PROOF THREE

Metrics, Meaning, Mumbai

A design studio sponsored by Robot Millennium, modeFrontier, CATIA, Buro Happold, and Skidmore, Owings & Merrill

Critic: David Benjamin

OVERVIEW

Metrics, age-old medium for information about the world, are on a roll. They drive spreadsheets, election polling, global supply chains, search engines, social networks, and computer simulations of everything from airplane flights to hurricane paths to crowd behavior. They are more available and more important than ever, but in many ways our understanding and use of them is confused and unimaginitive.

In the field of architecture, **parametric modeling software** can produce infinite variations of a building design. But how do we choose between them? Newly-accessible **simulation software** allows architects to model and measure the performance of buildings—in relation to environmental systems, safety, structure, and flows of air and water. But now what? How do we improve the numbers? When do we stop tuning them? How do we negotiate between competing objectives? What aspects of architecture should be optimized in the first place?

This is the territory of Proof Three, a design studio based on performance evaluation and the process of **testing**. In this studio, we will explore a new methodology: creating architecture through **design of experiments** rather than design of complete solutions.

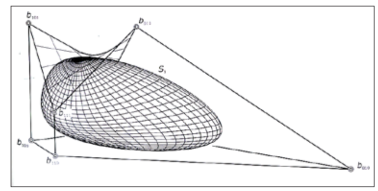
In our experiments, we will use advanced computational methods (evolutionary computing) and new multi-objective optimization software (modeFrontier). We will test with computer simulations (finite element analysis and computational fluid dynamics) and we will test with physical prototypes (digital fabrication and wind tunnel experiments).

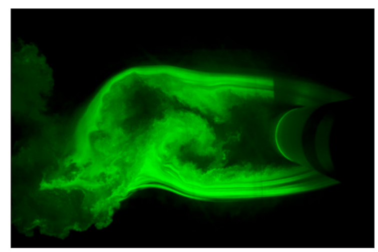
Yet, while we will employ serious tools of engineering and computer science, we will not limit our studies to numbers. We will also value positions about culture and program that were difficult to quantify. Over the course of the semester, we will have an **informed, critical, and open-ended discussion** about the future and meaning of metrics, and the future and meaning of architecture.

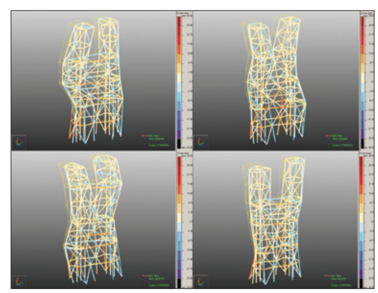
EVOLUTIONARY COMPUTATION

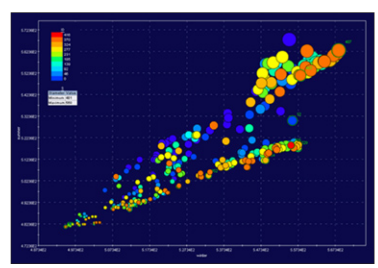
Evolutionary computation combines the power of fitness selection with the power of rapid machine computation. In this process, algorithms simulate biological evolution in order to solve complex problems and generate new designs.

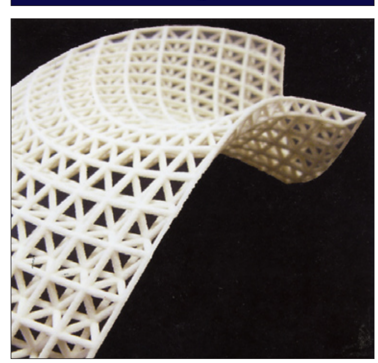
The procedure begins with the creation of a random population of designs and the evaluation of each design by a precise fitness test. Then a second generation











Images (top to bottom): Aerial photo of mid-century ariport; Parametric geometry defined by precise metrics (Axel Killian); Wind tunnel testing (Studio 4: Proof Two); Performance of structural model during FEA analysis, (Will Roedigger-Robinette, Studio 4: Proof Two), Analysis of possible designs in modeFrontier (Chad Kellogg, Studio 5: Proof); STL print of space frame for physical testing.

of designs is created through a specific combination of cross-breeding, mutation, and elitism. The cycle is automatically repeated for thousands of generations, and through this **human-machine collaboration**, it is possible to quickly find valid solutions beyond what a human alone could create.

