Computational Design Method based on Multidisciplinary Design optimization and optioneering techniques for Energy Efficiency and Cost Effectiveness
INTRODUCTION
PROBLEM DEFINITION

(Left) Pollution in Mexico City, (Right) Resources shortage in La Paz Potosí Bolivia
PROBLEM DEFINITION

Global Carbon Dioxide Emissions (1980-2016) - IEA 2017

Predicted global surface warming - IPCC 4th Assessment Report
“ARCHITECTURE IS THE WILL OF AN EPOCH TRANSLATED INTO SPACE“ - Mies van der Rohe
How architects and designers can benefit from the use of computational design techniques to integrate specific performative aspects in an energy and cost efficient conceptual design for complex buildings such as Sports halls.

• How can computer aided conceptual design can support the generation of geometric design alternatives?

• To what extend can computer aided design support the designers learning process and be easily understandable and interactive for the future users?

• Can an automated performance-based computational design method be able to achieve an optimal balance between energy regulations, sustainable rankings, restricted budgets and the return of investments?
METHODOLOGY

1. Current practice
2. Performance based design
3. Sports venues design
4. Optimization & design exploration

5. Workflow definition

6. Case study

7. Workflow comparison
8. Users validation
BACKGROUND RESEARCH
CURRENT PRACTICE

![Diagram showing the relationship between time, cost effectiveness, and cost in the design, development, and construction phases.](image-url)

- **TIME**: Time is represented on the x-axis, with the design phase, development, and construction phases indicated.
- **COST EFFECTIVENESS**: Cost effectiveness is represented on the y-axis, with the effect of time on cost effectiveness shown.
- **COST**: Cost is shown increasing with time, indicating a decrease in cost effectiveness.

The diagram illustrates the decrease in cost effectiveness over time, highlighting the importance of considering cost effectiveness during each phase of the project.
CURRENT PRACTICE
CURRENT PRACTICE

TRADITIONAL WORKFLOW
1. What is your background?
I am Julio Endara, a 30 year old student at TU Delft - Faculty of Architecture and the Built Environment. I am doing my master on the Architecture track and I am specializing on Dwelling. Before I came here I worked for 5 years of my home country (Ecuador).

2. How do you use the computer for design purposes?
I use the computer for most of the process. After I pass the sketching stage I rely on the computer for all the design work. I first create 2D basic drawings and after that I simultaneously combine the 2D and 3D explorations. When I finish my design drawings I make a post production process for my final product.

3. What kind of software do you normally use for your projects?

☐ BORO12answ: 3D modeling
☐ Structural Analysis

☐ BIM: 3D Parametric modeling
☐ Cost estimation
☐ Optimization

☐ CAD: 3D visualization
☐ Climate/Energy/Specific

☐ Sketchup: Conceptual
☐ Parametric modeling
☐ Cost estimation

☐ Autocad: Conceptual
☐ Parametric modeling
☐ Cost estimation
☐ Optimization

☐ Revit: Conceptual
☐ Parametric modeling
☐ Cost estimation
☐ Optimization

4. How do you deal with sustainability, energy and costs aspects, at which stage of the design process do you implement these considerations, please clarify?
☐ Conceptual
☐ Development
☐ Construction documentation

5. What do you think about Performance-based architecture (Quantitative/numerical assessment of a design) and Multidisciplinary design optimization design strategies?
I feel that Performance-based architecture is an essential need for the future of the profession. Its really useful to rely on numerical data to organize your work. So have a solid backup for the decisions you make on the design and construction process. I also feel that Multidisciplinary design is efficient and should be made more applied, specially on big offices.

6. How do you see the future of the architect in a technological era?
I wish that in the future I could learn more about these new techniques. At the moment I don’t use them, but it is definitely imperative for the Architect to get involved with the technological solutions as the world in every sense is getting more involved with it. My plans are to learn about numerical assessment methods and programs and implement that knowledge into the development of myself as an architect.

1. What is your background?
Bsc. and Msc. Arch. from TU Berlin and TU Delft. I started with experimental computational design during my studies with the Why Factory at TU Delft.

2. How do you use the computer for design purposes?
Digital tools are part of the design process starting from the earliest design stages. From sketching ideas in Photoshop and 3D modeling software to quantitative design evaluation (Grasshopper/Dynamo/Excel) and prototyping (CAM).

3. What kind of software do you normally use for your projects?

☐ BIM: 3D Parametric modeling
☐ Cost estimation

☐ CAD: 3D Visualization/HR
☐ Climate/Energy

☐ BORO: Conceptual
☐ Parametric modeling

☐ Sketchup: Conceptual
☐ Parametric modeling

☐ Revit: Conceptual
☐ Parametric modeling

4. How do you deal with sustainability, energy and costs aspects, at which stage of the design process do you implement these considerations, please clarify?
☐ Conceptual
☐ Development
☐ Construction documentation

5. What do you think about Performance-based architecture (Quantitative/numerical assessment of a design) and Multidisciplinary design optimization design strategies?
In the office we make a bit of all of it, since the conceptual is the construction with all the details, included furniture.

2. How do you use the computer for design purposes?
At the beginning we use computer to generate ideas. For instance, orientation, some simple things then the process starts with putting ideas in a model to look at the 3D model, and we develop the idea in SketchUp or AutoCad to advance with the function, if it is a two ways process. Finally we use the model to make renders and a presentation, and then if the idea is approved we make a Cost estimation in excel or Neodata.

