Simulation Software as a Design Tool in Multilayer Construction

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Abstract

In light of enhanced building performance regulations and the recent EU leader's commitment to cut greenhouse gas emissions by 40% by 2030, there is an ever increasing need to encourage architecture students to experiment with a wider range of environmental building materials to achieve high performance thermal envelopes whilst reducing their ecological footprint. Introducing students to simulation software at an early stage in their building design education encourages familiarity with such materials and encourages innovation and experimentation. However, when testing such wall constructions using building simulation software, it can be problematic to gain access to the necessary performance data of innovative organic building materials.

This paper outlines the project outcomes of a sample of 75 undergraduate architecture students from the Mackintosh School of Architecture in Glasgow who used the environmental analysis software to evaluate the wall constructions of their individual design project. This study uses the Integrated Environmental Solutions Virtual Environment (IES-VE) dynamic thermal simulation package, which has been widely validated and its calculation methodology meets the requirements of a number of national and international standards. Whilst the project had a very tight brief with regard to the design of the building form and location, the process of creating an innovative façade; consideration of the construction layers and choice of materials were key drivers of the project. In each scenario both the wall and roof constructions were modelled and the resultant U-values generated and evaluated against current building performance markers- UK Building Regulations (Scotland) and German Passivhaus certification criteria.

The thermal behaviour and the appropriateness of the different building techniques and materials are analysed, compared and discussed. The application of a dynamic simulation tool is explained and the output of the thermal simulation model is compared with the dynamic thermal properties of the wall constructions to assess their performance in summer and in winter. Whilst the study identified an extensive range of innovative materials, for the purposes of this paper only 3 variations are subject to in depth analysis. Finally, this paper assesses the strengths and weaknesses of the selected simulation software in completing this project. A summary of feedback from the project participants regarding the usability of building simulation software as a tool to supplement traditional studio based design explorations in the testing and creation of innovative wall constructions.

Keywords: thermal simulation, building simulation, materials, insulation, passivhaus

Introduction

The built environment is responsible for approximately 36% of Greenhouse Gas (GHG) emissions for the whole of the UK, with domestic operational carbon emissions 54% of the built environment total [1]. In response, a number of energy efficient design strategies have been implemented in the UK housing sector, including adoption of the German Passivhaus standard. These strategies aim to reduce building carbon dioxide emissions through increased fabric energy efficiency and the adoption of low carbon technologies. The efficiency of the building envelope is increasingly important given the 'fabric first' approach adopted by many building designers. Using thermal analysis software allows important decisions to be made at the early stages of design to ensure the selected construction materials meet current energy efficiency requirements. Energy modelling was once carried out by

engineers but now many designers are looking to use these tools to be able to test ideas at an early stage. It could be argued that architects are the most qualified members of the project team to lead the energy-modelling process, given their expertise in integrating program, space, and building systems. In light of this, the teaching of such tools to undergraduate architecture students is important to give them the confidence of using software to test ides and have the ability to engage in dialogue in the thermal performance of buildings once in professional practice.

This paper outlines the design, implementation, and outcomes of a teaching setup that was delivered during Term 2 of academic year 2014/15. The model proposed in this paper prepares students to learn about the physical behaviour of the building under different conditions and begin to frame a building concept which that articulates these issues.

Methodology

In order to test the hypothesis, 75 undergraduate architecture students in their 2nd year at The Mackintosh School of Architecture were set a project to establish whether advanced environmental modelling software (IES GAIA version 6.0) could be easily grasped and used to test the thermal performance of initial façade design ideas.

The study was undertaken during the academic term 2014/15. The project ran for 6 weeks with a combination of taught workshops and self directed learning. None of the students had prior knowledge of the software although all had a good grasp of at least one 3D modelling package (either AutoCAD, Revit, Sketch Up or Rhino) which allowed them to become quickly proficient in modelling in IES. The Sketch Up plug-in for IES was also tested on those students who already had prior working knowledge of Sketch Up software.

PM#1-Design modelling using IES GAIA version 6.0.

