AN ADVANCED TOOL TO VISUALIZE RESULTS OF PARAMETRIC ANALYSES

Mattia Donato[1], Roberto Caria[1], Toby Clark[1], Gianluca Rapone[1], Giovanni Zemella[1]
[1]Arup Façade Engineering, ARUP, London, UK
Correspondent author: Mattia Donato (mattia.donato@arup.com)

ABSTRACT

Sensitivity and optimization analyses are used to explore a wide range of possible façade configurations during the first design phases. However, design teams fully benefit from these assessments very rarely as the available software tools might not be suitable or may deliver unclear results.

This paper presents an approach to parametric analyses that aims at overcoming these limitations.

A project specific and fully tailored post-processing tool was built to allow design teams to organically work together, saving time and resources. Different software were used to ensure flexibility and accuracy. Finally, a 3D linkage was developed to take into account the effect of the surrounding buildings.

To conclude, this paper presents a new approach to parametric analyses that relies on an interactive, flexible and user-friendly tool, to help teams take full advantage of the first design phases.

INTRODUCTION

During early stages of project developments, design teams need to explore a wide range of possible concepts so that they can feel comfortable that their solutions address the project constrains.

Due to the restrictive requirements of building regulations (e.g. PartL 2013) and energy certifications, these phases have become very important when it comes to consider the whole life cycle of buildings (Figure 1). Indeed, these decisions account for 80% of the total impact on the final building performance (Bogenstatter, 2000).

Building envelopes play a key role in controlling the exchanged thermal, acoustic and light flows between the indoor and the external environment (Bogar et all., 2013, Zemella et all., 2011). Hence, it is common practice testing different configurations of façades to minimize the overall energy demand.

To do that, the most effective approach is to run sensitivity analyses in order to understand how a specific parameter affects the overall result.

Increased availability of computational power has made possible to test huge numbers of variations and to run optimization analyses via evolutionary algorithms (Zemella et All, 2014).

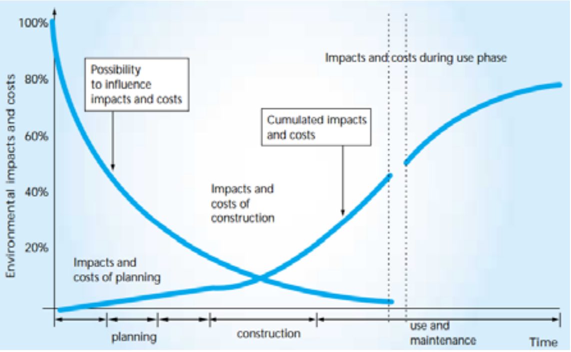

Figure 1 – Influence of design decisions on life cycle impacts and costs (Kohler N. and Moffatt S., 2003)

However, design teams fully benefit from such parametric and optimization analyses very rarely. This is due to a number of reasons, but two key issues are the following:

- Difficult balance among flexibility, accuracy and level of user friendliness of the software tools available for dynamic energy simulations;
- Difficulty in handling the amount of data and deriving clear indications that the design team can follow.

This paper presents an approach to parametric analyses that aims at combining their potential strength whilst limiting the downsides mentioned previously. The ultimate goal is to have a project-specific, fully tailored tool built to meet the needs of the design team.

The following paragraph describes its development and its key features.

SIMULATION

Early stages of project developments require rapidity in decision making about the best options to further develop. Decisions are driven mostly by performance requirements as well as by the ambition to meet the aesthetic and architectural vision.

Usually, the design may not appear organic and this may lead to repetitive analyses so that there is strong need for new and innovative tools. The one presented here aims at improving clarity of the results for the whole design team.

The idea

One of the main goals was to create a tool on which Architects and Engineers could work simultaneously on the design of a building. Figure 2 shows an efficient workflow with different stages, the professional figures involved and the main outcomes.