3. What kind of software do you normally use for your projects?

☐ BIM: 3D Parametric modeling
☐ Cost estimation

☐ CAD: 3D Visualization/HR
☐ Climate/Energy

☐ Sketchup: Conceptual
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It’s really useful to rely on numerical data to organize your work and to have a solid backup for the decisions you make on the design and construction process. I also feel that Multidisciplinary design is efficient and should be more applied, specially on big offices.
CURRENT PRACTICE
PERFORMANCE BASED DESIGN
PERFORMANCE BASED DESIGN

DAYLIGHT

STRUCTURE
PERFORMANCE BASED DESIGN

ENVELOPE

80% ENVIRONMENTAL STRATEGY 30% CONSTRUCTION COSTS

SO THEY NEED TO BE DESIGNED IN AN EFFICIENT WAY AND THIS REPRESENTS A CHALLENGE

STRUCTURE

20% CONSTRUCTION COSTS
DESIGN OPTIMIZATION

AEROSPACE

AUTOMOTIVE
SIMULATION-BASED OPTIMIZATION

1. PRE-PROCESSING

2. PROCESSING

3. POST-PROCESSING
ALGORITHM DESIGN

PRE-PROCESSING

Input 1
Input 2
Input 3

Instructions

Output

+Teabag + a Cup of Boiling Water + Sugar (Optional) = a Cup of Tea
EVOLUTIONARY ALGORITHMS

- Population
- Mutation creates Variation
- Unfavorable mutations selected against
- Reproduction and mutation occur
- Favorable mutations more likely to survive
- Survive
- Fitness test
- Reproduce
- Breeding
- Fitness test
- Survive

Population number
Number of generations
PROCESSING

OPTIMIZATION PROGRAM

- Results
- Run simulation
- Parameters

SIMULATION PROGRAM

OPTIMIZATION PROGRAM

- Optimization Program
- Criteria met?

OBJECTIVE FUNCTIONS

OPTIMIZATION SETTINGS

OPTIMIZATION RESULTS
PROCESSING

SIMULATION PROGRAM

- Results
- Run simulation
- Parameters

OPTIMIZATION PROGRAM

- Optimization Program
- Criteria met?

OBJECTIVE FUNCTIONS

OPTIMIZATION SETTINGS

OPTIMIZATION RESULTS
### TYPES OF OPTIMIZATION

<table>
<thead>
<tr>
<th></th>
<th>Single objective</th>
<th>Multiple objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single discipline</strong></td>
<td><img src="image" alt="Single objective" /></td>
<td><img src="image" alt="Multiple objectives" /></td>
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<tr>
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- **Objective**: represents the single or multiple goals to be optimized.
- **Discipline**: represents the single or multiple aspects or fields of expertise involved.
## TYPES OF OPTIMIZATION

<table>
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</table>

- **Objective**: represented by a black dot
- **Discipline**: represented by a cyan circle
MULTI-OBJECTIVE OPTIMIZATION

UTOPIA POINT

CLOSEST POINT

DOMINATED SOLUTIONS

OBJECTIVE 1

OBJECTIVE 2

NON DOMINATED PARETO FRONT
POST-PROCESSING

SIMULATION PROGRAM
- Results
- Run simulation
- Parameters

OPTIMIZATION PROGRAM
- Optimization Program
- Criteria met?

OBJECTIVE FUNCTIONS
OPTIMIZATION SETTINGS

OPTIMIZATION RESULTS
POST-PROCESSING
1. What is your background?

I did a double degree in civil engineering and architecture. I liked this because it combines the aesthetics of design with the efficiency of engineering. After that I did a year in R+H in Germany where I became very accustomed with computer aided tool and digital manufacturing. This lead to my postgraduate at the Bartlett in London which was very design oriented but backed by computational analysis.

2. How do you use Computational design in your office?

We use computational design for almost everything. The design philosophy of Foster + Partners is one of integrated design, where things don't only look beautiful but also are performative. We use a lot of solar, shading, view analysis to optimize facades which usually directly influence parameterically designed options.

3. Which are the most common aspects or disciplines that you normally apply for optimization purposes?

The two most common aspects are structural efficiency and energy efficiency. We look at making the best possible use out of the materials we choose and vary geometry and buildup to make this possible.

4. What kind of software do you use for energy and cost simulation and which one for optimization purposes?

We use a multitude of tools to achieve an optimal design and are always looking to expand and improve our knowledge. Our team uses a lot of Grasshopper and Dynamo which we usually augment with our own custom tools.

5. Why do you think Performance-based generative design (Quantitative numerical assessment of a design) and design optimization procedures are still not that common practice in most of the architectural firms?

Architecture and especially construction is a slow-moving field, not adjusting as quick as product and industrial design. Although many of the new generation of architects have some knowledge of performance-based design, it will take some time for this to become mainstream. For now it is limited to very large projects in big practices, where there is scope to hire specialist, and budget to look into optimization.

6. How do you see the future of the architect from a technological point of view?

I feel an architect will increasingly be enabled to make informed decisions to design in a more performative way. Creativity will always come from the human mind, but computers can assist a great deal in helping us to see things from a different perspective and open up solutions we might not have thought of ourselves.