The students used their concurrent studio design brief as a vehicle to test their proposed wall constructions. The design brief was for a small scale building (a shelter with an enclosed heated space) with a timber frame as the primary structure. This chosen site was a small village on the rural outskirts of Glasgow, in West Central Scotland. Many chose a timber stud construction with a variety of cladding material choices including brick, timber, tile or metal sheet. Using the ModelIT command within the software students created simple massing model of the enclosed heated space within their design.

PM#2- Assignment of wall construction materials.

Using the Building Template Manager, students created and assigned wall constructions by accessing the construction materials library within the software database. In addition to the cladding, the insulation and internal linings required to be selected. Where the preferred material was missing from the software database the student was required to visit the manufacturer's website to gain the technical specification/ performance data. Once the layers of construction had been input the U-value was calculated and reviewed against current Building Regulation (Scotland) requirements and Passivhaus certification criteria. The brief required the wall constructions to be a minimum of 0.15W/m^{2}K so if the resultant U-value failed to meet this figure then the construction detail required review to enhance the thermal performance.

PM#3- Evaluation of annual thermal demand.

In order to undertake an annual thermal demand prediction, roof/floor materials had to be assigned to the model and window/door openings inserted to complete the thermal envelope. These simple thermal enclosures were then subject to a simulation exercise to predict the energy consumption value. The results were then compared with Passivhaus requirements of a maximum space heating demand of less than 15 kWh/m^2. Variables in the model were then tested to evaluate the impact on the annual thermal demand.

Project Data

PM#1- modelling their proposed design using IES ModelIT. Students were encouraged to keep building models as simple working models rather than presentation models with excessive detailed elements. Figure 1 indicates one sample project in which the geometry posed a challenge to the students' ability to create a model in IES software.
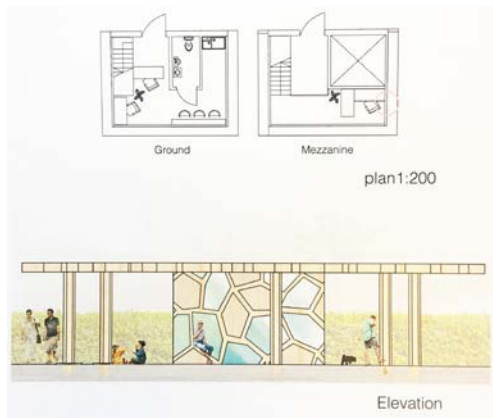
Figure 1: Sketch Design by Ploynapat Teerawatin, Mackintosh School of Architecture Undergraduate student, 2014/15.
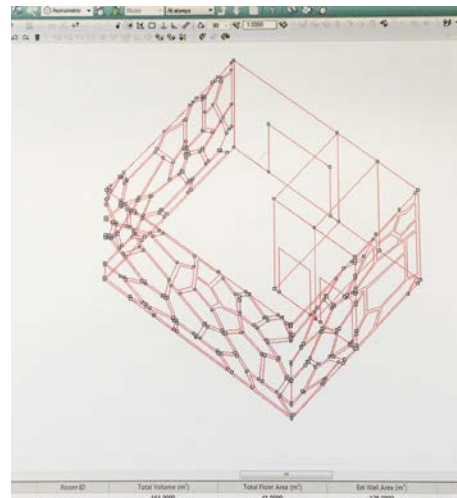
Figure 2: Sketch design translated into basic IES model by Ploynapat Teerawatin, Mackintosh School of Architecture Undergraduate student, 2014/15.

In Figure 2 it can be seen that only the heated space within the building has been modelled at this stage. Where students had complex geometric forms it was suggested that these were simplified to retain the same volume but more simple forms in order to minimise the amount of time spent using the modelling function to ensure sufficient time was allowed to undertake the analysis functions.

PM#2 -Assignment of wall construction materials. Students had make early design decisions regarding their choice of materials during their studio tutorials. Across the cohort the variations in their wall constructions were extensive with wide-ranging frame, cladding and insulation choices. The table below highlights some of the variations selected which generated over 20 variations.

