# Simulation in Architectural Design Education -Report on, and assessment of, an integral approach within the Design Studio

Stephen Roe & Chiafang Wu

Feng Chia University Taiwan & National Taiwan University of Science & Technology

**Introduction**

This paper documents and assesses the introduction of simulation tools into the taught architectural design studio from the early stages of the design process. And in the process attempts to initiate a discussion on how architectural education can address this technology, allowing students both a level of comfort with, and a degree of control over, an increasingly important part of the sustainable design process.

**Software Developments**

Up until quite recently simulation tools have been the preserve of engineering consultants, large architectural practices with "in-house" consultants, or researchers. In recent years , however we have seen the development of more user-friendly simulation software such as Ecotect, CFDesign, DesignBuilder, etc. and plug-ins such as Open Studio for Sketchup, Diva for Rhino and Geco for Grasshopper which integrate simulation into 3D modelling software environments. These tools increasingly allow students and architects to run rudimentary simulations early in the design process and to quickly manipulate their designs as a result. This process is only likely to accelerate and integration is likely to become even more smooth as can be seen in Autodesk's Project Vasari (currently in Beta) which integrates the parametric, building information modelling environment of Revit with, quite basic, but easy to use, light and fluid simulation engines. In parallel we are seeing increasing regulatory requirements for accurate building energy models which mean that innovative design must be allied to effective use of simulation throughout the design process (Hobbs et al., 2003).

What this means for architectural education is that simulation is likely to become an increasingly important part of the design process and so its incorporation into the design studio, in ways that are compatible with the way architects think and work, is an important issue. This paper describes 3 design studios which explored this issue and discusses them in the context of previous research on both the integration of simulation in the design process and the nature of design-thinking more generally.

**Example Studios 500**

The Design Studios discussed in this paper were carried out at the Architectural Association (AA) in the UK and Feng Chia University in Taiwan at different levels but generally Part II or graduate level. The overall academic approach in the two schools is very different, reflecting their different academic emphasis and student experience but in both contexts the incorporation of simulation into the design studio has been explored and the work done, while very different, is not unrelated.

The use of simulation in the Design studio began as a way to access and represent the inherent dynamics of our environment. While this work was always concerned with low-energy sustainable design, simulation was not used only for energy calculation but also to generate design ideas which make apparent this inherent dynamic of the environment.

*Example Studio 1: Architectural Association*

For example in a Diploma Level Unit at the AA called "the Weather Unit" students studied the dynamics of specific weather phenomena -snow, fog, turbulence, rain etc.- and used simulation tools to develop abstract temporal diagrams of these phenomena. These diagrams were then aligned to specific material performances for which they became the organizational diagrams. By identifying variations in spatial qualities -light, enclosure, active or restful moods- the resulting tectonic systems were used to create varying atmospheres within the city. Thus a link was made between dynamic simulation and geometry at the tectonic scale.

As an example one student, Billy Choi, studied the phenomenon of saltation -the rising of wind-blown snow near the ground. This phenomenon was simulated in Maya software using its particle-dynamics engine to incorporate virtual analogies of physical forces which then drive the complex, non-linear movement of particles. Maya was chosen because, through the toolset of Softbodies, it allows a direct translation of such particle dynamics into geometry. However, as has been recognized, it is not a true physics simulator (Kirkegaard et al. 2008).

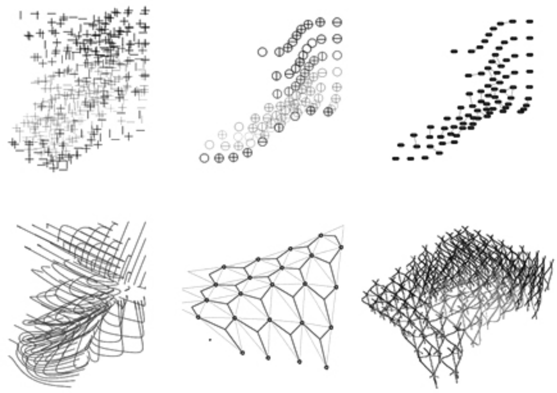

Fig. 1. AA Student Billy Choi's Development from Particle Simulation to Tectonic Organization

