Implementing building energy simulation into the design process: a teaching experience in Brazil

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ABSTRACT: For many reasons building simulation programs are still not recognised as useful design support tools to the same extent as Computer-Aided Design (CAD) or cost-estimating software. There is a strong perception that simulations are time consuming, costly, slow and require expensive or specialised equipment and knowledge that increase design costs. Additionally, simplifications applied to model description, algorithm inaccuracy, or deviations inherent to weather data treatment methods result in poor matches between measurements and predictions, which decrease confidence in obtained results. Finally, complex tools and interfaces raise doubts among potential users. In general terms, energy efficiency is a recent concern in Brazil, but has clearly come to the discussion forefront among all construction sector stakeholders. In architectural design teaching at the undergraduate level in Brazil, environmental comfort and energy efficiency have been traditionally kept as separate knowledge domains. To overcome these problems a new discipline has been introduced at the University of Campinas, UNICAMP in Brazil following a bioclimatic design studio, to consolidate the acquired knowledge and test concepts on student's designs. To evaluate this course an experimental follow-up research is currently underway. This paper discusses the contextual framework that motivated and founded the approach for the introduction of simulation as both a decision support tool and a design teaching resource. The bioclimatic design studio given in 2005 provided students a contact with simulation tools and was used to assess the suitability of the chosen tool for such experience.

Keywords: Energy, simulation, design process, design methodology

1. INTRODUCTION

Studies in the early 90´s [1] showed that commercial buildings consumed 57% of the electrical energy produced in developed countries, being HVAC responsible for approximately 10% of all electrical demand consumed in the world [2]. In 2002, the operation of buildings accounted for 25-40% of final energy consumption in the OECD area, being comparable to transportation figures [3]. Data presented in the 2004 Buildings Energy Databook indicates that HVAC consumes around 30% of the total electricity used in buildings in the United States in 2002 [4]. In Brazil, this parcel was above 40% in 1999 [5] and showed a clear growth trend.

In Brazil, the widely available renewable sources, mainly hydropower and biomass, sustained the perception of an essentially green energy matrix [6]. Substantial mind-set changes triggered in 2001 an unfortunate combination of lack of investment on the supply side and increasing power demand to support economic development on the other end, resulting in an unprecedented energy crisis. The electric consumption increased 44.6% in 1990/2000, while the installed capacity increased only 28.5% [7]. Energy efficiency has then clearly come to the discussion forefront, in Brazil, among all construction sector stakeholders.

Environmental comfort and energy efficiency have been traditionally kept as separate knowledge domains in architectural design education at undergraduate level in Brazil. This and other widely noted problems in design education directed the goals for the architecture course of the University of Campinas (UNICAMP). An important innovation in this course is the combination theory and practice in the design subjects. Environmental comfort is thus integrated into the design studio. With this integration it was hoped that the synthesis of theoretical concepts would occur. However the last five years have shown that a discontinuity between bioclimatic architecture teaching and its application in future designs still occurs. A discussion of how to improve the situation demonstrated the need to introducing simulations within the design curriculum.

The integration of simulation into the design process has been actively targeted in the past ten years in architectural science discussions. Integrating simulation in design teaching poses additional challenges that need special attention and experimentations. This paper presents the results of one such attempt.

2. INTEGRATION OF SIMULATION IN THE DESIGN PROCESS: ADVANTAGES AND DIFFICULTIES

Studies carried out some fifteen years ago showed that, by 2010, careful planning of buildings in the United States could save US$ 100 billion per year in energy costs [8]. In the United Kingdom, the Department of Energy estimated that appropriate design of new constructions could yield energy savings of 25%, while extra efforts on better design could even double potential savings [9].

For many reasons building simulation programs are not recognized as useful design support tools to the same extent as Computer-Aided Design (CAD) tools or costing software [10]. Economic, cultural and technical constraints interact to hamper their uptake and use.

There is a strong perception of simulation as a costly and slow process, that requires special and expensive equipment, as well as specialized knowledge for data input preparation and output interpretation that increase design costs [11, 12].