Evolutionary computation reflects a relatively new paradigm in research on **artificial intelligence**: rather than program machines to follow fixed and known rules, set up an emergent system to evolve new and unexpected results.

In this studio, we will conduct research into the use of evolutionary computation for (1) enhancing technical performance, and (2) generating architectural form.

TESTING WITH SOFTWARE

Our main operational strategy will involve **testing**. In two complementary processes, we will test with computer simulations and we will test with physical prototypes.

For our computer simulations, we will use **parametric modeling** software (CATIA) to create adaptive three-dimensional models and we will use finite element analysis software (Robot Millennium) and computational fluid dynamics software (Cosmos FloWorks) to test the performance of these models under various conditions.

Then, we will be among the first architects in the world to use the multi-objective optimization software **modeFrontier by Esteco**. The software will allow us to generate, evaluate, and evolve thousands of possible designs through the use of evolutionary computing and genetic algorithms.

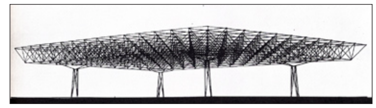
During the semester, we will compile our research for presentation at an **international conference on multi-objective optimization** in Trieste, Italy, alongside research by designers and engineers from BMW, Jaguar & Landrover, Airbus, and Motorola.

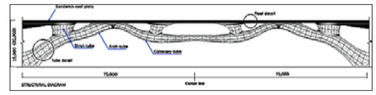
TESTING WITH PHYSICAL PROTOTYPES

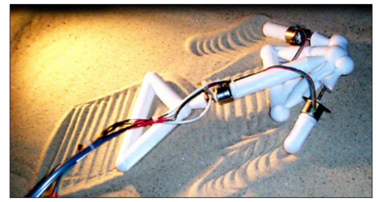
For testing with physical prototypes, we will use the Avery Digital Fabrication Lab—including the **CNC milling machines** and the **waterjet cutter**, as well as the **rapid prototyping machines**—to create part-scale and full-scale prototypes.

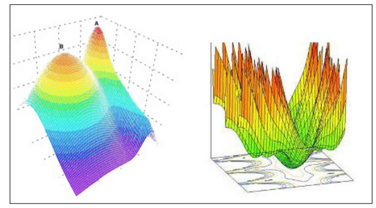
This is a digital fabrication studio with the premise that fabrication must be linked to testing. We will test our prototypes in a high-speed **wind tunnel** at the City College of New York, evaluating their performance in relation to lateral force, uplift, and vortex shedding.

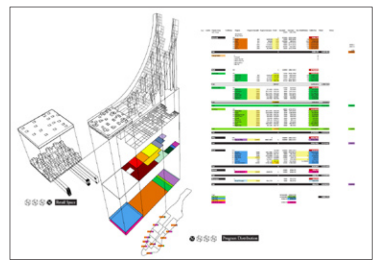
While computer simulation will be used to quickly explore a large field of possible design solutions, physical prototyping will be used to carefully study a small number of successful designs under conditions that are difficult to model in the computer.