In effect this process is less result-driven and more playful in its use of simulation tools. The results of this design process are not necessarily sustainable or energy-efficient per-se but, through the process, concepts of dynamics, pressures, forces etc. which are very different form the conventional object-centred way of working, conventionally employed by architects, are introduced. This would hopefully have the related benefits of familiarizing architecture students with this way of thinking without the need to produce scientifically verifiable results. And this familiarity may, in turn, help to overcome the lack of impact of simulation on design (observed by Venancio et al., 2011 Hobbs et al., 2003).

*Example Studio 2: Graduate Programme, Feng Chia University, Taiwan*

The second example was done as part of a graduate-level research seminar at Feng Chia University in Taiwan. This is a research-oriented Masters programme for students who already have a professional degree in architecture or a related discipline. Students must take 12 credits a semester in addition to which they must produce a written research thesis. This seminar was 3 credits each semester for 2 semesters. Students had no previous experience of using simulation tools. The seminar course was entitled "Tectonics of the Envelope" and was focussed on developing innovative responsive facade systems for buildings in the sub-tropical climate of Taiwan. This climate is characterized by a long cooling period with intense sunlight in the summer and a shorter "heating" period with strong winds in the winter (though heating is rarely used). Students began with case-studies of existing facades, they then looked at climate-responsive natural systems, abstracting them through a process of modelmaking. These kinetic prototypes were then remade in the computer using parametric modelling techniques to allow the production of different configurations. These different configurations, while still at an early stage of development, were then tested using simulation software (in this case Ecotect). A notional commercial building in a built-up area was given as a test site. This "site" was analysed (again in Ecotect) to identify varying performance requirements which produced a "map" of performance criteria. The performance possibilities of the individual components were then aligned with this map while the prototype was refined and the number of possible configurations reduced. Based on this several large scale prototypes (1:2) were produced (see figure 2).

The student illustrated here, Jimmy Diao, began with plant stomata as a natural system from which a folded paper model was developed the openness of which could be adjusted. Simulation showed that this could become an effective adjustable shading device placed in different positions according to different outside light-levels and sun-angles. Simulation in this case was used from the very early stages to develop the functional concept (shading); to test the effectiveness of this (and adjust the prototype accordingly); to analyze site conditions (the shading requirements) and to test the final implementation.

This was a much more conventional use of simulation than at the AA, using it to test performance throughout the design process and to test/ demonstrate the final result. The project also stayed within the relatively straightforward, and well developed, sunlight-simulation in Ecotect.

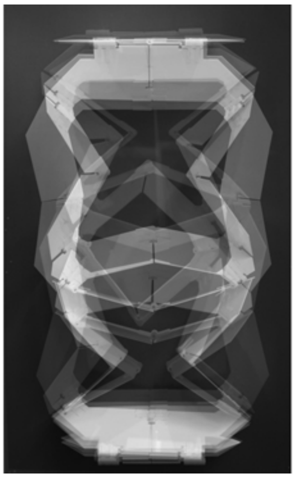

Fig. 2. Kinetic Prototype (1:2 Scale) Developed by Jimmy Diao, a student at Feng Chia University

*Example Studio 3: Undergraduate Programme, Feng Chia University, Taiwan*

A third example of the use of simulation is provided by an undergraduate design studio carried out as part of the 4th year of a 5 year professional architecture degree programme at Feng Chia University in Taiwan. Unlike in the UK relatively few credits are given for studio design (3 credits per semester out of up to 25) The amount of time spent on design does not reflect this but it does make it challenging to introduce new design concepts. The studio had a defined programme (a Museum of World Climate) and a site an intermediate semi-rural area between two densely developed urban areas (a not uncommon condition in Taiwan) zoned for "Cultural/ Recreational Uses". The intention was that the Museum would recreate past climates through the interaction of the building with the real local climate, using as little energy as possible. So in some areas (the Ice Ages) there would be requirements for cooling while in others there would be heating. These were given as a list of climate conditions in the brief. Students began by looking at different types of leafs and the relationships between form and constraint and form and performance -in terms of light and fluids. From these they developed adjustable paper models which could vary shape through the manipulation of one or two parameters (e.g. edge-length, curvature, fold-angle etc.). These were then recreated in the computer using parametric design software and the design was tested. Lighting performance was again tested in Ecotect while air-flow performance was tested in CFDesign (Figure 3). Based on these prototypes a variable roof prototype was proposed which could be adjusted to accommodate the varying climatic requirements of the different programmes.

