TOWARDS INTEGRATED DESIGN

A Generative Multi-Performative Design Approach

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Abstract. This paper examines a different design approach called integrated. The term "integrated" has a dual utilization in this study. The first use refers to the integration of form and building performance. The second use refers to the integration of interrelated and diverse building performances involving multiple disciplines. The integrated design approach analyzes and evaluates several interrelated design systems involving different disciplines in the early design phase. The goal of the approach is the generation of design alternatives guided simultaneously by two basic objectives: the aspiration for form exploration and the satisfaction of the performances of interrelated systems.

Keywords. Generative Algorithms: Building Performances; Multiple Building Disciplines; Optimization and Simulation Techniques; Coupled Building Systems.

1. Precedents: Dominant Design Paradigms.

In general, two dominant design paradigms govern current digital design efforts in architecture: the Generative Design paradigm and the Performative Design paradigm. *Generative design* can be broadly defined as an algorithmic or rule-based process through which various potential design solutions can be created. Generative design systems, such as cellular automata, L-systems, shape grammars etc, are the primary design tools; while the dominant aspiration for generative design is form exploration. On the other hand, *Performative Design* can be broadly defined as a design paradigm in which the dominant intention is meeting building requirements or else building performances, such as functional, environmental, structural, financial etc. In Performative Design, a building form is evaluated against performance criteria and modified after it is created using traditional methods. The primary design tools in this case are optimization and simulation algorithms.

Only recently, has a third design paradigm started to emerge: *Generative Performative Design*. By its name it is clear that this paradigm is a combination of the two aforementioned ones. Moving beyond form generation alone, Generative Performative Design includes performance models, simulation techniques and optimization algorithms. Indeed, the designer creates an evolving algorithm which encodes a generative algorithm and includes performance feedback. This way the computer is used to automatically generate and evaluate possible configurations, and present the designer with optimal or acceptable and approximated solutions for the problem under study. In the case of Generative Performative Design paradigm not many studies have been implemented yet. However, two representative examples are the Generative Design System [GDS] implemented by Luisa Caldas in 2001, (Caldas, 2001) and the EifForm developed by Kristina Shea in 2000, (Shea, et al., 2003). It is worth mentioning that these examples are software applications, design tools that are tested later on design projects.

2. Integrated Design: A Generative Multi-Performative Design Approach.

Examining thoroughly Generative Performative Design demonstrators, the conclusion that can be reached is that most of these are constructed in such a way to satisfy performances from one building discipline. For example, GDS focuses on energy efficiency and EifForm on structural efficiency. *Integrated Design* approach fills this gap by the introduction of more than one building performance from different disciplines at a time. This feature converts Generative Performative Design to Integrated Design as a Generative Multi-Performative Design approach. Integrated Design is governed by two principal components: the integration of form and performance and the integration of multiple building systems.

2.1. INTEGRATION OF FORM AND PERFORMANCE

The relation between form and building performance is manifold. Design problems should not merely be viewed as systems of representations outlined in composition and experienced in perception nor as mathematical equations solved by search techniques. If the focus is merely on the artistic or the scientific aspect of architecture, on form expression or on building performance then design loses its integrity. If the emphasis is on form innovation and complexity disregarding building requirements, then design loses its feasibility. Consequently, a design should meet both aesthetic and functional requirements. Within this scope, the term “integrated” is introduced. Redefining form not as the geometric representation of a material object alone, but as a multitude of effects and behaviors, the dualism of form and function is transformed to a synergy aspiring to integral design solutions.

2.2. INTEGRATION OF MULTI-BUILDING SYSTEMS

At the same time, the term “integrated” also designates an alternative framework in which multiple building performances can be considered. There have been two primary ways to perceive and deal with complex multiple performance requirements, in general. The first way is to perceive that a problem consists of discrete sub-systems whose existence and performance does not influence the rest sub-problems. These sub-systems are called *modularized*. The independent solution of modularized sub-systems leads eventually to the solution of the overall problem. The second way also is to perceive that a problem consists of sub-problems that all of them are tightly linked together. They interact and influence one another. That is why they are solved simultaneously. These sub-systems are called *coupled*. Such coupled sub-systems are usually met in industries like automobile, aerospace and naval where all sub-systems support a main function.