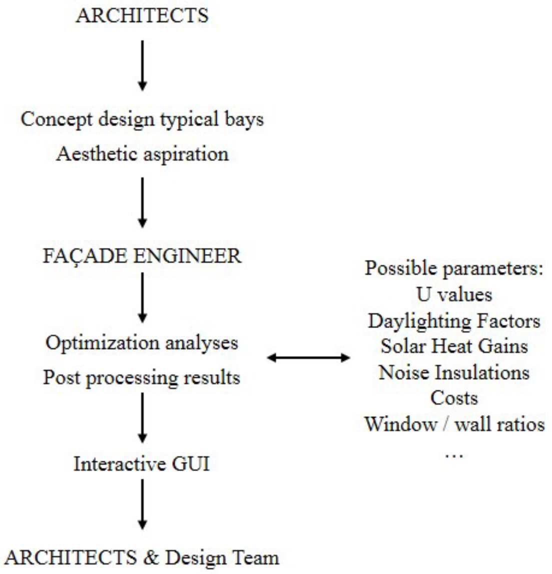

Figure 2 – Possible workflow of the analysis

With a holistic approach, Architects define their aspirations and possible solutions to achieve their goals. Façade Engineers then adopt the idea and rationalize the concept in order to create different possible façade configurations to assess.

They also select the variables and their ranges and run parametric analyses assisted by the design team. The results are then post processed and inserted into automatized spreadsheets, which can manage a huge number of data.

Finally, a user friendly GUI (*Graphic User Interface*) is developed to derive clear indications to be followed during the design development.

Methodology and assumptions

Arup Façade Engineering (AFE) followed this approach during the first phases of a project based in London.

At that stage, Architects appointed AFE to explore different façade configurations, ensuring good building performances such as overall U values, low solar heat gains and high daylighting without limiting architectural flexibility.

An agreement within the whole design team defined possible variables to be explored parametrically. Architects then provided possible façade modules to be assessed (Figure 3).

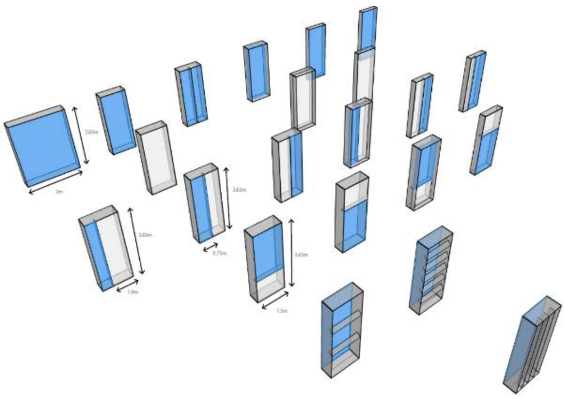

Figure 3 – Modules provided by Architects

Among them, 14 different elements were selected. Each module presented a different window / wall ratio and the presence of an external cornice, 300mm deep (Table 1).

In addition to these modules, the effect of horizontal and vertical fins was considered only for fully glazed ones.

Generally, the width of the modules was equal to 1.5m and the height was equal to 3.65m. The only exceptions were two modules types, which were 3m wide.

Then, AFE evaluated the overall performance of each one.

Before proceeding with the analyses, different parameters were defined such as the type of glass to test and the build-up of the opaque portions:

1) Double gazing units (DGU) with a centre pane U value of 1.0 W/(m^2K);
2) Triple Silver Coating: g value 0.28 and visual light transmittance of 60%;
3) Spandrel area with a centre pane U value of 0.22 W/(m^2K);
4) Unitized System.

In order to take into account the thermal performance of the frame arrangement, thermal models were carried out by means of BISCO (i.e. software tool provided by Physibel).

For each module, thermal, solar and daylight analyses were evaluated.

In particular, when the modules presented shading devices, sensitivity analyses were carried out considering different configurations of horizontal and vertical fins.