Timber frame type	Cladding/ Outer skin	Insulation
Timber stud frame	Metal (aluminium/copper/zinc)	Wood fibre
Cross Laminated Timber (CLT)	Timber (Cedar, Larch)	Cellulose
Structural Insulated Panel (SIP)	Glass	Recycled earth wool
Laminated I beam	Terracotta tiles	Sheep wool
Glue laminated curved structure	Stone veneer	

Table 1: Table showing the layers of construction variations

Consideration of ecological aspects of chosen materials was critical to the brief and students were encouraged to undertake investigations into their environmental impact. Whilst there were over 20 variations in the façade constructions across the year group this paper focusses on 3 key construction types which occurred most frequently- Traditional timber stud (WT1), Laminated timber stud (WT2) and Cross Laminated Timber construction (WT3).

WT1- Traditional timber stud	WT2- Laminated timber stud	WT3- Cross laminated timber
12mm plasterboard	12mm plasterboard	120mm thk Cross laminated timber structure
25x 25mm timber battens (vertical)	12mm OSB sheathing board	
12mm OSB sheathing board	200mm cellulose between 200mm x 100mm stud	80mm wood fibreboard
150mm sheeps wool between 150mm x 75mm stud	12mm OSB sheathing board	60mm wood fibre board
12mm OSB sheathing board	50mm wood fibre insulation	38mm battens/cavity
25x 25mm timber battens (vertical)	35mm terracotta tiles on metal brackets	19mm charred cedar cladding
25mm thick tongue and groove horizontal cedar timber cladding		

Table 2: Description of 3 main wall types

The cohort of students was encouraged to consider local climatic conditions when selecting materials for the harsh West of Scotland environment and make judgements accordingly on the material selection. For the simulation to be successful, students required to create wall construction types with material specifications as accurately as possible. This provided a platform for testing the IES material inbuilt database and during the exercise it became evident that the materials database was limited and contained materials more suited for larger commercial projects. The database lacked performance data for natural or more ecological materials such as sheeps wool or cellulose which many of the students were keen to use. If the preferred material could not be found within the library, students then had to undertake a search for key performance data from manufacturer's trade literature including Thermal Conductivity ($Wm^{-1}K^{-1}$) Density (kgm^{-3}), Specific Heat Capacity ($Jkg^{-1}K^{-1}$) and Vapour Resistivity ($s \cdot g^{-1}m^{-1}$). Whilst this challenged the student's ability to research and source information independently and to make informed judgements about comparative materials, it did however slow down the process of gaining quick and meaningful environmental analysis data.

Wall Type 1 – Timber stud

Project Construction (Opaque: External Wall)

Description: WT1- Traditional Timber Stud   ID: STD_WAL1   External   Internal

Performance
U-value: 0.1768 W/m²·K   EN-ISO   Thickness: 297.500 mm   Thermal mass Cm: 33.8660 kJ/(m²·K)
Total R-value: 5.4849 m²K/W   Mass: 53.1400 kg/m²   Very lightweight

Surfaces
Outside: Emissivity 0.900   Resistance [default] ☑ 0.0400 m²K/W   Solar absorptance 0.700
Inside: Emissivity 0.900   Resistance [default] ☑ 0.1300 m²K/W   Solar absorptance 0.550

Functional settings
Regulations

Construction layers

Material (outside to inside)	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[WBA] WEATHERBOARD	25.0	0.1400	650.0	2000.0	-	200.000	Timber
Cavity	25.0	-	-	-	0.1300	-	-
[CHBA] CHIPBOARD	15.0	0.1500	800.0	2093.0	-	450.000	Timber
[STD_PHF1] Sheeps wool	180.0	0.0380	23.0	1800.0	-	9.000	Insulating
[CHBA] CHIPBOARD	15.0	0.1500	800.0	2093.0	-	450.000	Timber
Cavity	25.0	-	-	-	0.1800	-	-
[STD_US1] Plasterboard	12.5	0.2100	700.0	1000.0	-	0.000	Plaster

Copy   Paste   Cavity   Insert   Add   Delete   Flip   System materials   Project Materials
Condensation analysis   Derived parameters   OK   Cancel

