st</sup> June 2014 at 12:30 in the afternoon. The 3D PHPP software tool is able to approximate the azimuth and altitude of the sun if the user can provide the time, date, and latitude and longitude information for the geo-spatial properties of the building. In addition to the geo-spatial location of the model, we also used the following default testing properties in Table 1 for the floor, wall, roof and window thermal insulation properties, as well as the outside and inside temperature.

Table 1: Material and temperature properties used for testing (Stojanovic et al 2013).

BIM Level 1 Object	Thickness (meters)	Thermal Conductivity	Ventilation Factor	R-values	Inside Temperature (Celsius)	Outside Temperature (Celsius)
Back wall	0.022	0.04	1.8	10.0	22.0	18.0
Left wall	0.022	0.04	1.8	10.0	22.0	18.0
Right wall	0.022	0.04	1.8	10.0	22.0	18.0
Roof	0.015	0.03	1.8	13.0	22.0	18.0
Front Glazing	0.009	0.05	1.8	1.25	22.0	18.0
Floor	0.0019	0.035	1.8	13.0	22.0	18.0

Table 2 shows the results for the direct solar gain we obtained using our 3D PHPP software tool and we then compare them to the results we obtained using Autodesk Ecotect. Figure 4 shows the direct solar gain value obtained in Ecotect for the hours between 12:00 and 13:00 for 1<sup>st</sup> June 2014 is between 596 W/m<sup>2</sup> and 585 W/m<sup>2</sup>. Our summed approximated solar gain result that we obtained and recorded in Table 2 from 3D PHPP, for 12:30 on the same day, is 575.437 W/m<sup>2</sup>. Additionally, we also

calculated the daily net energy difference for the LOD 100 version of the building envelope using our 3D PHPP software.

Table 2: Approximated direct solar gain values computed in 3D PHPP.

Component Name	Approximated Direct Solar Gain
Back wall	42.58
Floor	0.00
Right Wall	13.11
Left Wall	178.60
Roof	131.40
Front Glazing	210.00
<b>Summed Approximated Solar Gain:</b>	<b>575.43</b>

In 3D PHPP, the net energy difference is calculated by finding the difference between the heat loss value and the direct solar gain value. Table 3 shows the results of the summed component net energy values. The positive net energy indicates the approximated potential amount of energy gain per day. This result is dictated by the current seasonal factors and the material properties used in the calculation.

Table 3: Daily approximated net energy value for the BIM Level 3 building test model.

Component Name	Net Energy Value (kWh/m <sup>2</sup> )
Back wall	0.0178
Floor	0.0058
Right wall	0.0580
Left wall	0.0580
Roof	0.1964
Front Glazing	0.0280
<b>Summed Components Net Energy Value:</b>	<b>0.3643</b>

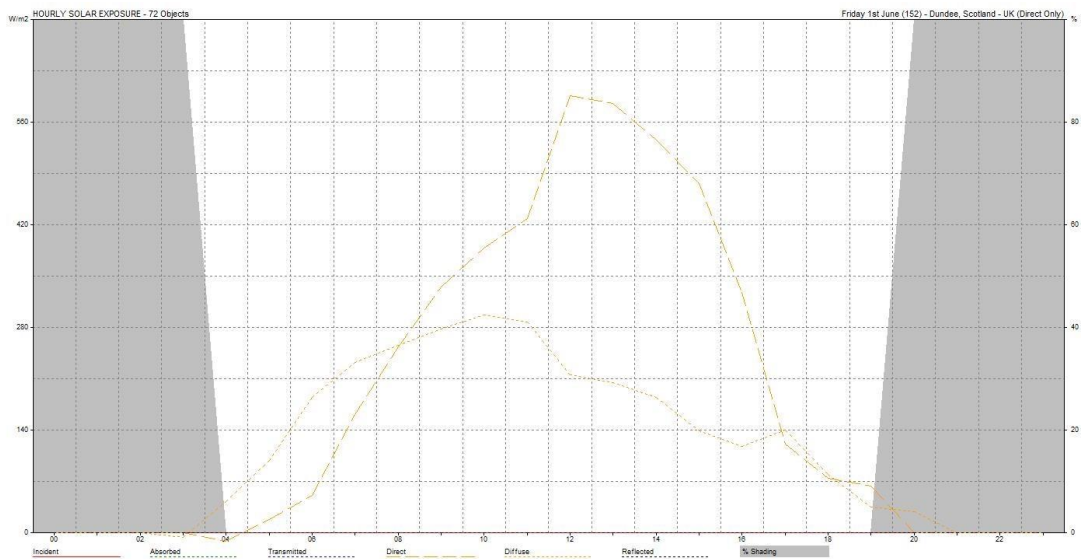


Figure 4: Daily approximated direct solar gain computed in Autodesk Ecotect. The bolder dashed line shows the peak direct solar gain at 596 W/m<sup>2</sup>.