1. What is your background?

BG-Civil Engineering (concentration on structures)

MS-Building Engineering (St. Delft, interest in special structures and facade structures)

Professional-Glass (stairs, structural fins, facades). Cable and membranes (shading structures, bicycle wheel stadi) Grid shell/steel, domes and shells, small and large). EFFE cushion facades and structures, facade engineering (mullions, system selection, glass sizing). Forensic-Glass breakages, Field Inspections (anchorage, splices, etc.) Pneumatic/Inflatable structures.

2. How do you use Computational design in your office?

The office is quite large, and uses computational design to varying degrees between groups and projects. Generally, Parametric design is used to aid the architect in formal and structural exploration as well as a way to produce drawings. This involves varying many computer programs (grasshopper, dynamo, Catia, Excel, and others). All the different stages of design computational design is used as a way to open up formal/geometric options to architect, at mid-stages these tools are used to evaluate design options and narrow down design space, at later stages these tools are used to adjust and improve the design, towards the end of a project these tools are used to finalize engineering design and eventually produce drawings.

3. Which are the most common aspects or disciplines that you normally apply for optimization purposes?

The most common aspects are structural efficiency and energy efficiency. We look at making the best possible use out of the materials we choose and vary geometry and buildup to make this possible.

4. What kind of software do you use for energy and cost simulation and which one for optimization purposes?

MS Excel works very well for everything, typing into it with python and other scripts, allows us to improve optimization and other techniques into most other software. Within my group in the office we typically use grasshopper to narrow down formal aspects with architects early on. Then we move on to SOFIE for more complicated form finding/force finding, and preliminary sizing, global buckling checks and eigen mode analysis are also checked here for confirmation with the wind consultant. To understand the structure from a different standpoint, from these we move on to SAP EASY, Strand or other software to validate our previous analysis, check against code, and to proceed with detail design.

1. What is your background?

I studied Architecture in Bachelor and Master, and my second Master is environmental building design.

2. Which kind of algorithms do you normally use for optimization problems related to buildings design?

I don't use any algorithm specifically in my daily work. What I do is mainly parameter sensitivity test, and this is what Collab and Design Explorer mainly do. They are designed to assist the design process, instead of providing the answer.

3. Which are the most common aspects or disciplines that you apply performance simulations and optimization procedures?

I use annual daylight simulation (sometime use point-in-time daylight simulation when designer is hard to understand the annual matrix), point-in-time glaze study, along with cooling and heating peak load for HVAC sizing.

4. What kind of software do you use for energy and cost simulation and which one for optimization purposes?

For the energy, I use Energy Plus along with Honeybee and OpenStudio. I don't do any cost simulation, that is usually done by our facade team.

I wouldn't say I do any optimization work, most of my work is exploring study and sensitivity test as I mentioned above.

5. What do you think about Performance-based generative design (Quantitative numerical assessment of a design) and design optimization procedures are still not that common practice in most of the architectural firms?

Well, I think the performance-based design is not common yet, but it is moving toward it. Second, what we can say about performance-based design is mainly focusing on daylight and energy, which are two aspects currently feasible to do alone with architecture design process. Designing a building is not only about daylight and energy, there are more other considerations that cannot be equally quantified. Just to name as “A” word, AI can do everything except the art, which is the part that still require humans to be involved. Third, even though we want to generate a building only focusing on energy, there are still too many parameters to test without cloud computing ability. But this one will be generally available in next five years, I believe.
POST-PROCESSING

SIMULATION PROGRAM
- Results
- Run simulation
- Parameters

OPTIMIZATION PROGRAM
- Optimization Program
- Criteria met?

OBJECTIVE FUNCTIONS
- Optimization SETTINGS

OPTIMIZATION RESULTS

DESIGN EXPLORATION
WORKFLOW DEFINITION
CONVENTIONAL WORKFLOWS

TRADITIONAL ARCHITECTURAL WORKFLOW

1. DESIGN DEFINITION
2. DESIGN OPTIONS
   - Structural
   - Environmental
   - Acoustic
   - Cost
3. PERFORMANCE FEEDBACK
4. DESIGN CHANGES

INEFFICIENT WORKFLOW

TYPICAL DESIGN OPTIMIZATION WORKFLOW

1. OPTIMIZATION OBJECTIVES DETERMINATION
2. DECISION VARIABLES SELECTION
3. PARAMETRIC SIMULATION MODELING
4. MULTI OBJECTIVE/MULTIDISCIPLINARY OPTIMIZATION
5. RESULTS VISUALIZATION

DESIGN LIMITATION
CONVENTIONAL WORKFLOWS

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DESIGN LIMITATION
PROPOSED WORKFLOW

TYPICAL DESIGN OPTIMIZATION WORKFLOW

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4. MULTI OBJECTIVE/MULTIDISCIPLINARY OPTIMIZATION

5. RESULTS VISUALIZATION
PROPOSED WORKFLOW FOR ENERGY EFFICIENCY AND COST EFFECTIVENESS

1. OPTIMIZATION OBJECTIVES DETERMINATION
2. DECISION VARIABLES SELECTION
3. OPTIMIZATION/DESIGN EXPLORATION STRATEGY SELECTION FLEXIBILITY
   - SEQUENTIAL STRATEGY
   - INTEGRATED STRATEGY
4. TOOLS COMBINATION
5. CUSTOMIZED DATABASE
   - Materials
     - Typical materials
     - Geographic location
   - Costs
     - Typical energy fees
     - Building typology
     - Local catalogues/contractors
     - Local market prices
6. PARAMETRIC SIMULATION MODELING
7. MULTI OBJECTIVE/MULTIDISCIPLINARY OPTIMIZATION
8. RESULTS VISUALIZATION
9. DESIGN EXPLORATION