Table 1
Summary of the assessed modules

MODULE	W/W [%]	CORNICE	SHADING DEVICES
Module A	~ 99%	X	X
Module B	~ 98%	X	X
Module C	~ 48%	X	X
Module D	~ 32%	X	X
Module E	~ 65%	X	X
Module F	~ 71%	X	X
Module G	~ 71%	X	X
Module A1	~ 99%	✓	X
Module B1	~ 98%	✓	X
Module C1	~ 48%	✓	X
Module D1	~ 32%	✓	X
Module E1	~ 65%	✓	X
Module F1	~ 71%	✓	X
Module G1	~ 71%	✓	X
Module Ver_x	~ 98%	✓	✓
Module Hor_x	~ 98%	✓	✓

Three software tools were selected to undertake the assessments. Indeed, combining different software provides the greatest levels of flexibility and accuracy, as each software allows to address a specific need.

In this case, EnergyPlus was adopted to assess the amount of solar heat gains per configuration and for different external shading system options per elevation.

Radiance was chosen to determine how daylight levels were impacted by different shading strategies. Thermal analyses with BISCO were carried out to determine the thermal bridge effects.

Due to the great amount of configurations (~ 600) – as combination of type of modules, layout shading devices and orientation - tailored scripts were built to run the parametric analyses for solar and daylight assessments.

Solar analyses were carried out in order to calculate the solar heat gains within a perimeter zone of 4.5m depth in accordance with BCO guide. They were calculated over daytime hours (07:30 am to 5:30 pm) in accordance with CIBSE Technical Memorandum (TM) 37. In this case, a percentile of 97.5% was considered rather than the actual peak values.

Daylight analyses were carried out considering points upon a grid at 0.7m height from the floor (work plane) and 0.5m far from the walls, in accordance with BS 8206-2:2008.

The following step was to provide the façade performance when these modules were combined together.

The solar heat gains were calculated by an area weighted average of the solar performance of each module of the façade.

With regards to the daylight performance, the evaluation was carried out taking into account the reciprocal effect upon the overall daylight levels of the analysis grid.

The interaction of the different modules generates a combined effect. This was translated into a linear combination of daylight factors upon the grid thanks to the superposition principle for linear systems.

No daylight influence was noticed after 3 modules. This leaded to choose seven modules in order to take into account all the interaction of one module with the lateral ones.

Finally, validation by means of Radiance was undertaken to ensure accuracy of the results.

Uniformity ratio in accordance with BS 8206-2:2008 was also calculated.

Design tool

All the results were collected into a user-friendly interactive spreadsheet that combines performance values with simplified diagrams that show the visual appearance of the façade.

There were up to 160 choices per bay for each elevation considering all the possible combinations of shading devices for depth, tilt and distance within each other.

Therefore, a façade combination could accommodate up to seven modules (~ 2^{15} possible combinations).

In addition, to ensure even greater flexibility up to ten façade options could be created (Figures 4 & 6).

Finally, the tool allowed to visually show three configurations per time over the ten built.

At this stage, two requirements had thresholds such as solar heat gains and average daylight factor.

The solar heat gain target was set up to 60 W/m^2 (suitable for cooling system with passive chilled beam or chilled ceiling) whilst the target minimum Average Daylight Factor (ADF) was set up to 2% (BSO guide for offices).

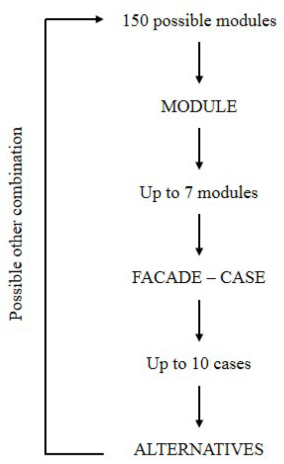

Figure 4 – Façade composition workflow

Figure 15 shows the GUI of the tool, which was subdivided into different sections as follows:

1) Section 1 (Figure 5), an overview of each module with geometrical, solar and thermal properties;