Wall Type 2 – Laminated Column (200mm x 100mm) (with cellulose insulation)

Figure 4: WT2-IES System Construction Data

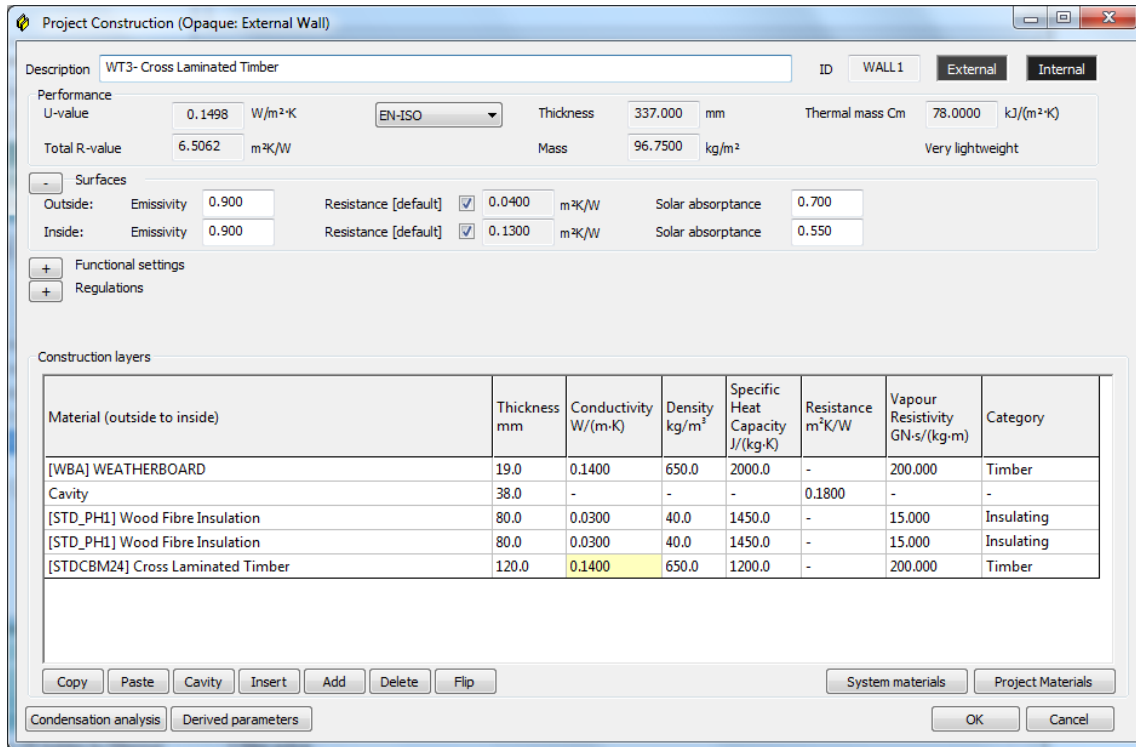## Wall Type 3 – Cross Laminated Timber (with wood fibre insulation)

Figure 5: WT3-IES System Construction Data

The cohort was then required to consider the overall thickness of the wall construction and not purely increase insulation levels to unrealistic levels to achieve the required U-value result. They were encouraged to consider layered insulation and also the practicality of inserting an insulated service zone. In order to emphasis the importance of using the software as a design tool students were encouraged to document the sequential construction layers, their thicknesses and the resultant thermal performance as their design progressed. This was to instil a habit of testing with the software rather than using it purely to prove an end condition.

In keeping with the design brief students had to achieve as close to Passivhaus standards as possible therefore the wall U-value of $0.15 W/m^2 K$. Figures 1, 2 and 3 above are examples of the wall types and their resultant U-values as generated by IES software. As the students were already familiar with manual U-value calculations through studies in Stage 1 they could therefore identify if numbers generated by the software were within an expected range and if not re-visit the input data to correct errors.