INFORMED & BALANCED DECISION
PROPOSED WORKFLOW

PROPOSED WORKFLOW FOR ENERGY EFFICIENCY AND COST EFFECTIVENESS

1. OPTIMIZATION OBJECTIVES DETERMINATION

2. DECISION VARIABLES SELECTION

3. OPTIMIZATION/DESIGN EXPLORATION STRATEGY SELECTION FLEXIBILITY

SEQUENTIAL STRATEGY — INTEGRATED STRATEGY

4. TOOLS COMBINATION

5. CUSTOMIZED DATABASE

6. PARAMETRIC SIMULATION MODELING

7. MULTI OBJECTIVE/MULTIDISCIPLINARY OPTIMIZATION

8. RESULTS VISUALIZATION

9. DESIGN EXPLORATION

INFORMED & BALANCED DECISION

Commercial availability
Open source
User support
Reliability
User-friendly interface
Interoperability

Materials
Costs
Local energy fees
Local market prices

Massing
Structure
Envelope
Systems

Size
Shape
Shape
Structure

Performance
Passive design implementations
Active design implementations

TRADITIONAL ARCHITECTURAL WORKFLOW

OPTIMIZATION/DESIGN EXPLORATION STRATEGY SELECTION FLEXIBILITY

SEQUENTIAL STRATEGY — INTEGRATED STRATEGY

1. OPTIMIZATION OBJECTIVES DETERMINATION

2. DECISION VARIABLES SELECTION

3. PARAMETRIC SIMULATION MODELING

4. MULTI OBJECTIVE/MULTIDISCIPLINARY OPTIMIZATION

5. RESULTS VISUALIZATION

6. DESIGN EXPLORATION

7. INFORMED & BALANCED DECISION

Geometric model
Structural model
Daylight model
Energy model
Costs model
Optimization model
Visualization model

COSTS DATABASE

Benchmark
Detailed

PARAMETRIC MODEL LINKED TO CUSTOMIZED DATABASE

Stage 1: Massing
Stage 2: Structure
Stage 3: Envelope
Stage 4: Systems
PROPOSED WORKFLOW

3. OPTIMIZATION/DESIGN EXPLORATION STRATEGY SELECTION FLEXIBILITY

SEQUENTIAL STRATEGY

INTEGRATED STRATEGY
PROPOSED WORKFLOW

SEQUENTIAL STRATEGY

3. OPTIMIZATION/DESIGN EXPLORATION STRATEGY SELECTION FLEXIBILITY

INTEGRATED STRATEGY

BRIEF → CONCEPTUAL → DEVELOPMENT → DETAILED

Lack of information → More available information → More available information

INTEGRATED
PROPOSED WORKFLOW

PROPOSED WORKFLOW FOR ENERGY EFFICIENCY AND COST EFFECTIVENESS

1. OPTIMIZATION OBJECTIVES DETERMINATION
2. DECISION VARIABLES SELECTION
3. OPTIMIZATION/DESIGN EXPLORATION STRATEGY SELECTION FLEXIBILITY

4. TOOLS COMBINATION
5. CUSTOMIZED DATABASE
6. PARAMETRIC SIMULATION MODELING
7. MULTI OBJECTIVE/MULTIDISCIPLINARY OPTIMIZATION
8. RESULTS VISUALIZATION
9. DESIGN EXPLORATION