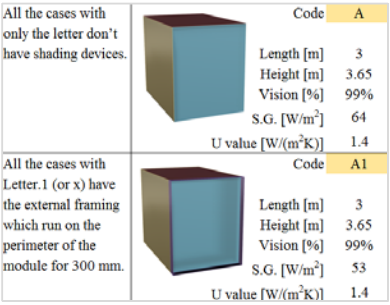

Figure 5 – Description of the bay via performance

2) Section 2 (Figure 6), a button to select the orientation of the current analysis. In this case, due to the urban constrains, the main orientations were South East, South West, North West and North East;

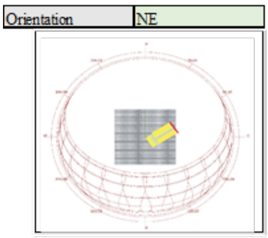

Figure 6 – Orientation selection

3) Section 3 (Figure 7), the main tab where a drop down menu allows to select the module per each cell and build the façade case;

Module	1	2	3	4	5	6	7
Case 1	A1	B	E1	B	D	B	B
Case 2	D1	E1	[illegible]	[illegible]	D1	G	D1
Case 3	B1	G1	[illegible]	[illegible]	A	A1	B1
Case 4	A1	G1	[illegible]	[illegible]	B1	A1	B1
Case 5	D1	E	[illegible]	[illegible]	D1	D1	B1
Case 6	D	C	[illegible]	[illegible]	E	F1	B1
Case 7	D	D	G1	A1	E1	D	D
Case 8	G	C	G1	C1	B	A1	B
Case 9	D	F1	G1	C1	B	D	D1
Case 10	B	G1	C	C1	D1	D	D1

Figure 7 – Main tab to choose façade configurations

4) Section 4 (Figure 8), the simplified visualization of the selected façade;

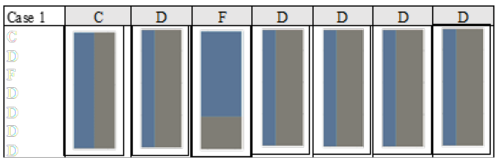

Figure 8 – Preliminary façade visualization

5) Section 5 (Figure 9), if a bay with shading devices is chosen, this tab will allow the user to choose the shading device configuration;

Vertical fins' summary				
Type	Spacing	Depth	Tilt	S. Gains
Ver_1	0.25	0.30	15	8
Ver_2	0.25	0.30	30	21
Ver_3	0.50	0.30	-30	11
Ver_4				
Ver_5				
Ver_6				
Ver_7				

Figure 9 – Main tab to choose shading device type

6) Section 6 (Figure 10), the first graphical outcomes. Per façade configuration, the area weighted solar heat gains are shown comparing them with the requirement of the mechanical system;

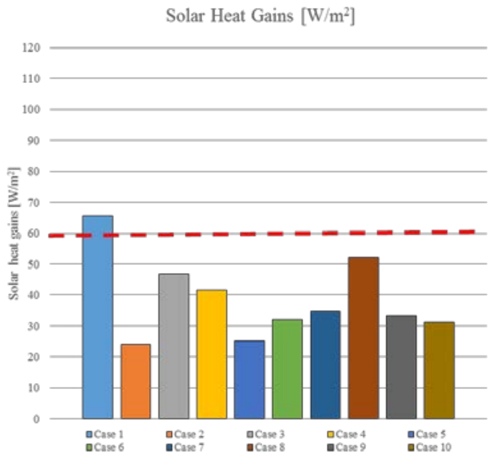

Figure 10 – Solar Heat Gain results

7) Section 7 (Figure 11), the second graphical outcomes. Per façade configuration solar heat gains and average daylight factor were represented to achieve better understanding of the façade overall performance. The configurations in the green area were meeting both solar heat gains and daylight requirements;