**Testing: Interactive visualisation, navigation and ease of use**

With the calculation of heat loss and gain verified, a testing session was conducted at Fife College aimed at evaluating the interactive visualisation, navigation and ease of

use of 3D PHPP prototype (see Figure 5). The testing session was conducted with a small group of individuals comprised of BIM professionals, academics and sustainable architecture students. The group of students were working on a project assessing the energy performance of early designs of new building development proposals for the Dundee Waterfront area (see Figure 2). The students were interested in having access to a tool that would allow them to quickly and rapidly prototype the different geo-spatial properties and energy performance of the design. This also provided us with the opportunity to see how the 3D PHPP prototype would work with more complex building models (instead of the default warehouse model used for internal testing as described in the case study). The testing session lasted four hours and was used to fulfil the two main requirements of software usability and functionality.

### **Usability**

During the testing session it was noted by the participants that the user interface for the 3D PHPP software tool is more games orientated than the traditional CAD software tools. It was suggested that for the next phase of the project a new keyboard based camera control system for inspecting the 3D scene that is closer to a CAD-like control scheme should be implemented. It was also suggested that the main tools for component manipulation should have better categorisation. An undo feature was suggested for the next version of the software, as well as more precise 3D object selection (as the user is able unintentionally select more than one component at the same time).

### **Functionality**

The first potential improvement that was suggested was for the concept stage of the design process, it would be good to come in from a whole building perspective (e.g. volume mass model) and then progressively be able to explore options at general arrangement (e.g. roof, floor and wall) levels. For example, this could be used to discuss with a client what effect reducing or increasing glazed areas and/or changing orientation was likely to have on the heating or cooling load. It was noted that 3D PHPP is more of a quick computation tool than a complete BIM software tool, and such it is most beneficial when used alongside standard BIM software tools such as Autodesk Revit. At the time of the testing, the current version of the 3D PHPP software tool only featured energy appraisal computation on a per component basis, rather than a whole building analysis. It was suggested that for the next version of the software, a whole building energy appraisal computation be implemented. We agreed that it would be beneficial to observe the file transfer process into 3D PHPP, ideally from a range of source files. During the testing session, the users noted there was difficulty importing complex 3D building envelopes as IFC files from Autodesk Revit, as once imported, the 3D building envelopes had to be manually set up in within the Unity 3D editor. Users noted that it was quite straightforward to import Wavefront Object model components using the default building model. There was confusion as to what constitutes LOD 100 and LOD 200 BIM concept geometry and how such levels of detail can be transferred from Autodesk Revit to the 3D PHPP software tool. It was agreed that the complexity of the model to be transferred should be limited to the compact “*volume mass*” level of detail. One of the participants during the testing session noted that the 3D PHPP software tool is able to compute the net energy values on a per component basis much faster than Autodesk Revit. The clients also felt that the 3D PHPP software tool was lacking true support for IFC models, as at present only



the geometry can be extracted and imported by 3D PHPP. Parsing and interpretation of additional attributes associated with a given IFC file are omitted.

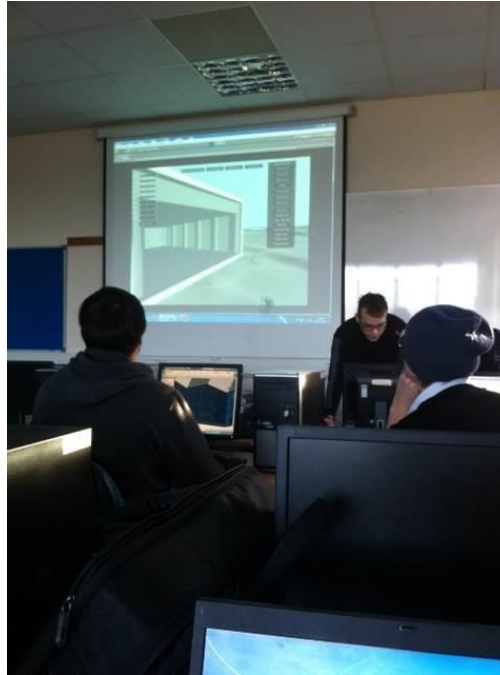


Figure 5: The testing session in progress at Fife College.

## CONCLUSIONS

Despite these criticisms and suggestions for potential improvements, the clients involved in the project felt that the 3D PHPP software tool prototype met the original specification requirements within the limited development time frame. We do not make a claim that 3D PHPP can replace standard BIM tools – but rather that it can be used beneficially in conjunction with standard BIM tools in order to quickly calculate energy appraisal values for concept building models. 3D PHPP also has no official affiliation with the Passive House Institute, and was developed on publicly available information and specification documents for the Passive House Planning Package. The end result of the 3D PHPP prototype was the creation of a games based interactive 3D software tool that was easy to use and conforms strongly to BIM principals. With further refinement based on the results of the testing, 3D PHPP can potentially benefit SMEs involved in low carbon building design and construction.

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