INFORMED & BALANCED DECISION

COMMERCIAL

COMMERCIAL

OPEN SOURCE

USER SUPPORT

RELIABILITY

USER-FRIENDLY INTERFACE

INTEROPERABILITY

MATERIALS

MATERIALS

BUILDING TYPOLOGY

LOCAL CATALOGUES/CONTRACTORS

LOCAL ENERGY FEES

LOCAL MARKET PRICES

COSTS

COSTS DATABASE

BENCHMARK

DETAILED

PARAMETRIC MODEL LINKED TO CUSTOMIZED DATABASE

STAGE 1: MASSING
STAGE 2: STRUCTURE
STAGE 3: ENVELOPE
STAGE 4: SYSTEMS

DESIGN DEFINITION

OPTIMIZATION OBJECTIVES DETERMINATION

DECISION VARIABLES SELECTION

OPTIMIZATION/DESIGN EXPLORATION STRATEGY SELECTION FLEXIBILITY

PARAMETRIC SIMULATION MODELING

MULTI OBJECTIVE/MULTIDISCIPLINARY OPTIMIZATION

RESULTS VISUALIZATION

DESIGN EXPLORATION

INFORMED & BALANCED DECISION

SEQUENTIAL STRATEGY

INTEGRATED STRATEGY

COMMERCIAL

COMMERCIAL

OPEN SOURCE

USER SUPPORT

RELIABILITY

USER-FRIENDLY INTERFACE

INTEROPERABILITY

MATERIALS

MATERIALS

BUILDING TYPOLOGY

LOCAL CATALOGUES/CONTRACTORS

LOCAL ENERGY FEES

LOCAL MARKET PRICES

COSTS

COSTS DATABASE

BENCHMARK

DETAILED

PARAMETRIC MODEL LINKED TO CUSTOMIZED DATABASE

STAGE 1: MASSING
STAGE 2: STRUCTURE
STAGE 3: ENVELOPE
STAGE 4: SYSTEMS

DESIGN DEFINITION

OPTIMIZATION OBJECTIVES DETERMINATION

DECISION VARIABLES SELECTION

OPTIMIZATION/DESIGN EXPLORATION STRATEGY SELECTION FLEXIBILITY

PARAMETRIC SIMULATION MODELING

MULTI OBJECTIVE/MULTIDISCIPLINARY OPTIMIZATION

RESULTS VISUALIZATION

DESIGN EXPLORATION

INFORMED & BALANCED DECISION

SEQUENTIAL STRATEGY

INTEGRATED STRATEGY
PROPOSED WORKFLOW

1. OPTIMIZATION OBJECTIVES DETERMINATION
2. DECISION VARIABLES SELECTION
3. PARAMETRIC SIMULATION MODELING
4. MULTI OBJECTIVE/MULTIDISCIPLINARY OPTIMIZATION
5. RESULTS VISUALIZATION

4. TOOLS COMBINATION

- Commercial availability
- Open source
- User support
- Reliability
- User-friendly interface

5. CUSTOMIZED DATABASE

- Materials
  - Typical materials
    - Geographic location
  - Building typology
- Costs
  - Local catalogues/contractors
  - Local energy fees
  - Local market prices

Sequential Strategy

INTEGRATED STRATEGY

Design Exploration

RESULTS

Optimization/Design Exploration

Strategy Selection Flexibility

Final Design

Results Comparison

STAGE 1: MASSING

- Size
- Shape

STAGE 2: STRUCTURE

- Structural performance
- Passive design implementations
- Active design implementations

STAGE 3: ENVELOPE

- Size
- Shape

STAGE 4: SYSTEMS

- Design
- Environmental
- Cost

TRADITIONAL ARCHITECTURAL WORKFLOW

TYPICAL DESIGN OPTIMIZATION WORKFLOW

PROPOSED WORKFLOW
PROPOSED WORKFLOW FOR ENERGY EFFICIENCY AND COST EFFECTIVENESS

1. OPTIMIZATION OBJECTIVES DETERMINATION

2. DECISION VARIABLES SELECTION

3. OPTIMIZATION/DESIGN EXPLORATION STRATEGY SELECTION FLEXIBILITY

4. TOOLS COMBINATION

5. CUSTOMIZED DATABASE

6. PARAMETRIC SIMULATION MODELING

7. MULTI OBJECTIVE/MULTIDISCIPLINARY OPTIMIZATION

8. RESULTS VISUALIZATION

9. DESIGN EXPLORATION

INFORMED & BALANCED DECISION
CASE STUDY
CUITLÁHUAC PARK, IZTAPALAPA, MEXICO CITY
### General
- **Source**: IWEC
- **Country**: MEXICO
- **Filename**: MEX_MEXICO_CITY_IWEC.epw

### Details
- **Latitude (*)**: 19.43
- **Longitude (*)**: -99.06
- **WMO station identifier**: 766790
- **ASHRAE climate zone**: 3B

### Summer
- **Summer start month**: apr
- **Summer end month**: jun
- **Extreme hot week, starting**: may-27
- **Typical hot week, starting**: may-20
- **Cooling degree-days (Base 10°C) (Degree days)**: -

### Winter
- **Winter start month**: oct
- **Winter end month**: dec
- **Extreme cold week, starting**: dec-3
- **Typical cold week, starting**: nov-12
- **Heating degree-days (Base 18°C) (Degree days)**: -
**REQUIREMENTS**

- **Situation 1 (Without spectators):**
  - Area: 1,536 m²
  - Volume: 16,896 m³
  - Program:
    - 3 Basketball courts
    - 2 Volleyball courts
    - 1 Soccer space
    - 1 Circulation space
    - 1 Steps space

- **Situation 2 (With possible spectators):**
  - Area: 2,640 m²
  - Volume: 44,880 m³
  - Program:
    - 3 Basketball courts
    - 2 Volleyball courts
    - 1 Soccer space
    - 1 Circulation space
    - 1 Steps space

Floorplans, Elevations, Isometric without spectators space, Isometric with possible spectators space.
DESIGN OBJECTIVES

PERFORMANCE EVALUATION CRITERIA

1. Minimize Costs
2. Maximize profits
3. Reduce Energy Use Intensity
4. Improve Daylight quality
DESIGN OBJECTIVES

1. Minimize Costs
2. Maximize profits
3. Reduce Energy Use Intensity
4. Improve Daylight quality
# Design Variables

<table>
<thead>
<tr>
<th>Building depth</th>
<th>Beam depth</th>
<th>WWR Ration (walls)</th>
<th>HVAC systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building width</td>
<td>Column depth</td>
<td>WWR Ration (Roof)</td>
<td>Lighting systems</td>
</tr>
<tr>
<td>Building height</td>
<td>Chord diameter</td>
<td>Opaque material - wall</td>
<td></td>
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<tr>
<td>Height of the peak</td>
<td>Chord thickness</td>
<td>Opaque material - roof</td>
<td></td>
</tr>
<tr>
<td>Position of the peak</td>
<td>Web diameter</td>
<td>Window material</td>
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<tr>
<td>Lateral connection thickness</td>
<td>Web thickness</td>
<td>Orientation</td>
<td></td>
</tr>
<tr>
<td>Divisions of the beam</td>
<td>Lateral connection diameter</td>
<td>Number of shadings</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Divisions of the column</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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## DESIGN VARIABLES