On the other hand pressures in a competitive market is stimulating property developers and designers in developed countries, to include novel design features in their architectural proposals [11]. In developing countries this market differentiation is still not fully recognized and low design investments and quick results are common practice. Purchasing, training and run-time costs can prevent small businesses from adopting new and important design tools [13]. Designers are also not always interested to dedicate their time to become acquainted with modelling and simulation procedures, even though their use has shown to gain quicker, better and cheaper design solutions.

Cultural barriers also exit due to the fact that the various parties involved in building design are not yet convinced of the advantages offered by computer modelling and simulations. Design professionals (architects and engineers) mainly use traditional design tools. The lack of experience of practitioners with modelling and simulation perpetuates the perception that simulation tools are ‘black boxes’.

But the recent energy crisis and the consumer pressure on better design quality have however had an influence on the professional practice in Brazil. Environmental comfort has become a issue in design criticism and formal education of architects. Professionals look for software technology able to complement current practice. Quick, integrated use of multiple simulation tools, designed to allow for energy considerations along with the plethora of building design criteria are sought. This “dream software” should be linked to CAD tools. Reliable built-in or external simulation engines are requested. Also intuitive, user-friendly interface are needed that filter the complex algorithms and present results through graphic, intuitive visualization schemes which can be elucidated effortlessly.

Although today an abundance of simulation tools are available on the marketed they still do not respond fully to designers´ expectations.

During the creative design process decisions on building mass and orientation of façades are made in early. Such decisions have a great impact on the building’s energy performance and consequently act on reducing consumption during building use. Performance feedback is therefore required as early as possible in the design process [14; 15]. Conversely, most simulation tools currently available are not applicable at early conceptual design stages, and assessments are mostly based on expertise and experimental knowledge of consultants [16]. For the sake of early design assessment, models are normally limited in relation to possible building descriptions. Also, they may adopt several default values to mitigate input data not yet available. Simulation tools for accurate analysis require detailed descriptions of the building and its context, which are not known at the first design stages. As different design steps pose different challenges to the simulation tools, the ideal simulation software should be capable of appropriately dealing with all design stages or should allow for preparation of a preliminary model that can be edited, elaborated and passed on as design development advances.

The parameters to be evaluated change with building design development as shown in Table 1. Decisions regarding the effects of enclosure and glazing, massing, orientation, natural ventilation are relevant questions for preliminary building design [17], while others are made later on, eg HVAC system dimensioning, glazing and envelope specification. The kind of answer needed to further the decision-making process plays the major role in defining the most suitable tool to be used. Table 2 demonstrates some of these questions.

Table 1: Parameters evaluated at the different building design stages (adapted form 10).

Outline design stage	Scheme design stage	Detailed design stage
Orientation	Glazing type	Heating system
U-values	Shading	Heating control type
Heat cover systems	Blind control	Cooling system
Light/heavy construction	Orientation	Cooling strategies
Space usage	Air change rate	Ventilation strategies
Glazing area	Materials	
Floor plan depth	Lighting strategy	
	Cooling/heating required? Yes/No	

Table 2. Key issues in simulation capability [18].

Software selection criteria	
Modelling methods	Can the program analyse your problems?
Program coding	Do you need a source code?
Computer specification	Do you have the right machine?
Input interface	How easy is the program to be use?
Output interface	Can results be understood?
Linked modules	Are CAD and other software compatible?
Associated database	Is necessary data readily available?
User support	Can you get help easily?
User base	Are there other users who can be contacted?
Validation	How accurate is the program?
Cost	What are the costs for the program, training etc.?

To date no single tool is fully capable of meeting these expectations as support for the design process [11]. Also, there is no full software interoperability as few simulation tools support the link between the geometric information contained in CAD drawings and non-geometric information about the objects that they represent. Different tools use different building concepts and context representation (i.e. site and operational characteristics such as climatic conditions, neighbouring buildings, occupancy schedules, thermostat settings etc). A thermal analysis tool, for example, represents the building in terms of thermal barriers with heat transfer properties, while a lighting analysis tool represents the building in terms of polygons with optical properties. The resultant models are usually incompatible, and ultimately multiple, complementary simulation tools are necessary. This implies that multiple input files must be prepared in addition to the CAD description traditionally needed for construction specifications.