These latter two design assignments take a more conventional approach to simulation to the studio carried out at the AA however the intention is not entirely different. It is intended that the students use the simulation software and become familiar with the concepts it is based on and how it works but, given the pressures of other courses and indeed the actual design process itself, it is not possible, nor expected to always produce scientifically accurate, verifiable results. On the contrary the intention is to "play" with the tool and to allow students to become comfortable with using it as part of a creative process.

**Assessment of Studios**

It is intended that the design processes described here fit more with the way architects learn and acquire skills  than the way simulation is most often taught to architects (or more commonly architectural-researchers (Venancio et al., 2011)) which is based on engineering paradigms of problem-solving. Those techniques while essential and important for training professional simulation consultants and researchers would form a barrier to the incorporation of simulation into architectural teaching (as a result of limited time, limited technical ability and incompatibility with the design process) and by extension into the architect's own set of conceptual tools which is the long-term aim.

Lawson who has researched and written extensively about how designers think (2006) and what they know  (2004) emphasises the importance of 'Knowing by doing" for designers and how the learning process is based around this core insight -carried out through the design studio- and how this is fundamentally different from how engineers are educated and learn. Davies (1985) who carried out extensive one-to-one interviews with esteemed designers discovered the importance of what many called "intuition" to their design process, however digging deeper it was revealed how this "intuition" was based on extensive experience. In this context it can be important to "play" with the tools which we are to use as it gives the freedom to approach them from different angles, or even misuse them but from this play we gain experience which becomes part of our the background of later intuitive decisions.

It is hoped that by the end of the studio students would have acquired enough skills to be able to use rudimentary simulation at the early design stage themselves, to understand results, their implications and limitations, and to be prepared to engage proactively with consultants for more precise simulation in the later design stages, understanding and respecting the specialized nature of this skill.

(In this way we see some analogy with the traditional teaching of structures in architectural design courses, where students learn the basic concepts and should be able to design reasonable structural designs at schematic stage but also recognize that at later stages any structural calculations must be carried out by those qualified to do so i.e. structural engineers.)

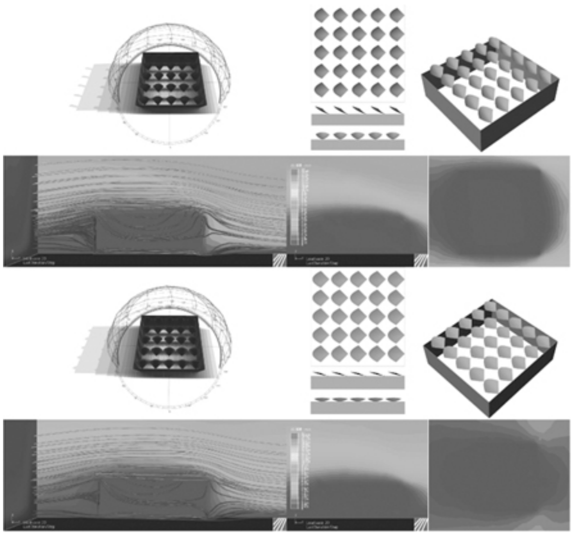

Fig. 3. Ecotect and CFDesign Simulations of Roof Components by Chasin Chen, a student at Feng Chia University.

It is also hoped that a more fundamental conceptual "shift" has taken place from seeing buildings as isolated objects and forms to seeing them as performative "instruments" which are intimately linked to the flows of light, heat and fluids within which they are immersed. It is this understanding that is potentially the most important and of most long-term benefit. For, whereas softwares change quickly and are soon out of date, the more fundamental issue of buildings' relation to the environment is not going to go away, certainly not in the professional lifetimes of today's students where it is, on the contrary, likely to become increasingly critical.