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<tr>
<td>Building depth</td>
<td>Beam depth</td>
<td>WWR Ration (walls)</td>
<td>HVAC systems</td>
</tr>
<tr>
<td>Building width</td>
<td>Column depth</td>
<td>WWR Ration (Roof)</td>
<td>Lighting systems</td>
</tr>
<tr>
<td>Building height</td>
<td>Chord diameter</td>
<td>Opaque material - wall</td>
<td></td>
</tr>
<tr>
<td>Height of the peak</td>
<td>Chord thickness</td>
<td>Opaque material - roof</td>
<td></td>
</tr>
<tr>
<td>Position of the peak</td>
<td>Web diameter</td>
<td>Window material</td>
<td></td>
</tr>
<tr>
<td>Lateral connection thickness</td>
<td>Web thickness</td>
<td>Orientation</td>
<td></td>
</tr>
<tr>
<td>Divisions of the beam</td>
<td>Lateral connection diameter</td>
<td>Number of shades</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
DESIGN STRATEGY

SEQUENTIAL

INTEGRATED

STAGE 1: MASSING
- Size
- Shape

STAGE 2: STRUCTURE
- Shape
- Structure performance

STAGE 3: ENVELOPE
- Passive design implementations
- Active design implementations

STAGE 4: SYSTEMS

BENCHMARKS COSTS
- Benchmark energy use

DETAILED COSTS
- Simulations / estimations

FINAL DESIGN

RESULTS

4/8

4/8

4/8

4/8
PARAMETRIC MODEL OPTIMIZER

(Iteration)

Inputs (Parameters)

Outputs (Performance results)

AGGREGATOR (Collects data)

Costs database

Mathematical operations

Results

COSTS DATABASE
1. Volumetric costs (Benchmarks)
2. Structural costs
3. Envelope costs
4. Systems (Add ons) costs
COST DATABASE

- **INSTALLATIONS [$]**
  - COOLING
    - DIRECT EXPANSION A/C $$
    - CHILLER $\$
  - HEATING
    - BOILER HEATING (COP .9) $$
    - ELECTRIC BASEBOARD (COP 1) $\$
    - GROUND SOURCE HEAT PUMP (COP 4) $$$
  - LIGHTING
    - MANUAL SWITCH $$
    - AUTOMATE SWITCH OFF $\$
    - AUTOMATE DIMMING $$$

- **ROOF**
  - **OPAQUE**
    - CHORDS
    - WEBS
  - **TRANSITIONAL**
    - ROOF MEMBRANE
    - IEAD NONRES ROOF
    - INSULATION-1.76
    - METAL DECKING
    - BRICK (100mm)
    - GYPSUM 1/2 (INSIDE)
    - CONCRETE (100mm)
    - GYPSUM 1/2 (INSIDE)
    - M01 100mm brick
    - M15 200mm HEAVYWEIGHT CONCRETE
  - **TRANSPARENT**
    - FIXED WINDOW
    - 3.24/0.25/0.16

- **WALLS**
  - **OPAQUE**
    - M01 100mm brick
    - M15 200mm HEAVYWEIGHT CONCRETE
    - I02 50mm INSULATION BOARD
    - F04 WALL AIR SPACE RESISTANCE
    - G01a 19mm GYPSUM BOARD
    - CLEAR GLASS (3mm)
    - AIR GAP (13mm)
    - CLEAR GLASS (3mm)
  - **TRANSPARENT**
    - F05 CEILING AIR SPACE
    - RESISTANCE
    - F16 ACOUSTIC TILES
PARAMETRIC SIMULATION MODELING

1. Geometrical parametric model
2. Structural parametric model
3. Daylight parametric model
4. Energy parametric model
5. Costs parametric model
6. Optimization
7. Data managing & visualization
## Results

<table>
<thead>
<tr>
<th></th>
<th>HONEYBEE MODEL</th>
<th>DESIGN BUILDER MODEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>1728m²</td>
<td>1728m²</td>
</tr>
<tr>
<td>Volume</td>
<td>18816m³</td>
<td>19308</td>
</tr>
<tr>
<td>Wall area</td>
<td>3056m²</td>
<td>3373m²</td>
</tr>
<tr>
<td>Window area</td>
<td>395.52m²</td>
<td>450m²</td>
</tr>
<tr>
<td>Annual Cooling demand</td>
<td>45.70 kWh/yr</td>
<td>45.69 kWh/yr</td>
</tr>
<tr>
<td>Annual Heating demand</td>
<td>0.011 kWh/yr</td>
<td>0.011 kWh/yr</td>
</tr>
<tr>
<td>Annual Lighting demand</td>
<td>64.24 kWh/yr</td>
<td>64.22 kWh/yr</td>
</tr>
<tr>
<td>Total Annual energy demand</td>
<td>102.93 kWh/m²/yr</td>
<td>106.39 kWh/m²/yr</td>
</tr>
</tbody>
</table>

### General
- **Location (weather file):** Mexico City.iwec
- **Orientation:** N-S

### Geometry
- **Height:** 11m
- **Width:** 36m
- **Depth:** 48m
- **KRW Skylight:** 10%
- **KRW (all walls):** 40%

### Materials
- **Roof:** 500mm Ins. 200mm Heavy weight concrete
- **Walls:** 100mm concrete, 1/2" Gypsum
- **Windows:** 3mm clear glas, 13mm air gap, 3mm clear glas