If the software enables simple modifications of the model, comparisons are made possible and the best design solutions can be evaluated through “what if” questions, as typically done in any design process. For example, during the design phase of the “IACtect” project suggestions were made to structure the model such a way that new classes of objects and information, required by new tools, could be added without major modifications to its structure [15]. Such additions should not require major changes to previously defined interfaces with design tools. Other possibilities to eliminate redundancy and minimize input workload are the so-called coupled and integrated simulation approaches, which support dynamic exchange of information. Coupled programs link applications at run-time in order to co-operatively exchange information. Integrated programs provide the facility to simulate different domains within the same program using a single data model [19].

The lack of detailed input data like weather files [6, 12, 13, 21] and of building material reference databases [12, 13], or in some cases the lack of adequate hardware [12] have been recurrently pointed out as major technical barriers in the use of simulation software. These difficulties can persist independently of software linkage achievement and algorithm improvement. Last but not least, presentation of performance data is a vital element of building interface design. It is important to turn the raw results into quality information [10]. Processing and interpreting large amounts of information tend to obscure important aspects and cloud major issues [13].

Notwithstanding these above-mentioned difficulties, simulation should be used as a common focus point in the decision making process by design teams and as a repository for project information [11].

3 BUILDING SIMULATION IN BRAZIL

Building simulation in Brazil is still mainly concentrated in academic circles with modest application in architecture and engineering practice. The prediction of energy consumption in buildings began in the 80’s in Mechanical Engineering Departments, and little has changed since then [6].

The use of such tools in design education poses additional, regarding teaching methods to be applied and course level definition as well as choice of tools to be used in undergraduate disciplines. In Brazil, specialized simulation software like DOE2 and ESP-r are used by researchers and graduate students. In mechanical engineering courses have recently introduced such programs.

Energy-10 has been used in architectural design education in the USA [20]. This software however does not allow for natural ventilation investigations, an important factor in bioclimatic design for hot and humid climates typically found in Brazil.

Other aspects influence difficulties in using simulation in the teaching studio in Brazil. Weather data files, covering the large areas of the country, are not readily available. Standard databases of thermo-physical properties of local construction materials are also difficult to obtain. National simulation tools are considered important to allow for local design practice incorporation since foreign tools have language or contextual application difficulties especially since they are meant for HVAC consideration only [6, 22].

Recently climate data are gradually becoming more available. In 1997, the first TRY (Test reference year) weather database for 14 Brazilian cities (Porto Alegre, Florianópolis, Curitiba, Belo Horizonte, São Paulo, Rio de Janeiro, Brasilia, Vitória, Salvador, Natal, Recife, Fortaleza, Belém e Maceió) was published by Goulart and Lamberts [22]. However these files do not include solar radiation data. Other initiatives exist. A TMY2 (typical meteorological year) file was created for the city of São Paulo, based on a ten year data set [23]. The authors of the “Energy Plus” software also made available weather files for twenty Brazilian cities [24].

4. TEACHING BIOCLIMATIC ARCHITECTURE: THE CASE OF UNICAMP

Widely noted problems in architectural education directed the development of goals for recent course created at the University of Campinas (UNICAMP).

The most mentioned difficulties stem from viewing architecture as pure art and the finding that in practice architects often fail to anticipate users' needs, especially concerning environmental comfort [25]. Importance given to the artistic content often causes architects to ignore social aspects in architecture and to emphasize their self-expression. This can be shown further through the content of most architectural publications, used as principal teaching material in design disciplines [26]. These are virtually devoid of human content and are directed towards the formal aspects of design with little attention given towards problems of environmental comfort. To overcome this problem in architectural education an attempt is made in the UNICAMP course to structure design disciplines to discuss and develop specific themes; therefore connecting theoretical content with the creative exploration of solutions to problems [27].