*Issues*

On the other hand it must be acknowledged that simulation software takes some time to learn (indeed not all students in the studios mentioned were able to do so) and it certainly takes a long time to master these tools to the point to be able to effectively set up, control and interpret the simulation. This is especially true of CFD simulation which, even in the relatively user-friendly interface of CFDesign, requires detailed and careful setup to even start simulation and this difficulty is then exacerbated by the non-linear and sometimes unpredictable nature of the results. This, combined with the many other things students at this level today need to learn in design studio, can lead to a feeling of "information overload" for some students, especially those struggling with other aspects of the curriculum. While these studios were designed to make use of the richness of information produced this could easily become a hindrance. Therefore means to manage and prioritize large quantities of information need to be developed. For instance even "simple" solar simulations produce variable data for different days and different times. How to use this vast range of possibilities requires the development of an understanding of temporal change but also a prioritizing and "statistical" approach to design optimization.

One of the dangers with this kind of software being used by untrained architects and students is "garbage-in, garbage-out". This is inevitable but, if we see the use of these softwares as the beginning of a process of education -and not as an end in itself, then in the wider context of exposing students to the techniques used by their engineering colleagues, and which are likely to become more widely used in future architectural practice, this may be less of an issue. Nevertheless it is hoped that students can gradually become more, if not expert, then proficient in inputting relevant information and obtaining meaningful results.

**Abductive Decision-Making**

Richard MacCormac has been quoted as saying: "I don't think you can design anything just by absorbing information and then hoping to synthesize it into a solution. What you need to know about the problem only becomes apparent as you're trying to solve it" Alvelos (2011). This Alvelos takes as an example of what March (1976) called, following C.S. Peirce, "abductive thinking" ("Deduction proves that something must be; induction shows that something actually is operative; abduction suggests that something may be.") and is particularly prevalent in design. Abductive thinking means that the problem & solution are "emergent", emerging into clarity together through the process of design. As Alvelos writes:

> "Emergent properties are those that are perceived, or recognised, in a partial solution, or a prior solution, that were not consciously included or intended. In a sketch, for example, an emergent aspect is something that was not drawn as itself, but which can be seen in the overlaps or relationships between the drawn component s. In the process of designing. the problem and the solution develop together." Alvelos (2011)

What is important in the context of the teaching described here is that it is through doing, through working with the problem that the problem becomes clarified and the solution emerges synchronously. The corollary of this is that if the issues raised by simulation are not worked with, solutions will not arise, as the problems are not visible. In these studios the design decision-making process is altered by the integration of simulation into design from the very beginning of the process, rather than close to, or at the end, as is more common. Simulation gives the students the possibility to understand, work with and clarify the issues of energy in building through working directly with the interaction of matter and energy through the tool of simulation. Simulation gives not just another tool, but another way of visualizing the problem and moving towards a solution.

**Comparison to previous research**

Morbitzer et al. (2001, 2003) describe some admirable work in developing tools to incorporate simulation into the working methods of an architectural practice. However as Venancio et al. (2011) have already pointed out, the tools are specifically intended for use at 3 distinct design stages and as such correspond more closely to the model of "internal consultant" rather than reflecting true integration into the architects' design process. As Venancio et al. also point out this analysis at discrete points in the process is not related to the way architects actually think (see above). One reason for this approach was that, at the time that research was carried out (over 10 years ago) simulation software was very expensive, and, even with the improved interfaces designed by the researchers required quite a bit of time to set up and to run simulations (hence the need for "QA" or restriction of access which is emphasised in the papers). Today however simulation software is more easily available, and easier to learn so there is more potential for a seamless integration into architects' working methods throughout the design process.