### Activity
- **Occupancy schedule:** 6am-9pm (Monday-Sunday)
- **HVAC schedule:** Always on
- **Heating setpoint:** 28°C
- **Heating setback:** 8°C
- **Cooling setpoint:** 22°C
- **Cooling setback:** 22°C
- **Metabolic rate:** 120W
- **Equipment:** 2W/m²
- **Lighting density:** 1 W/m²

### HVAC
- **Infiltration rate:** 0.0025 M3/s/m²
- **HVAC System:** Ideal loads + natural gas/electricity from grid
- **HVAC System:** Heating 35°C / Cooling 12°C
- **HVAC System:** Heating 35°C / Cooling 12°C
- **Economizer:** Yes (7)
- **Heat recovery:** Yes 1/7
- **Infiltration schedule:** Always on
- **Infiltration rate:** 0.0025 M3/s/m²
- **Design wind pressure:** 1.524 kPa

### Results
- **EUI:** 102.93 kWh/m²/year
- **EUI:** 106.39 kWh/m²/year
IMPLEMENTATION

Stage 1: Massing
- Calculations
- Optimization
- Design Exploration
  - Design Decision Results

Stage 2: Structure
- Simulation
- Optimization
- Design Exploration
  - Design Decision Results

Stage 3: Envelope
- Simulation
- Optimization
- Design Exploration
  - Design Decision Results

Stage 4: Systems
- Simulation
- Optimization
- Design Exploration
  - Final Design Results

SEQUENTIAL STRATEGY

INTEGRATED STRATEGY

PARAMETRIC MODEL LINKED TO CUSTOMIZED DATABASE
IMPLEMENTATION

- Stage 1: Massing
  - Calculations
  - Optimization
  - Design Exploration
  - Design Decision Results

- Stage 2: Structure
  - Simulation
  - Optimization
  - Design Exploration
  - Design Decision Results

- Stage 3: Envelope
  - Simulation
  - Optimization
  - Design Exploration
  - Design Decision Results

- Stage 4: Systems
  - Simulation
  - Optimization
  - Design Exploration
  - Final Design Results

Sequential Strategy

Integrated Strategy

Parametric Model Linked to Customized Database

- Masing
- Structure
- Envelope
- Systems

Design Exploration

Results Comparison

Optimization

Selection

Strategy

Environmental Performance Feedback

Traditional Architectural Performance Feedback

- Design Changes
- Design Options
- Design Definition

Optimization

- Parametric Model
- Geometric Model
- Structural Model
- Daylight Model
- Energy Model
- Costs Model

Benchmark

Detailed

- Passive Design Implementations
- Active Design Implementations

Optimization/Design Exploration

- Design Limitations
- Implementation

Efficiency and Cost Effectiveness

Proposed Workflow for Energy

Informed & Balanced Decision

Decision Variables Selection

Optimization Objectives

- Acoustic
- Cost
- Structure

Typical Design Optimization

Simulation

- Sequential Strategy

User-Friendly

- Availability
- Reliability
- User Support

Open Source

- Interoperability
- Commercial
- User-Friendly

Design Exploration

- Final Design
- Results

Multi-Objective/Multi-Disciplinary

Decision

- COMBINATION
- SEQUENTIAL
- STRATEGY

Materials

- Typical Materials
- Geographic Location
- Local Market Prices
- Local Energy Fees
- Building Typology
- Local

Catalogues/Contractors

- Typical Catalogues/Contractors
- Geographic Location
- Local Market Prices
- Local Energy Fees
- Building Typology
STAGE 1: MASSING
STAGE 1: MASSING
STAGE 1: MASSING

<table>
<thead>
<tr>
<th>STAGE</th>
<th>NUMBER OF PARAMETERS</th>
<th>NUMBER OF GENERATIONS</th>
<th>DESIGN SPACE</th>
<th>DOMINATED / NON DOMINATED</th>
<th>COMPUTATIONAL TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1: Massing</td>
<td>5 Parameters</td>
<td>6 Generations</td>
<td>313-576</td>
<td>115 Non-dominated</td>
<td>15 Minutes</td>
</tr>
<tr>
<td></td>
<td>100 Population</td>
<td></td>
<td></td>
<td>73 Dominated</td>
<td></td>
</tr>
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</table>
STAGE 1: MASSING
STAGE 1: MASSING
STAGE 2: STRUCTURE
STAGE 2: STRUCTURE
STAGE 2: STRUCTURE
STAGE 2: STRUCTURE

<table>
<thead>
<tr>
<th>STAGE</th>
<th>NUMBER OF PARAMETERS</th>
<th>NUMBER OF GENERATIONS</th>
<th>DESIGN SPACE</th>
<th>DOMINATED / NON DOMINATED</th>
<th>COMPUTATIONAL TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13 Parameters</td>
<td>50 Generations</td>
<td>320 from 118125000</td>
<td>140 Non-dominated, 60 Dominated</td>
<td>2.5 Hours</td>
</tr>
</tbody>
</table>
STAGE 2: STRUCTURE
STAGE 3: ENVELOPE
STAGE 3: ENVELOPE
STAGE 3: ENVELOPE
## STAGE 3: ENVELOPE

<table>
<thead>
<tr>
<th>STAGE DESIGN SPACE</th>
<th>DOMINATED / NON DOMINATED</th>
<th>COMPUTATIONAL TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>NUMBER OF PARAMETERS</td>
<td>NUMBER OF GENERATIONS</td>
<td>DESIGN SPACE</td>
</tr>
<tr>
<td>10 Parameters</td>
<td>7 Generations</td>
<td>900 from 2774800</td>
</tr>
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STAGE 3: ENVELOPE
STAGE 3: ENVELOPE
STAGE 4: SYSTEMS
STAGE 4: SYSTEMS
STAGE 4: SYSTEMS