In Brazil, comfort topics are usually taught as subjects totally isolated from design studio practices, and concepts are seldom deeply rooted in students' repertoire. As a response, UNICAMP proposed an innovative approach, in which environmental comfort is specifically taught in three design subjects where theory and design practice are combined. An applied physics discipline and introductory design classes prepare the students for the discussion of comfort problems. Bioclimatic design is introduced in the fifth semester of the six-year course. The remaining design studios expect the students to combine their environmental comfort knowledge as a synthesis in resolving more complex design issues.

However after the first five years of the course some difficulties are still apparent. Even good students do not profoundly understand bioclimatic principles to direct their design choices. Thermal analysis of the designs, performed at the end of the semester, is often disappointing. On the other hand students can reach a fair amount of good detailing in one semester when they adopt a good design basis early and feel confident throughout the term to develop the concept [27].

The UNICAMP course has come full circle in 2004. The first graduating class indicated that the extra effort to introduce comfort concepts early in the design process is revealed in the most final designs, but a gap still remains for thermal design to be a part of architectural solutions. Faculty members reflected on possible causes for the apparent superficiality of the application of issues of bioclimatic design in student projects and pointed out the following aspects of the specific teaching method adopted:

- Difficulties exist to visualise feelings of comfort during the design process, so that theoretical knowledge can be transferred correctly and efficiently. Lab experiments work well for fundamental physics aspects but students have difficulties to internalise concepts if they cannot experiment and perceive implications of their design decisions in a clear and tangible way. Also students opt for solutions they are confident with to proceed design development, which not necessarily are correct or adequate options.
- There are inherent difficulties in communicating feelings of comfort through the design medium of architectural designs [28]. Due to peculiarities of graphic communication, problems exist in incorporating environmental comfort parameters and simulation results into design expression. The design process necessarily includes evaluations, which would be greatly enhanced through graphic images of comfort concepts. Attempts to evoke feelings of comfort through traditional architectural drawings often deceive. Ventilation effectiveness, for instance, can be misinterpreted from the typical representation of air movement through arrows passing through the section or plan of a building. On the other hand, results offered by simulation software, in the form of numerical data are usually not easily read by non-specialists.

On the other hand some design instructors believe that simulation exercises during design development may be the answer to overcome some of the difficulties identified.

5. PROPOSED RESEARCH: AIMS AND METHODOLOGY

The use of simulation in design studio activities presents practical limitations. Simulation tools are not fully available or adapted to the design studio practice or to local conditions. Students would have to learn how to use the tools, develop their designs to a degree of detail able to provide input data for simulations, then go through a series of iterations to improve their designs within the time constraint of a regular 15-week academic semester.

To overcome these problems, UNICAMP thermal comfort and bioclimatic design instructors propose the introduction of a specific discipline on building simulation following the bioclimatic design studio, to consolidate the acquired knowledge and test concepts on students' designs. As a preparation, an experimental research was carried out and the bioclimatic design studio monitored. Lessons learned from this experience launched the bases for the specific Applied Computation discipline.

The design object for that semester was an elementary school. The students visited several public schools in the region, covering both good and bad design examples. They fully analysed the buildings and interviewed users, placing emphasis in comfort aspects. After this field characterization, design activities began. The architectural brief was presented together with thermal comfort conditions expected for interior spaces. In previous editions of the bioclimatic design studio, final thermal analysis of produced designs has been based on design crits and on a simplified thermal analysis method included in the discipline scope, but these have shown limitations in fully checking achievement of comfort conditions. Simulation is expected to help to bridge this gap.

Several simulation tools were reviewed, to select the most suitable one to be integrated to design studio activities. Energy-10 [23] and Energy Plus [29] have been investigated as potential tools in previous works. Energy-10 was discarded because, despite its user-friendly interface, it necessarily assumes that a HVAC system is used, which is not the case in most Brazilian conditions. Energy Plus was considered as an excellent simulation engine which allowed for natural ventilation studies, but with a hard interface and the input data module. In both cases, the weather file had to be specially created, as only TRY files for a restricted list of Brazilian cities were available by that time. Ecotect was selected to be investigated as it was conceived and written by architects. The common modelling interface for light, thermal and sound that facilitates data input and results communication and proved to be of huge benefit. It has been used in undergraduate courses of several universities, including Brazilian ones, normally in parallel to design studios, with impressive results, learning curves drastically shorter when compared with other software. Finally, despite this software has indeed focused on the user interface side and still presents inaccuracy problems, it does support export of the building models to more robust simulation tools such as EnergyPlus, ESP-r, HTB-2, and Radiance, able to provide more accurate results.

