Environmental Simulation Tools in Architectural Practice.

The impact on processes, methods and design.

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ABSTRACT:

Today almost every building is designed with the use of Environmental Simulation Tools (ESTs). Sustainability and its implementation of simulation tools, oftentimes called "Performative Design" (PD), appear to have changed not only the shape of buildings but also the shape of architectural practice and the design methods. The research, based on interviews, surveys and dialogues with international architecture practices, focuses on sustainable design and highlights how simulation is used as a decision-making tool and how it acts to generate design solutions. SOM, HOK, William McDonough, Kirien Timbarlakein the US, Foster and Partners, BDP and Aedas in the UK, 3XN, Henning Larsen and CF Moller in Denmark, Renzo Piano Building Workshop (RPBW) and Mario Cucinella Architects (MCA) in Italy, and Bennish Architecten in Germany are notable examples of firms that have brought about significant changes in building design in the past decade through their implementation of sustainability simulation.
The majority of the architecture firms above have set up special research groups that are dedicated specifically to sustainable design and the use of simulation tools. New models of collaboration with consultants and researchers are emerging and impacting the design process. The evidence shows a trend in moving from a traditional, sequential design towards a more interdisciplinary, circular model, integrating simulation across professional boundaries. While architectural practice has begun to transform since the implementation of simulation tools, it is also possible to observe, in turn, how ESTs are adapting to the nature of architectural design.
Finally, the role these tools play in integrating the concept of sustainability into the design process is discussed. It is an irrefutable fact that the simulation of energy and sustainability-related parameters has become a frequent part of the criteria for shaping the basic form, program and fabric of buildings in current design practice. Noted should be the way in which simulation is used creatively to achieve design ideals and a building performance that not only meets but surpasses the target established by rating systems such as LEED, BREEAM and DGNB.

Keywords: environmental simulation tools, architectural practice, sustainable design process

NEW STRUCTURES OF ARCHITECTURAL PRACTICES

The in-house specialist teams

Architects used to be limited by what they could calculate. Nowadays with the use of Environmental Simulation (ES) architects can model as well as calculate. New digital and Environmental Simulation Tools (ESTs) allows them to handle the spatial and regulatory complexity of today's buildings.
Firms with a focus on sustainability have a strong interest in using the ESTs to inform architectural design parameters. Addressing the building's design factors (orientation, massing, program, materials, etc.) with digital design, and its environmental performance with simulation, has recently given rise to a new design approach called "Performative Design" or (PD). Performance design is not, as the name might suggest, aimed solely at meeting performance criteria through the manipulation of form [1Rather, PD involves the consideration of a wide array of building performance issues in conjunction with other design aspects from the onset of the project. The proposed research, which is based on the dialogue with several sustainable design specialists in different practices, compares different design approaches to performance design.
In general, it could be recorded how the difference between practices which had integrated engineering teams for structural and HVAC design and those which primarily provided architectural services is being eroded under the impact of PD. However, the need to ensure that both engineering and environmental aspects are given due weight from the inception of a project has driven an increasing number of practices to follow an integrated model [2]. Some of the world's leading architectural practices have developed teams with a special focus on sustainability have implemented the use of building simulation, parametric design techniques and customized computational tools.

For example, Foster + Partners has its "Specialist Modeling Group", Aedas has the "Computational Design Research", and 3XN has a research group called GXN where G stands for Green. Henning Larsen and MCA have their own sustainable design groups as well. In the US, SOM has special groups such as the "Performative Design Studio" targeted at Sustainability, and "BlackBox", which integrates different computation-based disciplines. Similarly, HOK and BDP have technical and engineering divisions that specialize in simulation.

It could be said that, irrespective of the structure of each practice, the same personnel dedicated to ES tend to work on similar projects thereby building up a body of knowledge, which is tested and developed over several commissions [2, 3, 4]. The teams are composed of experts whose mission it is to engage in all stages of the design process, leveraging the power of ESTs, advanced computational design tools and methods to expose and explore new frontiers of conceptual thought and innovative form/space/place-making in the work of design studios and service disciplines [5].

The groups not only engage in creating geometries, which respond to a new understanding of environmental flows, they also carry transmit new skills and knowledge from the center to the outlying offices. The simulation teams interact with the designers on the ground providing a horizontal forum spanning across design groups. This matrix of specialist teams weaving between the vertical axes of design generation provides one of the main vehicles for environmental sustainable design knowledge transfer. Having an internal, qualified team is seen as a long-term investment since not all clients are willing to pay for externally conducted performance simulations [3].