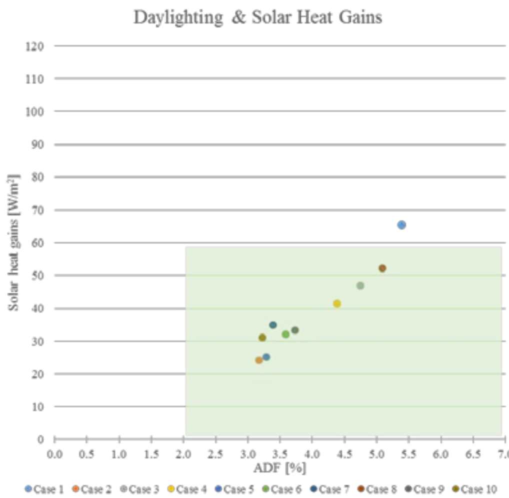

Figure 11 – Solar Heat Gains Vs Daylighting results

8) Section 8 (Figure 12), the third graphical outcomes. Daylight factor false colour distribution upon a grid at 0.7 m height is shown for one selected case;

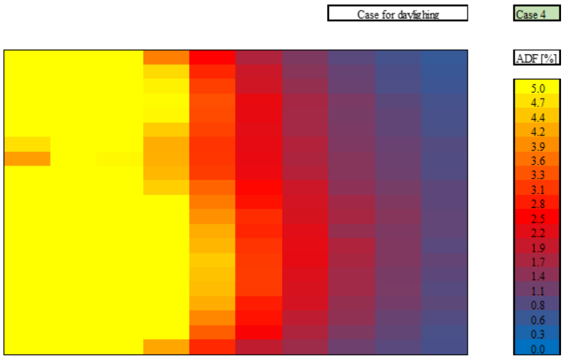

Figure 12 – Daylight Factor distribution

9) Section 9 (Figure 13), the summary of the main outcomes of the analysis. In this case, total length of the façade case, % of vision area, solar heat gains, overall U value, average daylight factor and uniformity ratio are shown.

Module	Total lengh [m]	% Vision Area	Solar Gains [W/m^2]	U overal [W/(m^{2}K)]	Average DF [%]	Uniformity ratio
Case 1	12	86%	66	1.5	5.4	0.12
Case 2	10.5	48%	24	1.4	3.2	0.10
Case 3	13.5	84%	47	1.5	4.7	0.11
Case 4	13.5	83%	41	1.4	4.4	0.12
Case 5	10.5	54%	25	1.4	3.3	0.12
Case 6	10.5	56%	32	1.4	3.6	0.07
Case 7	12	58%	35	1.4	3.4	0.08
Case 8	12	79%	52	1.5	5.1	0.10
Case 9	10.5	55%	33	1.4	3.7	0.10
Case 10	10.5	52%	31	1.4	3.2	0.09

Figure 13 – Summary of the outcomes

In addition to the main GUI, additional graphs were generated to support the user in selecting the shading device configuration.

Each graph presented an overview of the amount of solar heat gains corresponding to certain options. For instance, the graph in Figure 14 shows for a certain orientation and a defined depth of horizontal fin, the amount of solar heat gains per different spacing and tilt.

These charts were generated per elevation.

Having an overview of the solar heat gains for each shading device configuration could assist the Architects in selecting the most suitable louvers configuration that meets both solar heat gain target and design aspiration.

Therefore, this interactive spreadsheet combined performance values with simplified diagrams showing the visual appearance of the façade. This is a key part to allow the design team to associate performance values and visual appearance at the same time.

Finally, to increase the tool efficiency, the effects of the surrounding buildings were also taken into account as illustrated in the following section.

