WHAT ARCHITECTS WANT? BETWEEN BIM AND SIMULATION TOOLS: AN EXPERIENCE TEACHING ECOTECT.

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ABSTRACT  
This research has the aim to investigate what kind of tool is really the best for architects and architecture students. It focuses on the experience using several tools in professional engineer life (TRNSYS, Ecotect, Lider-Calener, Archisun, Energy Plus) and teaching simulation methods to architecture students. Probably architects and architecture students desire to have instruments of simulation and analysis of building, without obligation of knowing details on buildings physics and systems functioning.

This fact was partially confirmed during the second part of 2010 and first part of 2011, teaching Ecotect to architecture students. Students were pupils of 2nd, 4th and 5th course. They have low building physics formation, but high information on architecture process and a really interesting capacity to use different design tools. In the first days of the course, a frequent question was: “how to import models by Revit or 3DMax or Archicad?”

INTRODUCTION  
First step of paper is presentation of a classification method for simulation tools, proposed by author and M. Massetti developing their PhD thesis. This method is founded on four concepts: complexity, transparency, design impact, and uncertainty. Tools can be classified thinking on these four concepts. A simulation tool is complex if permit high levels of precision (finite elements). A simulation tool is transparent when all the values that user has to insert are clearly explained in the tool. A simulation tool has high impact on design if permit rapidly and easily to modify the simulation object (normally a building). Finally, a tool has low uncertainty if results don’t change significantly when input parameters change.

With this classification method, tools can be divided in two or three categories: The first is the category of tools with high complexity and high precision (low uncertainty), but with poor possibility to influence directly the design. These are the tools used by engineers, normally in the final stage of the building project, when architects have just finished with the building’s form design. The second ones are opposite tools: these are tools with high possibility to influence design since the earliest stage of it, but low complexity and transparency. Precision of this kind of tools depends strongly by the fixed parameters in the data input process. Like suggested by various authors, it can be possible that tools like these will have a robust behavior more than others. The third group of tools is the group of BIM and simulation tools like Ecotect, which has the characteristics of good design impact, intermediate level of complexity and transparency, and direct relation with the design basic instruments like Autocad.

The last part of this research shows the students attitude during the entire Ecotect Course, and suggest that is very important to search new approaches to the building simulation, using different tools and preparing students to understand the basic processes of the energy exchanges in buildings.

METHODOLOGY

Classification method

Existing literature (see for example the works of Crawley et al. (2008), Waltz (2000), Clarke (2001) and reference therein), put in evidence the difficulty to classify and compare different tools due to the large variety of calculation approaches. Energy simulation of building is assuming more and more a relevant role in Architecture Engineering and Construction (AEC) sector, with the recent policies and regulations in the international scenario, e.g. EU directive application, ISO/FDIS (2006).

The Energy simulation application is expanding from the research ambit to the architectural practice. In fact, while in the research ambit it is consolidated in the ordinary architectural practice it is not. It has just been used mainly in exceptional cases but not in the common practice for ordinary buildings until the present. The widespread application of energy simulation in ordinary architectural practice primarily requires the formulation of classification criteria. Such classification is necessary to identify the proper tools to be used at each different stage of building life cycle.

In architectural practice instead a multidisciplinary approach is expected because is fundamental to consider a wide variety of problems together (e.g. economical, formal, structural ...). Therefore energy analysis has to be integrated within a large variety of analysis. Moreover competences of professionals,
budget and time available, depending on the case, may be very limiting constraints in ordinary practice. In architectural practice proper energy simulation tools are necessary to fit with the needs of different design stages. At the initial design stages several problems are faced maintaining a high degree of indefiniteness. Very different design possibilities are opened and only general concepts and characteristics are considered. At the final design stages most design solutions are defined and the design problems are treated with more detail.

The proposed methodology is a classification of energy simulation tools by four steps analysis. Characteristics investigated are: the discrete reduction of space and time of the tool; the transparency and repeatability of the tool; the possibility of the tool to modify a design solution with immediacy and with a rapid feedback on the calculation results; and the uncertainty of the calculation results. Each step is described in the follow.