The dialogue between design architects, simulation specialists and researchers

In some other cases, certain firms adhere to the tradition of a practice of 'purely architects' where external sustainability specialists and analysts support PD. Seeing a potential market of consultancy, specific engineering companies traditionally oriented toward HVAC optimization, such as Arup, Transolar, Atelier 10, Ramboll, BuroHappold, are increasingly proposing additional services to support façade and detail development based on ESTs (Martin).

Partnerships between architects and sustainability consultants, such as the ones between Behnisch Architecten and Transolar [6], McDonough + Partner and Loisos + Ubbelohde [7], RPBW and Arup, CF Moller and Ramboll [8], bring together a solid understanding and implementation of sustainability in design [7, 9]. The collaboration generally starts at the beginning of the design process and incorporates all aspects of the design project (formal, programmatic, climatic, site, energy, social, economic, regulatory, etc.) as primary parameters for PD. The dialogue with consultants enriches both the quality of the project and the architects' ability to implement sustainable solutions in future commissions.

Finally, there are also interesting cases of collaboration between architects and research laboratories. An example is LBNL (Lawrence Berkeley National Laboratory), which was involved in the design of buildings such as the New York Times Building with RPBW (fig.1) and the San Francisco Federal Building with Morphosis and the NASA Sustainability Base with William McDonough + Partners [10, 11, 12].

Figure 1: New York Times Building mockup: morning view. (credits: Eleanor Lee, LBNL)

Whether ES specialists and researchers are in-house or external consultants, their involvement in a project increases its chance of becoming a high performance building. Simulation specialists have the expertise to support designers and, with different degrees of impact, they have the possibility to affect the decision making process. Researchers in simulation usually apply methods rigorously, using a wider range of technical and theoretical knowledge [7].

Integrated teams composed of the afore mentioned professionals show that it is possible to promote and conduct applied environmental research that is disseminated through peer reviewed conferences and journals more now than it was before the introduction of simulation-based design. The culture of "peer review" is becoming more important and it is employed more widely in architecture in order to uphold standards, improve performance and provide credibility [13].

SIMULATION TOOLS ADAPTATION TO ARCHITECTURAL NEEDS

Practices are changing their internal structure in order to create simulation and sustainability teams and software developers are conceptualizing new tools that are more fit for the architectural design process. Surveys (table 1) highlight a wide range of tools used in architectural practices [5, 7, 14, 15].

On a general level, it could be said that the most commonly used tools are the ones related to shadows and radiation analysis (i.e. Ecotect and Vasari) (Figure 2). Within the category of energy simulation EnergyPlus and IES are the most used by specialist teams and consultants. However, “Architect-friendly” interfaces of EnergyPlus such as DesignBuilder and OpenStudio are increasingly adopted [11].

Software developers are aware of the difficulties typically experienced by designers when they use energy or other types of simulation. Wishing to tap into a potentially large market created by the needs of architectural practices, software houses are now looking to create very simple tools that are targeted at the early design stages (known as Performance Sketch tools). These tools may not allow the exact definition of all the parameters of a building, but they allow for intelligent simplifications in order to have a basic understanding of building performances. Performance Sketch uses high-quality simulation to create an accurate yet simple representation of the essential properties of a building.

Examples of Performance Sketch tools currently available for whole building simulation are Sefaira and Vasari (beta). The latter incorporates analyses that are derived from Ecotect, which is still the most popular EST in architecture. Analysis of shadows, incident solar radiation and wind are therefore included (in addition to energy simulation which is calculated using cloud computing technologies).

Table 1: Table of main Building Performance Simulation tools today used in the analyzed architectural practices

	Geometry andData Modeling	**Energy and Thermal Simulation, Climate Analysis**	**Daylighting Simulation**	**Computational Fluid Dynamic Simulation**
Main scope	Create geometrical and data models that support simulations	Predict the impact of architectural design on energy consumption and emissions	Anticipate natural light quality and visual comfort as a function of a space’s geometry and material surfaces	Model airflows inside and outside the buildings, predict comfort
Concept Design	Rhino, Sketchup, Vasari	Ecotect Sun Tool, Ecotect, Vasari (Beta), Climate Consultant, EcoDesigner, ComFen	Ecotect, VeluxDaylighting Visualizer, Radiance, DIVA	Vasari Wind Tunnel (Beta), Design BuilderCFD
Design Development	Revit, Archicad	OpenStudio, EnergyPlus, DesignBuilder, IES-VE, eQuest, TRNSYS	3ds Max, Radiance, Daysim, DIVA	Fluent, Virtual Wind
Parametric Design	Grasshopper, Dynamo	JePlus, JePlus AE	Grasshopper and various plug-ins	