PM#3

Energy Consumption

In order to calculate energy consumption within the proposed building enclosure each wall construction required to be assigned to the model; a roof was then added and again the student had to assign materials to the roof construction (which again had significant levels of variation). Students were limited to 1 hour to test baseline annual thermal consumption (kWh/m^2). This short time frame was used to assess whether the software could be used to generate meaningful results quickly. The brief stated that the annual thermal energy consumption should also meet or be as near to Passivhaus Standard as possible (maximum space heating demand of less than 15 kWh/m^2). In the next task, the students then had to suggest methods of improving the energy efficiency within their design to achieve the required energy consumption. Students who found that the thermal energy levels excess of 15kWh/m^2 were advised to vary the roof construction and the window area in order to reduce energy levels.

Wall Type	WT1	WT2	WT3
U-value of roof	$0.15W/m^2K$	$0.15W/m^2K$	$0.15W/m^2K$
Floor Area	$20m^2$	$30m^2$	$29m^2$
Window area (% of facade)	23	40	15
Annual energy consumption	$21kWh/m^2$	$24kWh/m^2$	$17kWh/m^2$

Table 3: Baseline annual thermal consumption in kWh/m^2

Discussion

The exercise was carried out during a 1 hour weekly time slot over a 6 week period. This limited time frame provided an indication of how quickly students could be expected to grasp the key functions of the software. It was evident that those who had prior modelling knowledge mastered the drawing functions quicker then those with limited exposure to CAD modelling. However, those who spent most time in creating 3D geometry did not necessarily get more accurate results from the simulation exercises.

Time (hr)		Students completed task (%)	Students completed task with expected results (%)
1	ModelIT tutorial	89%	
1			
2			
1			
1	Energy consumption analysis		

This study highlights that design students are reluctant to work with simple massing models with many expressing concern that a simplified model made their design will look rather crude and unresolved. A focus group of students (40%) were asked to provide feedback from their experience of using the software. Most suggested that although more time was needed to grasp the key commands, they found it a useful tool in quick testing of ideas. There was genuine engagement in the energy prediction exercise and a level of competition between peers to achieve the best performing thermal envelope.

It was also evident from student feedback that the main concern during this exercise was the lack of access to the necessary performance data of organic building materials within the software. Students using more experimental materials struggled to obtain thermal data and resigned to making valued judgements using their existing knowledge of comparative materials- this lead to a perception that the analysis results weren't quite as accurate as hoped. Despite the student's prior familiarity with manual thermal calculations and the expected range of results there was still a feeling of mistrust or apprehension of the data produced. On the other end of the scale are examples where students had in error input a wrong value at the analysis stage and then gladly accepted the wildly incorrect result in which the simulation had produced.

During the workshops, when using the software students became more conversant in the terminology associated with the subject. Students were not simply using the terminology but were able to explain the results of this analysis when discussing their design projects. Overall however, students valued the results and found the process rewarding although many acknowledged that an environmental analysis programme which could easily integrate their existing design models previously generated in the studio would be the best option for analysis.

Conclusion

Predicting a building's post-occupancy performance early in the design process gives the design team the greatest opportunities to optimise a building project and understand the design decisions that will have a significant impact on carbon footprint. This is a skill which can be taught to architects early in their education thereby encouraging a greater dialogue regarding building performance at the early stages of the design process. This paper outlines a method which can be used in teaching of environmental simulation software in an undergraduate context which can enhance concurrent studio design projects. Teaching with IES software tools can reinforce the notion that design is iterative and balances many different dimensions. In relation to a design effort, while the the quality of the results is important, the mere idea and process of comparing between several options is essential.

The IES GAIA software introduces designers to a basic level of simulation which can be added to as the student progresses through their architectural education and develop more sophisticated responses to more challenging design briefs. This paper highlights the level of useful analysis which can be achieved within a short timescale however it also acknowledges that in later phases of the design process, accuracy takes precedence over immediacy as a building becomes more defined.

To conclude, whilst computer models for the simulation of the thermal performance of buildings have been in existence for many decades they still rely on designer's intuition and experience to achieve optimum solutions for architectural design problems.

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