Complexity
In energy simulation tools, the representation of a building is made by a model consisting of a system of objects with different levels of complexity according to the tool. The discrete description strategy is the basic characteristic of a building performance simulation tool. How the model is subdivided in basic objects strongly influences calculation and results. There are two fundamental discrete reduction of the reality in a simulation tool: the space description and the time dependence. The space description regards the zones of the building definition and the elements definition (walls, windows, systems). The time dependence definition regards the climate files used, the user-dependent variables definition and the system functioning determination (c.f. the categories proposed in ISO/FDIS (2006): quasi-steady-state methods and dynamic methods).

Transparency
Simulation tools transparency and repeatability proprieties are fundamental for the designer. Transparency is the clearness of the tool in the data inserting process, this means, the simplicity in the description of the parameters, the immediateness of the concepts, the language used, etc. Repeatability relates to transparency, and indicates the no-dependence of the result by the user of the tool. It is very common that results change as tool’s user changes, caused by different interpretations of instructions, parameters and concepts.

Two transparency concepts are proposed to consider the architect’s point of view: qualitative and quantitative transparency. Qualitative transparency relates to the immediate intelligibility of building simulation parameters such as elongation, compactness or in general building characteristics of geometry and form. Quantitative transparency relates to the clearness in the physical parameters definition (e.g. in the physical units, the use of the international system, the significance of the extremes when a per cent value selection is proposed, etc.).

Design Impact
A relevant characteristic of the tools is the possibility to modify design solutions with immediacy and with a rapid feedback on the calculation results. According to the tool it is easy, difficult or impossible to modify the model to explore different alternatives along the design process without the need of creating again the model from scratch. For an effective reiterative design flow, the immediacy of the sequence of modification – result – interpretation – modification is fundamental.

Uncertainty
Validation of the tools can be searched by sensitivity analysis, as suggested by Saltelli et alt. (2000). However, role of uncertainty is not clear. Uncertainty can be regarded as a problem in the tool’s calculation model, but at the same time the objective of a simulation is to validate different architectural options.

Uncertainty of inputs has different origin, and in the majority of the cases is both epistemic and aleatory. Epistemic uncertainty includes errors in the data introduction, design uncertainty, materials provision differences, estimations or suppositions of both simulation and building designers. While aleatory uncertainty is defined as irreducible, epistemic uncertainty is reducible, as shown by Hoffffman and Hammonds (1994). In the aim of this work, will be interested to separate the design uncertainty, this means, the architectural options, and reduce as much as possible all others epistemic uncertainty. Especially simulator related uncertainty, that origin by bad transparency in the data insertion and by approximations in calculation methods has to be minimized.

A good tool for building performance simulation has a minimized epistemic tool-related uncertainty and permit design option test. Moreover, is uncertainty only an error in the model, or is the substance of the human description of the reality? The same buildings are sensitive to changes in the conditions (climatic, dependent of the users, dependent of the systems).

Uncertainty in the consumption result is maybe no eliminable. If it is true, a good behavior of a building can be determine by robustness, this means, by a low sensitivity. In this case, the aim of a simulation will be determine the range of uncertainty of the building, and validate the project. So, a goal for the tool can be the capacity to indicate the building sensitivity, and the consumption result variability seems not to be an error, but a desired tool’s character.
Categories
By using prior methodology to classify the simulation tools, it appears that existing tools can be divided in three big categories. Categories are respectively: tools used by engineers, with high level of discretization and low possibility to internal use to design modification; architectural tools characterized by low discretization and high design impact, with uncertainty solution like fixing uncertain parameters; tools with medium level of discretization and precision but with the important character of linking with other software (energy BIMs). As an example, consider tools analyzed en table 1, where TRNSYS is a typical engineering tool, Archisun is a didactical architectural tool and Ecotect is an intermediate tool with some BIM characteristics:

<table>
<thead>
<tr>
<th>CHARACTER</th>
<th>TOOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discretization</td>
<td>TRNSYS</td>
</tr>
<tr>
<td></td>
<td>ECOTECT</td>
</tr>
<tr>
<td></td>
<td>ARCSUN</td>
</tr>
<tr>
<td>Qualitative transparency</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Quantitative transparency</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Design modification</td>
<td>Very low</td>
</tr>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Validity and precision</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
</tr>
</tbody>
</table>

Actually, this classification does not take into account the fact that tools can be linked each other, and especially Ecotect seems to be this kind of tool, and have the important propriety of supply to the internal relatively bad calculation by linking out. So geometrical definition of the building can be very high, spatial visualization is great, and calculation is reminded to better calculators.