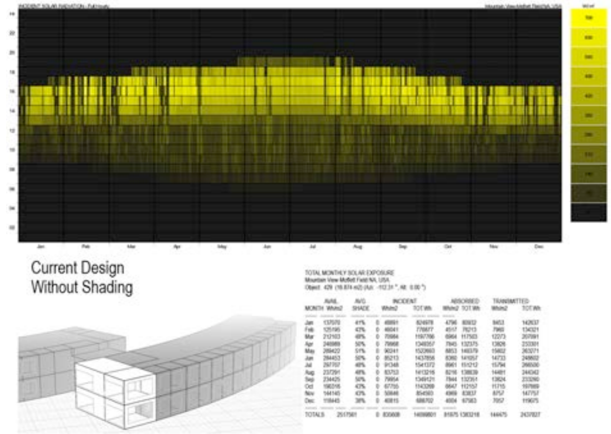

Figure 2. Nasa Sustainability Base comparative analysis: Ecotect study of west bay with shading (credits: Ubbelhode)

For façade studies ComFen (COMmercialFENestration), based on EnergyPlus, is regarded to be a valuable resource and one that architects can easily become familiar with it [10]. In addition to energy, daylighting and natural ventilation modeling are other common domains of interest, as indicated by the professionals that were interviewed. Given the significant influence that light has on building language and spatial experience, it is not surprising that design practitioners are increasingly using daylight simulation tools for competition and design developments [2, 3, 5, 16, 17, 18, 19].

Daylight modeling is more accessible and easier to carry out than thermal or airflow analysis, and so it tends to be an in-house service. Daylight tools commonly used today are Radiance, Ecotect, Daysim and most recently, Velux Daylighting Visualizer [4, 8, 14]. Velux Daylighting Visualizer addresses the need of architects to import models from other 3D drawing tools (such as Rhino, Sketchup, Revit and Archicad) and perform fast simulations with accurate results.

Natural ventilation modeling is supported by computational fluid dynamics (CFD). As computing power becomes less expensive, CFD is used to model wind, natural ventilation, pedestrian and indoor comfort, and it is used by practices in applications related to site planning and architectural design. External consultants generally perform accurate CFD simualtion. However, very simplified CFD tools such as Vasari Wind Tunnel, and simplified tools such as DesignBuilder CFD are now available in order to meet the architects’ needs of visualizing airflows in and out the buildings [8, 19].

Finally, tools that calculate the energy and the environmental impact of materials and construction techniques are starting to be used in architecture. Since building information models are based on 3D objects and material properties, it would be expected that BIM tools should have plug-ins for life cycle assessment (LCA). However, this is not yet the case. The available tools, such as Athena Modeler in the USA, are not based on geometry [5,19]. Currently, the Kieran Timberlake's Research Group is working on a BIM plug-in that is able to account for the life cycle assessment (LCA) of buildings, but this is the only example. An LCA approach to design is therefore far from being standard practice in architecture [20].

Interoperability: promised but never achieved

From the interviews it has become clear that the software packages for different aspects of environmental modeling (e.g. energy, daylighting, air flow modeling, LCA) do not interface because they do not use the same geometrical model or share the same data [2, 8, 17, 19]. As of yet there is neither an integration of software tools at the early stages of the design in Building Information Modeling (BIM), nor an integration with simulation tools. Ideally, one would use the same model so that it is possible to perform different types of analyses without having to redraw the building's geometry for each simulation. This would lead to cost savings of the design. In practice however, it is still necessary to redraw analysis models for each of the different specialized simulation tools [11].

In house-customized tools

Practices have their own criteria and use different software packages for predicting environmental impacts and generate designs. For instance, Aedas structures design priorities according to its own online Green Tool which is accessible to employees though the practice's knowledge management intranet. Similarly, Henning Larsen Architects has developed a multicriteria-based assessment tool [4], HOK the Guidelines for Sustainable Design [19] and 3XN the Green Design Strategy internal manual [21]. HOK created a tool named Fully Integrated Thinking (FIT) [19].