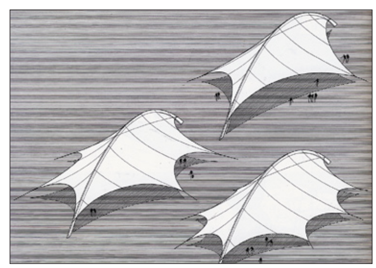


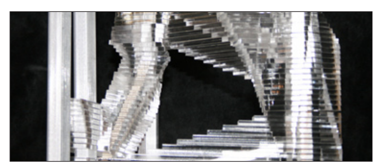


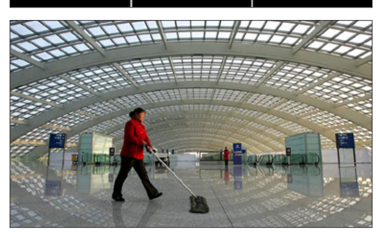












Images (top to bottom): Physical model of spaceframe (Henio Engel); Enhanced Evolutionaly Structural Optimization (Matsuro Sasaki); The Golem Project, Robot designed through evolutionary computation (Hod Lipson, Jordan Pollack); Multi-modal distribution diagrams of discontinuous design space (modeFrontier); Diagram of parametric control of skyscraper design (Troy Therrien, Studio 4: Proof Two); Long-span structures (Henio Engel); Physical model for testing (Mat Staudt, Studio 4: Proof Two); Wind tunnel testing (Studio 4: Proot Two); Beijing Terminal 3 (Norman Foster).

PURE RESEARCH, APPLIED RESEARCH, OPEN SOURCE RESEARCH

Our experiments will involve **pure research** on new tools for automated performance evaluation and **applied research** on designs that address urgent urban and architectural issues. The goal of the studio is not simply to master the technical skills of scripting, optimization, fabrication, and testing. Instead, the goal is to **test the techniques themselves**, and to have an informed and critical discussion about their role in architecture.

In the spirit of open source research, we will document all of our findings and share all of our files and code in an **open source** public wiki site. We will exchange our tests as well as our results. Collectively, we will produce a body of research for future generations to build on, and individually we will create unique and innovative building designs.

AIRPORTS

In the 20th Century, the number of people who fly over the earth on any given day went from zero to four million. Now, at any moment, there are 10,000 planes in the air. Over 1,000 international airports handle this traffic.

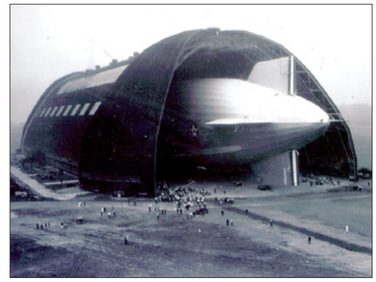
In its relatively short life, airports have transformed from rural fields to modern technological utopias to machines for shopping and secure, efficeint movement. They have become unique human environments. We will apply our research to **new possibilities airport design**.

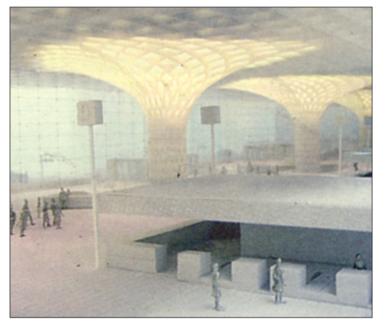
MUMBAI INTERNATIONAL AIRPORT

Every year since 2000, airport traffic in India has increased by 10% or more—the highest growth rate in the world. As the country becomes more mobile, its infrastructure is transforming radically. In dozens of Indian cities, fast track projects are underway to build new and updated airports. In Mumbai, the county's center of culture and finance, the primary airport currently has only 18 international gates, and 90% of domestic passengers are bussed to their planes. A new operating agreement calls for 40 international gates and no more than 10% of domestic and international passengers to be bussed. The future superpower and future world capital are growing and gaining wealth, and its people are on the move.

At the same time, by some estimates 60% of the population of Mumbai lives in some kind of informal housing. Over 350,000 citizens live in **slums on airport property**. While the design of the new airport must negotiate the dizzying flows of airplanes, trains, cars, international and domestic passengers, baggage, and cargo, it must also negotiate the people living in and around the the airport.

Our studio will work closely with **Skidmore, Owings & Merrill (SOM)** and a **private developer in Mumbai** to design the new Chhatrapati Shivaji International Airport. (SOM is currently in the design development phase for this real project.) Each student will explore forms, structural systems, and program layouts for the project, and each







Images (top to bottom): Early terminal for blimp; Bejing International Airport (Norman Foster); Rendering of Mumbai International Airport (SOM); Photo outside of Mumbai International Airport; Photo of informal housing in and around Mumbai International Airport; Sam as previous; Automated luggage handling system.

will address the political and cultural issues involved in the new development. We will begin with a briefing by SOM on the project requirements and constraints. Over the course of the semester, we will meet with SOM partners, structural engineers, and airport experts who are interested in our experimental design approach and use of software. We will conclude with a presentation of our own designs to the firm and the developer.