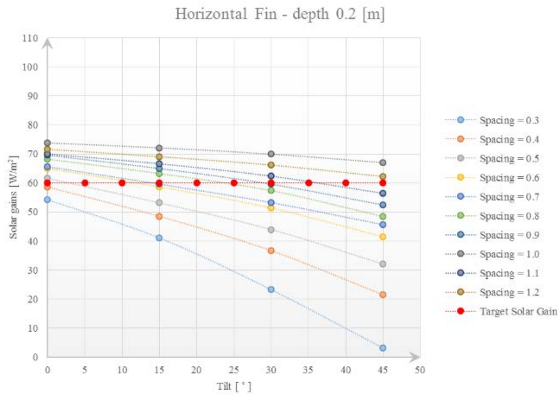

Figure 14 – Example of chart provided in the tool

Effect of the surrounding buildings

Once the approach was considered viable for the typical areas at the top building (i.e. for the areas fully exposed to solar radiation), the impact of the surrounding buildings was also taken into account, as some parts of the façade are shaded.

This required an additional step through a 3D model.

The Architects provided the 3D model of the building whose envelope was sub-divided into typical module size (1.5 m width and floor-to-floor height of 3.65 m). The surrounding buildings were included.

A script by means of HoneyBee and LadyBug (Grasshopper plug-ins environment) was composed to assess the incident of solar radiation throughout the year per façade bay.

The maximum value of each bay was then compared to the maximum value for the corresponding unobstructed elevation.

The result of this exercise was a false colour scale of the assessed 3D model showing a reduction percentage for each bay to be applied to the solar heat gains obtained by the new tool.

Furthermore, the percentage reduction could be read in the object name of the selected bay. Figures 16 and 17 show the false colour scale of the 3D model.

Since the 3D model and spreadsheet were not fully linked together (as they were developed during different stages of the project), the solar heat gains provided by the spreadsheet had to be decreased manually by the percentages shown in the Rhino model.

A similar analysis could be carried out to evaluate daylight factors in order to consider the impact of the surrounding buildings. This is possible with the same methodology applied to assess the solar heat gains.

In the following paragraph, the obtained results and the key features of the tool are illustrated.