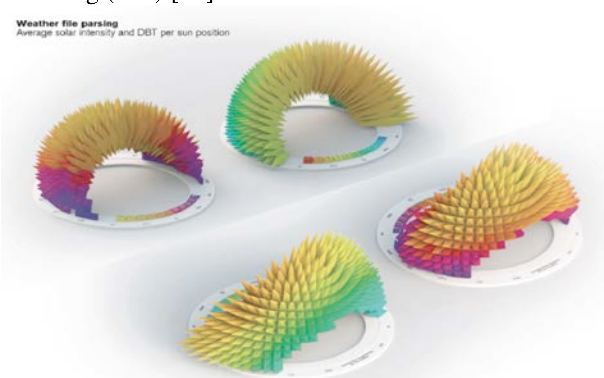

Figure 3: Customized visualization of average temperatures and radiation according to solar position. Developed by the Specialist Modelling Group at Foster + Partners (credits: Foster + Partners)

This is similar to BDP where specific teams work with the Concept of Information Modeling (CIM), a designer-friendly technical interface implemented at from the beginning of projects. On a micro level, practices develop customized tools in order to improve the efficiency of computation, results retrieval and visualization. Foster + Partners SMG develops tools that allow to graphically relate and visualize multi performances of building (figure 3) [16]. GXN, the specialist sustainability team of 3XN, is now developing Grasshoppers' based tools in order to generate façade shapes using daylighting metrics [14]. The Structural Engineering Studio of SOM, developed a proprietary tool that calculates carbon footprints over buildings' life in order to analyze their environmental impact. Finally, Kieran Timberlake's Research Group—building on an existing BIM-based workflow—built a plug-in that calculates embodied environmental impacts in all phases of project delivery (Real Time Environmental Impact Tool) [26].

SIMULATION TOOLSIMPACT THE DESIGN IDENTITY

The interviews indicate that it is possible to distinguish two main categories of ways in which tools are utilized in PD. The first includes semi-digital designs that are developed according to the architect's knowledge of sustainability, experience and sensitivity to climatic contexts and human factors. In this category the process is related to the traditional way of "form making" and designing architecture and simulation tools are only used to test scenario-by-scenario designs. The second category includes fully digital designs that are driven by environmental data. "Form finding" and "parametric optimization" methods fall in this category. ESTs and modeling tools have a significant impact on the building's final identity, language and form.

Form finding or parametric optimization is based on the use of plug-ins of geometrical tools, the most well-known of which is Grasshopper. These types of tools will automatically generate optimal building massing [17] or façade shapes when specific performance objectives and their geometrical relationship to objects are input..

It should be noted that architectural practices cannot be divided according to whether they use semi-digital design or form finding techniques.. The method used generally varies from one project to another within the same office. However, each firm implements a semi-digital process to some extent or another [2, 3, 5, 7, 16, 17, 18, 19], whereas form finding is done only in a small number of special projects carried out by, for instance, SOM, Kieran Timberlake Architects, Foster + Partners and 3XN [2, 5, 14, 18, 27].

The semi-digital design process

ESTs have two main areas of application. The first is to help architects optimize the early design, and the second is to subsequently quantify in more detail the performance figures in order to ensure compliance with the project goals and certification levels [2]. For early design purposes, building simulation is used by practices to achieve the most sustainable design option by conducting comparative studies of design alternatives, rather than to predict the exact level of energy consumption [4].

Generally, architecture teams sketch a range of possible solutions before any specific software is employed [5, 7, 14, 15]. These early sketches are shaped by the project brief, building site and other factors including the client's green priorities. The team specializing in sustainable design helps to define the broad criteria for achieving sustainability in a project, and consequently performance modeling tends to follow. The design concept is then tested against broadly based software tools (table 1) in order to test its relationship to sun, wind and light. Following, energy and daylighting performances are studied. At this stage the design is fluid and user-friendly ESTs are preferred over more technically advanced programs, which are used later.

In this approach the architect's sensitivity and experience are the main factors in determining the building's character and language. The tools play a secondary role in establishing the merits of each design solution. Unlike with parametric design, performance is not mathematically optimized. However, if the architect is willing to modify the design according to the ESTs´ analysis, high environmental performances can be achieved.

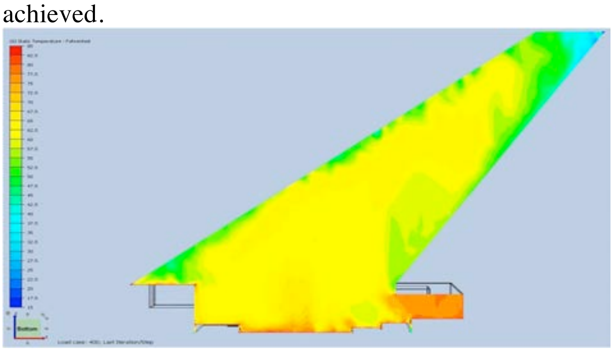

Figure 4: US Air Force Academy Center for Character and Leadership Development. Contours of thermal distribution in the space to verify comfort condition in winter. Performative Design Group of SOM (credits: SOM)

Later in the design, as the complexity of the project increases, more technically advanced simulations are implemented by in-house or external expert users (figure 4). However, some firms employ more complex tools from the start of the design process, such as Radiance, EnergyPlus and CFD tools [2, 5, 7]. When complex tools are used from the beginning then the data inputting and the computations are considerably time-consuming. In order to speed up the design flow and to coordinate simulation and design, practices and consultants have developed scripts that enable multiple simulations to run simultaneously, which does require an investment in servers or cloud computing [7].