CLEAN, SYNTHETIC JET FUEL

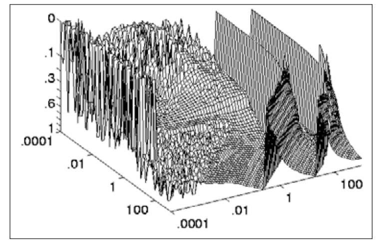
Everyone knows the earth is in trouble and jet travel is not helping. While electric and hybrid fuel technologies are viable for automobiles, they will not work for airplanes. Ethanol is too heavy. Butanol is not well enough understood. But recently sceintists have been using **synthetic biology** to genetically engineer compounds that could power jets without petroleum and without emissions that contribute to climate change.

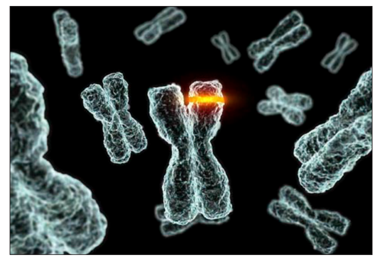
Development in India can be **sustainable**, and our studio will explore the possibilities for using clean, synthetic jet fuel and the impact it will have on the entire airline infrastructure. Our airport designs will incorporate facilities for synthetic biology research, as well as features that will prepare it for a new age of clean jet travel.

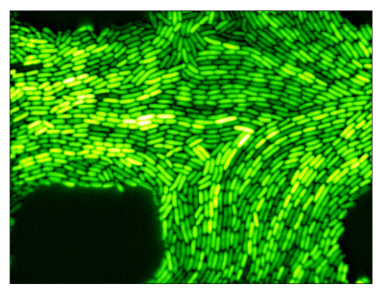
COLLABORATORS

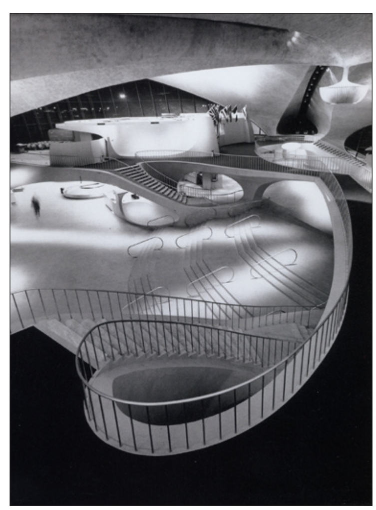
The studio will be sponsored by several companies and organizations outside of the School. All of them are personally invested in the studio. Our collaborators will include:

Yiannis Andreopoulos (Professor of Mechanical Engineering, City College of NY)
Jonathan Colby (Hydrodynamic Engineer, Verdant Power)
Roger Duffy (Design Partner, Skidmore, Owings & Merrill)
Laura Ettelman (Project Manager, Skidmore, Owings & Merrill)
Nader Fateh (VP of Business Development, Esteco)
Natalie Jeremijenko (Director of xClinic and Professor of Art, NYU)
Ian Keough (Senior Technical Designer, Buro Happold)
Hod Lipson (Professor of Aerospace Engineering, Cornell University)
Matthew Melnyk (Senior Structural Engineer, Buro Happold)
Derek Moore (Associate, Skidmore, Owings & Merrill)
Chas Peppers (Project Manager, Skidmore, Owings & Merrill)
Michael Reed (Designer, Blue Sky Studios, and Professor of CS, Columbia)
Steve Sanderson (Technology and Software Coordinator, SHoP Architects)
Anthony Vacchione (Managing Partner, Skidmore, Owings & Merrill)









Images (top to bottom): Design for Vigin Galactic Spaceport (Norman Foster); Multi-modal disribution diagram; DNA manipulated through synthetic biology; Vials of genes used for to experiment with clean, synthetic jet fuel; Cells manipulated by synthetic biology; TWA Terminal (Eero Saarinen).