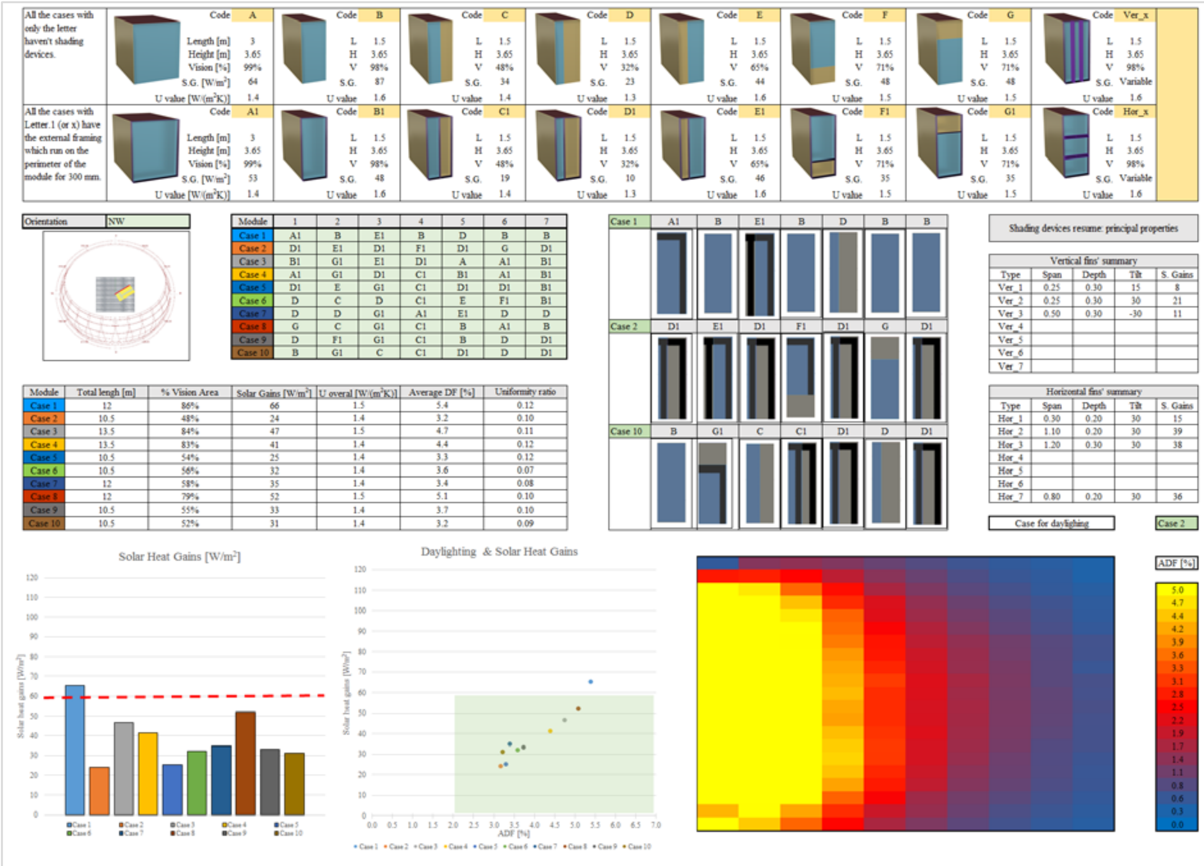

Figure 15 – Main GUI of the tool

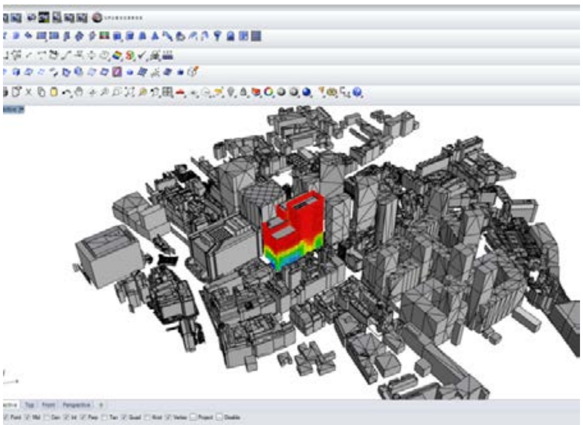

Figure 16 – Context analysed

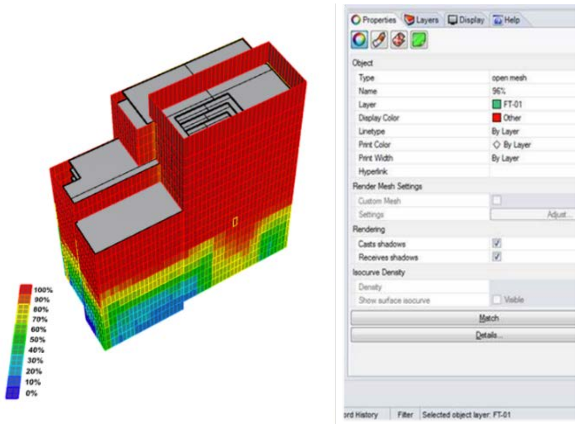

Figure 17 – Zoom into the module properties

DISCUSSION AND RESULT ANALYSIS

Model use considerations

Usually, results from parametric analyses or optimization assessments provide ranges of variables within a domain to obtain certain goals.

However, the results might not be clear or sufficiently flexible for the whole design team.

The main advantage of this tailored tool is its user-friendly interface that provides clear and flexible results.

Moreover, thousands of options can be investigated in detail ensuring sustainable achievements without limiting architectural flexibility.

Hence, accuracy and flexibility are two key features of this tool.

Key features and future upgrades

The interactive spreadsheet introduced in this paper presents different features, which may improve efficiency and effectiveness during early design stages.

The tool was designed by means of Microsoft Excel (VBA) and the analyses by means of Energy Plus, Radiance and BISCO. A link was developed by means of Rhino and Grasshopper.