Architects seems to approve this kind of tools, and inclusive complex certification processes like LEED revision recently starts to accept Ecotect as “mother” of a family of simulations done by Radiance (lighting), WinAir (air movement) and EnergyPlus (thermal performance).

TEACHING EXPERIENCE
With this prior consideration, it can be analyzed teaching-laboratory work of the second semester 2010 in the UCN School of Architecture. School direction and various professors were searching for a new teacher in energy simulation fields.

Ecotect was the selected tool, justified by the expressed spatial visualization necessity for architecture students, especially in countries where architecture and engineering are not “friendly” disciplines how should be. Therefore, study plane was the integration of physical concepts into Ecotect modelling lessons, and it was also difficult because of the generic student attitude. Pupils are quite indolent nowadays, and the software technology is not often a good example for them. Ecotect software permits to construct good visual building models, so students often consider calculation as less important part of simulation.

However, calculation was included in the programme of the course by presenting the physic principia and separating the model creation from the simulation conducted by Ecotect itself and by other tools, like Radiance and WinAir. Output linking possibilities offered by Ecotect (exportation windows) are satisfactory. The problem is, in case, the import management. In theory, Ecotect imports graphical models 2d and 3d, but reality is very different to theory. Imported models have to be always submitted to revision and often they have to be strongly modified to respond to simulation order (zoning, materials, etc…).

Projects presented by students are interesting architectures, with a large form typology, material research, formal expression, urban context insertion consideration… Ecotect modelling solution was not the same for each project. Some projects were remodelled inside Ecotect from zero. Some projects, at the other hand, were imported by 3d models (Revit, ScheckUp, 3DMax). In the result discussion, importation process is presented and discussed statistically.

Under professional point of view, the goodness of some complex building model is a very important result. More interesting for an academic discussion was probably the same physic teaching process. Method was finally very simple: lessons included a theory part with the principle enunciation. Especially material proprieties and relative Ecotect data input were discussed.

Student’s attitude was obviously quite different, depending on the age and on the involvement in sustainable architecture and energy simulation fields. However, all pupils of 2<sup>nd</sup>, 4<sup>th</sup> and 5<sup>th</sup> course had to participate to the laboratory and to try to insert their projects in Ecotect simulator.

In general, they ware more interested in the graphical modelling, because of prior formation, which is stronger in design than in energy fields. Building physics interested only a small part of the students.

Table 2 shows the number of students divided by course and the results in terms of improvement of modelling Ecotect, building physics and sustainable architecture knowledge in general.

Some student of 6<sup>th</sup> course included Ecotect studies in the thesis. Results in this case were quite good, of course, depending to the reasonable involvement of the student in the field.
Table 2
Students results by course

<table>
<thead>
<tr>
<th>COURSE</th>
<th>GENERAL RESULTS OBTAINED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ECOTECT MODELLING</td>
</tr>
<tr>
<td>2nd</td>
<td>Poor</td>
</tr>
<tr>
<td>4th</td>
<td>Good</td>
</tr>
<tr>
<td>5th</td>
<td>Quite good</td>
</tr>
<tr>
<td>thesis</td>
<td>Quite good</td>
</tr>
</tbody>
</table>

Moreover, course objective were quite different. Study plan of the UCN School of Architecture organises in 12 semesters, in which students is taking inside the architecture concept, using as steps the classical invariants of the architecture. So, courses are characterized like the follow:

1. initial cycle (1st and 2nd semester)
2. basic cycle (3rd to 6th semester)
3. professional cycle (7th to 10th semester)
4. thesis cycle (11th and 12th semester)

Basic cycle is characterized by the invariants: cover (3rd semester); resource (4th semester); language (5th semester) and context (6th semester).