2.3. INTEGRATED DESIGN APPROACH

In architecture coupled sub-systems are not usually identified, while modularized sub-systems are. Architecture is not a monolithic unity but constitutes multiple and diverse components that operate at different scales and levels. That is why the paper acknowledges that both independent and interrelated sub-systems co-exist in a building. Many design processes have been proposed for dealing with discrete sub-systems; the paper will focus on coupled sub-systems proposing Integrated Design as an alternative design approach to deal with them. Integrated Design propose the simultaneous analysis, evaluation, and generation of interrelated building systems, which belong to different disciplines, in order both form exploration and performance efficiency to be satisfied.

It is worth mentioning at this point that Integrated Design approach is not an optimization method. On the contrary, the research has been built upon the notion of “alternative” rather than “optimal.” That is because the term optimum, either referring in a process or a building, is vague in design. Also, the end product of the proposed approach is not a single building. Actually it is not even a building. Through the utilization of this approach several potential design solutions emerge. They are digital visualizations of primitive design "ideas" that embody a higher level of intelligence combining both efficiency and form exploration. However, they should be used as basis for further investigation and elaboration in the next steps of design process.

2.3.1. Potential Benefits of Integrated Design Approach

The potential benefits from the utilization of Integrated Design approach can be many, such as the increase in the number of examined design scenarios and alternatives, the improvement of the overall design understanding, promotion of multi-disciplinary collaboration, reduction of the design circle. The final result of these benefits, undoubtedly, is the reduction of the overall cost. Last but not least, through the use of a generative multi-performative procedure, new levels of complexity might be explored and new unexpected aesthetics might emerge. The potential occurrence of these benefits should not lead to the conclusion that this approach has no difficulties or weaknesses.

2.3.2. Prerequisites for the Utilization of Integrated Design Approach

Indeed, there is a set of prerequisites that should be met in order for Integrated Design approached to be used. These prerequisites demand changes not only in architectural practice and computational technology but also, and most importantly, in the way architects have been taught to perceive design. Multi-disciplinary Collaboration is the first prerequisite. A collaboration that will promote sharing of knowledge, conceptual brainstorming, multiple goals, creative negotiations, and performative feedbacks, will be necessary at the early design phase and not when the design solution is solidified. The second prerequisite is the early integration; early introduction and analysis of variables, objectives, and constraints of interrelated and multi-disciplinary performances. The identification and operation of the design sub-systems is the third prerequisite. Design sub-systems should be operated in a holistic and synergetic way during the evaluations and synthesis phase.

Another prerequisite for the utilization of Integrated Design approach is the real-time interaction. Given the fact that many of design problems are ill-defined, designers who apply Integrated Design should better avoid static formulations of the design problems and prefer more dynamic ones which will allow interactive modifications of the system. The next prerequisite is the development of a design multi-tool. In order for an integrated generation to be achieved, the integration of design tools with simulation and evaluation tools and the exploration of generative capabilities of digital design tools are needed.

The ideal scenario will be the development of a unified environment in which the three basic digital tools will be used both for analysis and synthesis phase integrating generative, optimization and simulation algorithms. A design solution is rarely perfect and almost never found without sacrificing any requirement. Within this context, the last prerequisite is that the design solution of a problem that is approached by Integrated Design should not be a single and optimal solution but a set of "satisficing" design solutions (Simon, 1957) that perform reasonably well with respect to several criteria and acceptably with respect to some others.

3. An Integrated Design Paradigm: Case Study.

To demonstrate that Integrated Design approach has validity and can be realized I developed a proof-of-concept study, or case study. Through it, it is examined how a computational model could be defined taking into account a number of interrelated performances and how the conflict or synergy of these forces could be visualized through form. More specifically, the computational model generates high-rise buildings guided by zoning, structural, solar, and aesthetic criteria. In order to perform the necessary generative, optimization, and simulation algorithms I developed a model that involves Rhino, Excel, and Ecotect environments. However, the model is very much an early prototype. The goal is neither the specific generated buildings that will emerge nor the satisfaction of the specific objectives that were selected but to see generally how form and multiple performances might be handled simultaneously.

3.1. PROCESS

In order to streamline the process of designing buildings, a design algorithm implemented in VBScript for Rhino was used. The user inputs the main characteristics of a site – length and width – and the general geometry of the building – height, floor shape, and core size. Based on the building type of skyscrapers, a very dense urban environment was selected in order to create a rather intriguing scenario by stretching solar and zoning performances. Indeed, the selected lot is located in downtown Manhattan, New York, between Pine, Wall, Front, and Pearl streets.