Weather data available for the city of Campinas, SP is provided by IAC (Agronomy Institute of Campinas). IAC collects relative humidity, wind velocity and direction, direct solar radiation and precipitation data, at 20-minute intervals. Such data is sufficient to run simplified analysis using Ecotect. For more in-depth analysis, the weather file should include diffuse solar radiation, and cloudness measurements. However, the available data was collected discontinuously between 2001 and 2004. Data quality and measurement period were not enough to support a good statistic treatment to generate a typical or treated reference year. Measured data of the year of 2001 (the only one measured uninterruptedly) was therefore used to run the simulations.

The opportunity to use Ecotect was presented to the students in the second half of the academic semester, assuming that they already understood the mechanisms governing the thermal behaviour of buildings and sun-shading devices design. They would therefore have an idea of the expected simulation result and of alternative solutions for performance improvement.

Students interested in simulating their design pre-scheduled assistance sessions and brought their models in CAD format, that were imported into Ecotect. In that first contact with the simulation tool, they were not exposed to the major barriers that tend to discourage potential users, as the weather data file and a basic building materials database were previously prepared. The same professional conducted all simulations, to accelerate data input and ensure methodological consistency. The original models were gradually modified with students' participation, and re-simulated as many times as judged necessary, using "what if?" questions to analyse and help to associate implications of possible design decisions to quantitative metrics of the resultant space.

The last research stage included design methodology follow-up of this group of students in the subsequent design studio that emphasized daylighting and energy conservation.

The main questions expected to be answered with this experience were if the students felt that simulation had actually helped them to enhance their final design and, if the perceived improvement in design process provided the necessary stimulus to integrate simulation into their quotidian practice and if and in which way it has modified their design thinking process.

6. CONCLUSIONS

This paper describes the contextual framework that motivated the research and fundamented the approach for introduction of simulation as both a support decision tool and design teaching resource at the undergraduate architecture course at UNICAMP, Brazil.

In the initial simulations, the students usually were more interested in analyzing shadows and designing *brise soleils.* Thermal analysis was left to the second simulation sessions. It was interesting to notice that, even though the students were consistently exposed to theoretical concepts, they were frequently surprised by unexpected simulation results, which indicates that such concepts were not completely absorbed and incorporated in their design thinking. However, problem-solution visualization was substantially improved with the use of the simulation tool. Though the work model needed not necessarily to be three-dimensional, the first question asked by students was if and when they should bring their 3D digital model, which reaffirmed users' expectations to link geometric and non-geometric information about the represented objects.

Despite this experience was reported as very positive, the number of involved students was still below expected levels. Some possible reasons, as indicated by students, included:

- lack of awareness regarding the potential offered by the tool; and simulation was perceived as one extra task to be carried out;
- the need to pre-schedule the simulation sessions (many of them got the class notes and tried to learn by themselves how to use the software);
- little incentive to use simulation during design studio crits; and
- lack of simulation equipment in the design atelier.

Most of these aspects can be overcome by the implementation of computerized ateliers, able to combine manual and computer aided design, drafting and simulation environments. This is our next step.

It is paramount that the whole team of instructors, on the other hand, be involved and stimulate the introduction of simulation practice in design studios.

Part of the students observed during this experience did choose to continue to dedicate themselves to insert the broader simulation scope in their design routine. The results of the reported activity paved the ground for the formulation of a specific discipline dedicated to building simulation, to be offered in parallel to design studios. The experimental version of this course is currently being offered (first academic semester of 2006). The objective is an illustration of an informed design evolution. So far, comments in students´ submissions were very positive with clear development of their understanding of solar geometry, light, shading devices and building form and orientation. The refined version, enriched by the practical experience, will be proposed for inclusion in the architecture undergraduate course curriculum.

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