Professional cycle is characterized by materialization (7th semester), territory (8th), energy (9th) and theory (10th).

Ecotect teaching was inserted in the first semester of the basic cycle, in the first of the professional, and in the energy and architecture course of the 9th semester. Obviously, teaching strategy was not the same in the tree cases.

Pupils of “Taller 3” are younger and need to understand the bases of the architecture. They study the first invariant, cover, that is, an important architectural concept related to people, buildings and environment. Cover means, for instance, protect and use the environment, to obtain favourable conditions to live. Material of walls and roofs are also the first matter they use in their exercises. Ecotect lessons include propriety of the matter, transmittance and solar calculations, ventilation use discussion. Modelling is basic and physicist conceptualisation quite important.

Students of “Taller 7” are just in the middle of their study. Materialization means that students make better (professional) a project of the prior courses. This is the first complete architecture project they do. Ecotect modelling have to help students in tacking decisions and making real the project idea they have. Modelling is also privileged in teaching, and building physics is not prevalent. Really, decision have to be tackled thinking in energy efficiency and comfort concepts, but formal investigation are not secondary in this phase.

Students of “Taller 9” have to realize a complete professional project, and often they participate to competition with the result. They need advanced modelling notions, but are not always prepared for this level of software management. Of course, energy building use and general sustainability concepts are worked hard in this case. Other characteristic of this course was also the urban context analysis, which was tried to be inserted in Ecotect modelling.

Finally, thesis works includes energy use in the discussion, and some student worked hardly in the energy field. However, it seems that physics concepts are suddenly forgotten, and modelling is often done under pressure for final presentation, without real attention to reach sustainability. Use of the tool was more justify the results than searching for solutions or different possibilities.

Table 3 shows the number of students that participate to the Courses during the second semester 2010 and the first semester 2011. Students that failed the final exam are shown as result of the course.

Table 3
Number of students of the courses

<table>
<thead>
<tr>
<th>COURSE</th>
<th>STUDENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
</tr>
<tr>
<td>Taller 3</td>
<td>25</td>
</tr>
<tr>
<td>Taller 7</td>
<td>17</td>
</tr>
<tr>
<td>Taller 9</td>
<td>21</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

Different kinds of results were obtained from the teaching experience. First, different modelling philosophies were compared, thanks to the high number of the students projects analysed.

One strategy was the classical “redrawing” model inside Ecotect. This is probably the most applied strategy in energy simulation of buildings. Another possibility tested is the file importation by 3D modellers, like Revit for example, that it has been published as a BIM of Autodesk with especial facilities to link with Ecotect. The last strategy was a mixed strategy: the main part of the models was done inside Ecotect, whilst complex geometry parts were imported by external tools.

Different strategy has pro and contra, of course, one of its is for example the weight of the file, that difficult analysis and model export to other tools.

Table 4 shows the number of objects of different models, realized respectively using the tree strategies.

It has to be notice that students of 2nd course use the same model to exercise, so number of models created is less than total number of students.
Table 4
Weight of the models

<table>
<thead>
<tr>
<th>DESIGN STRATEGY</th>
<th>WEIGHT OBTAINED</th>
<th>CASES</th>
<th>NUMBER OF OBJECTS</th>
<th>BYTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal modeling</td>
<td></td>
<td>38</td>
<td>500-1000</td>
<td>1-200 kb</td>
</tr>
<tr>
<td>Import by other tool</td>
<td></td>
<td>22</td>
<td>35000-90000</td>
<td>6-8 Mb</td>
</tr>
<tr>
<td>Mixed model</td>
<td></td>
<td>27</td>
<td>3500-5000</td>
<td>3-400 kb</td>
</tr>
</tbody>
</table>

Result shown by this table is the clear weight increment obtained using Revit or other external tool importation. This fact is due to the triangulation that the link operates on the objects of the model.

Figure 1 shows an example project inserted directly in Ecotect. Figure 2 shows an example of mixed mode strategy: base zones are directly drawn in Ecotect, solar protections are imported by Revit.

Figure 3 shows an example of urban modelling, obtained by autocad plan import and direct zone draw in Ecotect. Weight of the file is also very high, inclusive without 3D import process.