Next, the script produces a random population of buildings based on these characteristics and by applying randomly various spatial transformations, such as rotation, move, and scale. The script also creates an output file with the geometric properties of each building that is used for the calculation of fitness and evaluation of population, implemented in Excel.

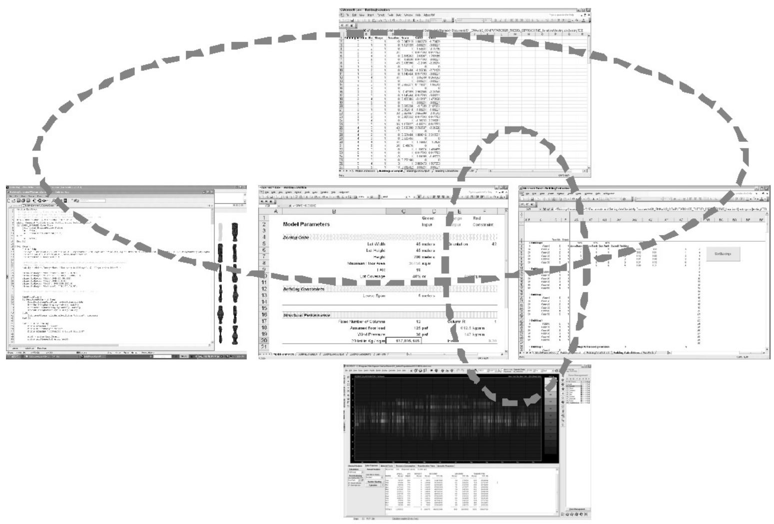

Figure 1. Integration process using software interconnection of Rhino, Excel, and Ecotect.

For the evolution of generations the concept of Genetic Algorithms is used. In zoning, the restriction of total allowable built area and the lot coverage acted as design objectives. In structural, the basic objective is the minimization of weight of the selected material; in this case it is steel. However, in order to ensure the stiffness of structure to the gravity and lateral wind loads, the total stress of any column at any level should not exceed the allowable steel stress. Finally, in solar performance the objective is the maximization of daylight penetration. As for the aesthetic, it is inevitably involved in the creation of the design algorithm, as it will be described in the next sections, and the final selection of the design solution.

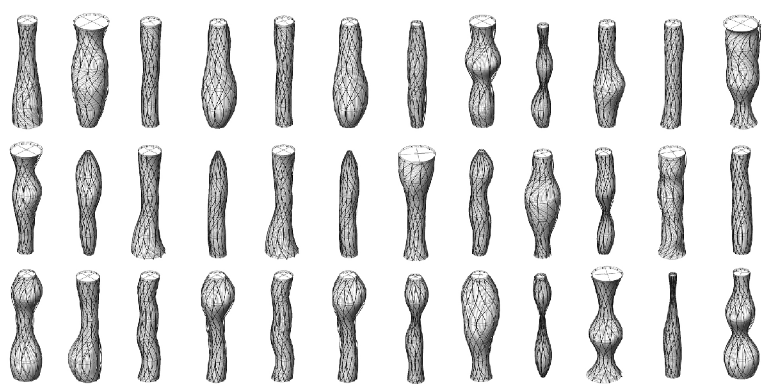

Figure 2. Sample of initial population.

The outcome of the evaluation algorithms is used to rank the buildings from best to worse. Ranking is based on the fitness of each building in each of the performances. To do that, all three rankings are fed into an excel spreadsheet that assigns weights to each and calculates the overall fitness of the building under consideration. The weighted ranking is used to sort the buildings by fitness. When this process is completed, the function of crossover and mutation take place and offspring are created. This newly created generation, is again going through evaluation, being measured for fitness, ranked and fed back to the script that again creates a new generation. The process is over when the participants involved in the design phase judge that the latest design solutions satisfy both aesthetic and performative criteria and then the phase of final selection takes place.

After the creation of this model, some possible solutions are shown. These examples represent various generations whose difference lies on the modification of weights. Indeed, I was experimenting how the relation between the selected interrelated performances could be mirrored on the form changing the importance of weights. Three different weight sets were assigned (the sum of which has be one or one hundred if it is assigned as a percentage): the first set was 0.33 for zoning, 0.33 for structure, and 0.33 for solar, the second was 0.5 for zoning, 0.1 for structure, and 0.4 for solar and the third was 0.15 for zoning, 0.15 for structure, and 0.7 for solar.