Form finding

"Form finding" is based on automatically generating forms using specific customized ESTs to meet environmental performance targets defined by the designer. In search of the optimum wide-ranging performance criteria may be used to define goals that drive fitness functions embedded in form-finding algorithms (i.e. CO2 emissions or heating, cooling and lighting loads).

Performance may be defined beyond environmental targets, and encompass programmatic requirements, structural efficiency, energy consumption, daylighting quality, constructability, economic feasibility, or any other possible performative criterion. This approach can be useful for architects who are interested in adapting the shape of their buildings to site and climate specific boundary conditions.

SOM, Foster + Partners and MCA (figure 5), have encouraged a culture of collaborative working between designers and ESTs modelers [5, 16], have recently proposed PD building concepts based on form-finding. Some practitioners are skeptical with regard to the implementation of form- finding techniques. They claim there is a risk that as simulation begins to determine the character or quality of architecture the human component is marginalized.

According to them the design sensibility of architects coupled with their unique ability to relate design to social and cultural factors needs to temper the power of energy related computing. Leaving the form creation to a computer leaves too many variables uncontrolled and departs from real design quality. Skeptics believe that computers can amplify our knowledge of environmental systems but ESTs cannot solve all of our environmental and architectural problems.

Tools are used to support wider scopes than purely code or certification system compliances

While certification schemes such as BREEAM, LEED and DGNB are major client drivers they do not impact the architect design tactics right at the start of a project. Following from the interviews certification schemes appear to determine the use of ESTs mainly for the purpose of calculating how to comply with targets that are too generic, bypassing customization of design solutions via simulation [2, 3, 4, 5, 7, 8, 14, 16, 18, 19].

In Foster + Partners, SOM and MCA for example, the use of ESTs is customized according to a PD strategy that varies as a function of the building type, the context, the climate, and the client's and final users' needs. The emphasis here is on establishing a deeper knowledge and achieving more ambitious standards than set by

BREEAM, LEED or DGNB. The majority of architectural practices follow this approach.
HOK takes a similar view, suggesting that their own assessment tool introduced in 2010 and called Fully Integrated Thinking (FIT) is more demanding than LEED [19]. Many firms use ESTs in order to develop innovative PD concepts that are not awarded by rating systems. Compliance with rating systems is oftentimes evaluated by external consultants (with the exception of SOM and BDP, which have an in-house MEP division [5]). These provide periodical feedbacks to the design team and as such conflicts that may occur later are largely avoided. These conflicts may involve cost penalties for the modification of the design and non-compliance with high standards (i.e. LEED platinum or BREEAM Outstanding).

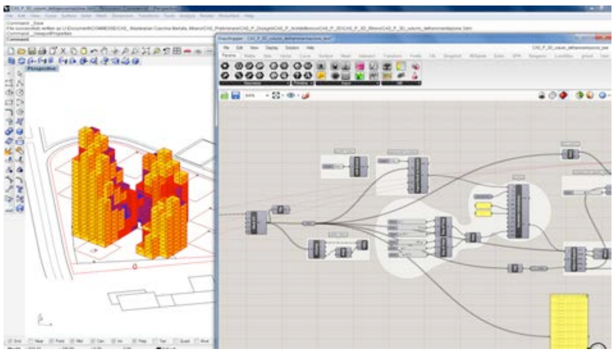

Figure 5: Parametric study of ideal massing according to right to light of each façade. (credits: Mario Cucinella Architects)

CONCLUSION

This study aims to understand how some of the world's leading architectural practices implement new paradigms of Environmental Simulation in Performance Design. The larger architecture firms with a focus on sustainability, like those discussed in this paper, already take advantage of recent developments in performance simulation [22]. Environmental simulation tools do not only have a significant impact on the way buildings are designed, but they are also changing the internal structures of architectural offices, the design methods these offices use and the way design is thought about. As a consequence, an increasing number of practices are starting to approach design differently and are challenging the preconceptions of rating systems.

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