Another result obtained is the indication on the variety of analysis done by the tool. Selected models were analysed in acoustics, lighting, solar and thermal analysis.

Result interpretation has to be done thinking on the real possibility offered by Ecotect analysis. Lightening projects can be discussed using Ecotect and Radiance, but it is quite difficult to do it only using Ecotect, because of low sensitivity and bad discretization. Air movement analysis is, at the other hand, impossible without externals tool use. Figure 4 shows a CFD-Ecotect urban analysis. Wind analysis was one of the most used by student improving sustainability of their projects.

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Figure 1: Ecotect model obtained by redraw

Figure 2: Ecotect model obtained by mixed strategy

Figure 3: Urban Ecotect model obtained by redraw

Figure 4: CFD-Ecotect air flow urban analysis

This fact confirms the result indicating the high impact of air movement on the final building proposition. Ecotect without considering external links confirms itself as a good solar simulator, but not much more.
Effectiveness of analysis can be shown by influence of the Ecotect results on the replant of the exercise. Table 5 shows the importance of Ecotect suggestions on final proposition.

**Table 5**

<table>
<thead>
<tr>
<th>ANALYSIS</th>
<th>IMPROVING DUE TO ECOTECT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CASES ANALYZED</td>
</tr>
<tr>
<td>Thermal</td>
<td>87</td>
</tr>
<tr>
<td>Air movement</td>
<td>54</td>
</tr>
<tr>
<td>Acoustics</td>
<td>22</td>
</tr>
<tr>
<td>Lighting</td>
<td>43</td>
</tr>
<tr>
<td>Solar</td>
<td>93</td>
</tr>
</tbody>
</table>

Another kind of results, is the understanding of the physics, by working on the own project. It is difficult to quantify this result, but probably modelling in Ecotect helps definitively in knowledge transmission to the students. Work on a practical case makes more understandable the complex functioning of the buildings, that appears heuristic and maybe boring to architecture students when is done by mathematical development.

However, it is recommended to use traditional methods with younger pupils, who can easily take the minimum time necessary to construct Ecotect model, without profound in results feedback on the project, that is the most important step in practical education. Alternating theory and practice seems to be the better educational method in this case.

**CONCLUSION**

Ecotect is a tool that architects desire to use because of the high visualization character that offers. Moreover, link possibility among tools contributes to improve the Ecotect suitability in professional energy simulation and certification.

This paper focused on the suitability of Ecotect as didactical tool. Architecture students were obviously interested in the tool offer, but less opened to study the basic physical concepts related. Inclusive air conditioning systems are not one of the most interesting fields for them.

As expected, students worked hard on design and modelling. Some student reaches very good level inserting geometry, as shown by the figures. Using software to study the energy proprieties of the buildings, only few models were quite useful. Air movement and solar analysis were the most effective analysis, that is, analysis that lead to radical changes in the project between the first proposition an the final presentation. Professor evaluates the use of the tool in the final design strategy.

Building physic and sustainable architecture concepts in general, were achieved by practical experience within the software modelling management, much more than by traditional lessons. These results leave some teachers quite surprised. To be honest, it is not so strange: if architecture students are formed in modelling and tool management, obviously they will have facility in the practical education of study experimenting tool characters and proprieties.

Physic discussion was done posterior, using the student's experience in the laboratory. It appears definitively a good approach the idea of first do the effort to model the building, and then discuss its proprieties. For this, it is evidently necessary the student motivation. Result was better with final course or 5th course students than with 2nd and 4th. They really needed separate lessons on building performance characterization and physics.

Use of linked tools appears not obligatory, but recommended, especially in the case of CFD calculations. Air movement is one of the most effective analyses in the feedback work, when indication of analysis are used to manipulate the original architectural idea and proposition. So, facility offered by Ecotect in visualization of imported CFD calculations is a great character of the program, very useful in professional practice and in educational training as well.

As a conclusion, this year teaching Ecotect was an important experience, which indicates the student disposition to improve environmental knowledge if helped in a practical work that appears to them more interesting than equations and theory. Reliability of the method depends strongly on teacher capacity to insert elements of the theory when needed.

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