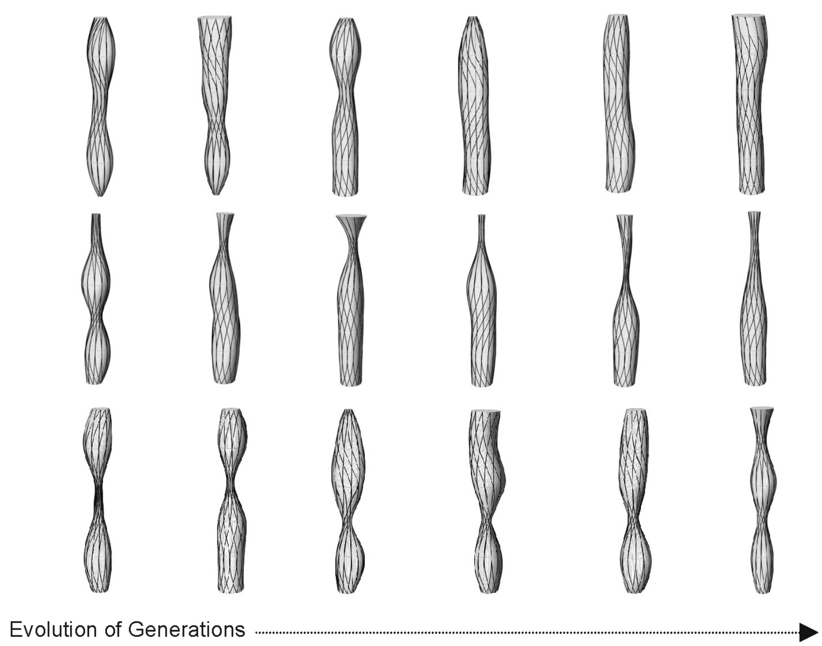

Figure 2. Sequential generations. First row generations of weights (0.33, 0.33, 0.33). Second row generations of (0.5,0.10.4). Third row generations of (0.15, 0.15, 0.7).

3.2. REFLECTIONS ON THE INTEGRATED DESIGN PARADIGM

Usually most of the weights of criteria are assigned based on the subjective judgment of the architect. After the completion of the case study it is concluded that this statement is true if and only if the criteria have firstly met all the strict regulations and safety rules. This prerequisite is grounded on the fact that some building performances represent restrictions while others represent needs. The first are strict and have to be met while the latter are open to interpretations and subjective judgments of the designer. Indeed, it is pointless to find a satisfying solution to a building in which the stress of columns exceeds the allowable one and consequently it will yield under the pressure of applied forces. A way to deal with performances that have this feature is the introduction of a “pass or fail” or else an “if else” statement routine before the weighting. This routine will check whether a building satisfies the conditions defined by the relative regulations, safety rules etc. If the building will not fulfill the conditions, it “fails” and its fitness score is null. If the building satisfies the conditions, it “passes” to the next step, which is the weighting routine.

4. Epilogue

Summarizing, Integrated Design is a different design approach that analyzes and evaluates simultaneously more than one interrelated performance from multiple disciplines, such as civil, mechanical, and electrical engineering etc. The goal of the approach is the generation of design alternatives guided simultaneously by two basic objectives: the aspiration for form exploration and the satisfaction of the performances of interrelated systems.

However, as every action is followed by a reaction, the integrated design approach has several implications for architectural practice, design, architects, and buildings. For example, the prerequisite of interactive multi-disciplinary collaboration will have a direct effect on the organizational chart of most of the big corporative architectural firms. It requires a lively collaboration which in turn presupposes a more flexible work environment. Inevitably, regardless of the size of an architectural firm the utilization of Integrated Design approach implies the redefinition of architectural services since it presupposes the rethinking of dogmatic architecture. After all, it could be concluded that generally in an integrated design approach participants are in a continuous negotiation and confrontation for the determination of what is objective versus what is subjective, what is well-defined versus what is ill-defined, what is automated versus what is manual, what is a restriction versus what is a need, what is conflicting versus what is coexisting etc. However, such negotiations are an integral part of design and that is what makes design such an intriguing and creative activity.

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