As a counter to this problem Venancio et al. (2011) propose, following Nigel Cross' (2006) so-called "Designerly" approach to the use of simulation tools. The ambition was to reduce the reliance on purely qualitative methods in design and to introduce more useful quantitative information into the process. According to Cross (2006): "Due to the ill-defined nature of the design problem, the definition of design solutions is made according to a solution-based approach, in contrast to the scientific problem-based approach" so it was proposed to use simulation to provide answers to design "dilemmas" but also possibly to identify the "dilemmas". Some of the assumptions provided in the paper are of most interest in this context:

- One of the most significant is that simulation for design can be less accurate, freeing up time from inputting highly detailed and irrelevant data.

- Dilemmas consist of both pragmatic constraints (which can be directly input) and abstract constraints (which need to be processed by the designer before being input into the simulation) - In this case the architect becomes integral to the simulation process, and actually reduces the problem of "garbage-in, garbage out" as the designs inputted take account of the many intangibles that purely pragmatic constraints cannot.

- Shortcuts -precedents, experience etc. are an important part of the process in practice, and cannot be discounted.

All of this points towards the benefits of a closer integration of simulation into the design process and counter-intuitively how the recognition of the importance of qualitative, abstract criteria can actually make simulations more accurate and quantitatively more useful.

**Conclusions**

The following conclusions can be drawn from the teaching and research described:

- From recent developments in software and regulation it is clear that simulation is likely to become an increasingly important part of the design process for architects.

- One approach to overcoming the current lack of impact of simulation on design is to increase architectural students' familiarity with the software, its processes and protocols.

- "Play" is an important part of this process of familiarization.

- A conceptual "shift" is needed, from seeing buildings as isolated objects and forms, to seeing them as performative "instruments" which are intimately linked to the flows of light, heat and fluids within they are immersed.

- Simulation software takes some time to learn but using and "playing" with it while being learnt can accelerate the process.

- Students need to develop the means to prioritize large quantities of information and use this effectively in their designs.

- "Garbage-in, garbage-out" is less critical than it would be with purely analytical research, though it is still an issue.

- To truly become part of architects' design process simulation must be incorporated into the "abductive" reasoning process.

**Future research:**

Future teaching in this direction would look at:

- Streamlining workflow between different softwares so that the focus can be on simulation, interpretation and design rather than, as is currently still often the case, issues of software compatibility, data translation etc.

- Teaching students to manage and prioritize the large amounts of information they produce

- Continuing to develop "playful" ways of using simulation as an integral part of the design process.

**Notes**

Alvelos, Heitor. "Too Much by Too Many? In search of a role for Design in 2010" in *Notes on Doctoral Research in Design - Contributions from the Politecnico di Milano*, Milan, 2011, pp. 13-16

Cross, Nigel "Designerly ways of knowing: design discipline versus design science". in *Design Issues*, (2001) 17(3), pp. 49–55

Davies, Robert. *A Psychological Enquiry into the Origin and Implementation of Ideas,* M.Sc. Thesis, Department of Management Sciences, University of Manchester. 1985

Hobbs, Dan; Morbitzer, Christoph; Spires, Brian; Strachan, Paul; Webster, Jim. "Experience Of Using Building Simulation Within The Design Process Of An Architectural Practice" in *Proceedings of the Eighth International IBPSA Conference* Eindhoven, Netherlands, August 11-14, 2003, pp. 491-498

Kirkegaard, P.H.; Hougaard, M.; Stærdahl, J.W. "On Computational Fluid Dynamics Tools in Architectural Design" in *DCE Technical Report No. 55,* Aalborg University, 2008

Lawson, Brian. *What designers know*. Architectural Press, Oxford, 2004.

Lawson, Brian. *How designers think: the design process demystified*. Architectural Press, 4th ed. Oxford, 2006.

March, Lionel. ”The Logic of Design" in *The Architecture of Form,* Cambridge University Press (1976, reissued 2010)

Morbitzer, Christoph; Spires, Brian; Strachan, Paul; Webster, Jim; Cafferty, David. "Integration Of Building Simulation Into The Design Process Of An Architecture Practice" in *Proceedings of the Seventh International IBPSA Conference,* Rio de Janeiro, Brazil, August 13-15, 2001 pp. 697-704