Except for BISCO, which could be replaced with the free THERM by LBNL, all the other platforms are open source or free and available at any architectural or engineering office. Moreover, they can be adapted to the specific needs of the project.

In addition, on this unique platform both Architects and Engineers may work simultaneously leading to better understanding of the different options explored during the design phase. This practice may improve efficiency as it helps saving time and resources.

Finally, this tool could also raise wider understanding of the physics involved in the construction by users who are not usually involved in the building physics assessments such as Architects.

Limitations

Alongside the benefits of this approach, there are some limitations.

The tool is tailored made so that the definition of the building performance as input (solar, daylight and U-value performance of the envelope) and the choice of the output to be visualized are project specific. Therefore, it cannot be used for other projects, unless the input data are updated.

Moreover, since it is a post processing tool it does not allow changing the chosen variables after the parametric analyses are completed.

Finally, the linkage with Rhino should be further developed to ensure better accuracy and flexibility of the approach. This could be possible via software interconnections.

Despite these limitations, the tool can still be adapted to projects that have different needs (i.e. for this specific case the properties of the glass were unique).

Indeed, it is possible to consider the effect of different glass types with small adjustments. Similarly, it is possible to visualize other performance like heating and cooling loads rather than solar heat gains and daylight levels.

CONCLUSION

This paper presents a new approach to parametric analyses that relies on an interactive, flexible and user-friendly tool. Arup Façade Engineering adopted it during the first phases of a project based in London.

The main objective behind its development was for the design team to fully benefit from sensitivity and optimization analyses overcoming the limitations imposed by current software.

This implies a close collaboration between Architects and Façade Engineers from the very beginning of the design stages.

Indeed, they need to agree on design specifications and then explore different façade configurations, ensuring good building performances such as overall U values, low solar heat gains, high daylighting and architectural flexibility.

In this specific project, the analyses were undertaken relying on three different software to ensure accuracy and flexibility.

Subsequently, all the results were collected in an interactive spreadsheet that combined performance values with readable diagrams showing the visual appearance of the façade. Architects could then use this tool to determine the façade design that meets the energy performance requirements and the aesthetic aspirations.

Finally, since sensitivity analyses (mainly for high rise building) are quite often carried out without considering the effect of surroundings and then focussed on a typical bay, an additional step through a 3D model describing the whole façade was necessary.

Even though there are still some limitations that require further research (i.e. the linkage with Rhino), teams can still fully benefit from its flexibility and accuracy.

To conclude, this paper presents an accurate and flexible project specific and fully tailored post-processing tool, which enables design teams to work organically together, saving time and resources by avoiding misleading.

REFERENCE

Bogar et all., 2013. GA-optimisation of a curtain wall façade for different orientation and climates. IBPSA 2013. Bolzano (Italy).

Bogenstatter, U., 2000. Prediction and optimitization of life cycle costs in early design. Building Research & Information.

British Council for Office (BCO) 2009. Guide 2005 Best practise in the specification for offices.

British Standard Institution. 2008. BS 8206-2, Lighting for buildings – Part 2: Code of practice for daylighting. London (United Kingdom).

Chartered Institution of Building Services Engeneering. 2006. Technical Memorandum 37, Design for improvde solar shading control. London (United Kingdom).

HM Government. 2013. Conservation of fuel and power. Approved Document PartL. London (United Kingdom).

Kohler N. and Moffatt S. 2003. Life-Cycle Analysis of the Built Environment, United Nations Environment Programme Division of Technology, Industry and Economics Publication, UNEP Industry and Environment.

Zemella et all. 2011. Optmized design of energy efficient building facades via Evolutionary Neural Networks. Energy and Building.

Zemella et all. 2014. Evolutionary Optimisation of Façade Design. A New Approach for the Design of Building Envelopes. Springer-Verlag. London (United Kingdom).