<table>
<thead>
<tr>
<th>STAGE</th>
<th>NUMBER OF PARAMETERS</th>
<th>NUMBER OF GENERATIONS</th>
<th>REDUCTION</th>
<th>DOMINATED / NON DOMINATED</th>
<th>COMPUTATIONAL TIME</th>
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<tbody>
<tr>
<td></td>
<td>3 Parameters</td>
<td>1 Generations 100 Population</td>
<td>24-24</td>
<td>23 Non-dominated 106 Dominated</td>
<td>5 Hours</td>
</tr>
</tbody>
</table>
STAGE 4: SYSTEMS
INTEGRATED STRATEGY
INTEGRATED STRATEGY
INTEGRATED STRATEGY
INTEGRATED STRATEGY

<table>
<thead>
<tr>
<th>STAGE</th>
<th>NUMBER OF PARAMETERS</th>
<th>NUMBER OF GENERATIONS</th>
<th>DESIGN SPACE</th>
<th>DOMINATED / NON DOMINATED</th>
<th>COMPUTATIONAL TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>18 Parameters</td>
<td>10 Generations</td>
<td>1200 from 97820835840000</td>
<td>88 Non-dominated</td>
<td>2.5 Days</td>
</tr>
</tbody>
</table>
INTEGRATED STRATEGY

[Graphs showing relationships between Energy Costs, Construction Costs, UDLI, EUI, and Sale price]
INTEGRATED STRATEGY
# Strategies Comparison

<table>
<thead>
<tr>
<th>Stage</th>
<th>Number of Parameters</th>
<th>Number of Generations</th>
<th>Design Space</th>
<th>Dominated / Non Dominated</th>
<th>Computational Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 Parameters</td>
<td>7 Generations</td>
<td>313-576</td>
<td>72 Non-dominated 245 Dominated</td>
<td>1.5 Hours</td>
</tr>
<tr>
<td></td>
<td>13 Parameters</td>
<td>50 Generations 100 Population</td>
<td>3200 from 118125000</td>
<td>140 Non-dominated 60 Dominated</td>
<td>2.5 Hours</td>
</tr>
<tr>
<td></td>
<td>10 Parameters</td>
<td>7 Generations 100 Population</td>
<td>900 from 277544800</td>
<td>60 Non-dominated 64 Dominated</td>
<td>1.5 Days</td>
</tr>
<tr>
<td></td>
<td>3 Parameters</td>
<td>1 Generations 100 Population</td>
<td>24-24</td>
<td>23 Non-dominated 106 Dominated</td>
<td>5 Hours</td>
</tr>
<tr>
<td></td>
<td>18 Parameters</td>
<td>10 Generations 100 Population</td>
<td>1200 from 9782083584000</td>
<td>88 Non-dominated 1 Dominated</td>
<td>2.5 Days</td>
</tr>
</tbody>
</table>
USERS VALIDATION
<table>
<thead>
<tr>
<th>Architect/Student</th>
<th>Shape</th>
<th>Reasoning</th>
<th>Energy Efficiency</th>
<th>Cost</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daniel Laredo</td>
<td>This shape fits the structure I chose. I was looking for a structure with the lowest amount possible of supports. The building will be mostly used during daytime, so it takes advantage of solar energy and sunlight. Low cost. The system combines function, energy efficiency, and the location of the building.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Israel Hernández</td>
<td>Shape with average volume. Average cost of structure with the first shapes. Lower cost of support for orientation. Only need lighting system and cooling system. The most similar between shape and structure with a average energy cost.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jayanti Juárez</td>
<td>I was looking for a tall peak. I was looking for few frames and division of the beams. I prefer an option with little use of energy. I don’t understand if the systems are natural, if they’re not I prefer the cooling system than heating and lighting system. I tried to combine all the aspects before written.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monserrat Martínez</td>
<td>By form H. Eight and number of frames. Orientation and lower use of energy. Low use of cooling and lighting. Combines all the aspects.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gelene Guerra</td>
<td>Irregular form. Low cost. Low energy consumption. Low energy cost. Low energy consumption.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Héctor Fuentes</td>
<td>By form. Structure according to form. Lower energy use. Low cost. Low cost.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1. How complex do you consider the interface?
- Easy ☐
- Medium ☒
- High ☐

2. Which stage was more helpful when talking about decision support?
- Stage 1_Massing ☐
- Stage 2_Structure ☒
- Stage 3_Envelope ☐
- Stage 4_Systems ☐

3. Which stage was more complicated to understand or to deal with it?
- Stage 1_Massing ☐
- Stage 2_Structure ☐
- Stage 3_Envelope ☒
- Stage 4_Systems ☐

4. In a scale of 1 to 5 how did each section helped you to take a design decision?
- Stage 1_Massing: ☒
- Stage 2_Structure: ☐
- Stage 3_Envelope: ☐
- Stage 4_Systems: ☐

5. When comparing the two different approaches (Stages / Complete) which one do you prefer?
- Stage division ☐
- Complete ☒

6. For which phase of the project would you think this strategy would be more helpful?
- Conceptual ☐
- Development ☒
- Documentation ☐

7. What else would you also include inside the interface?
- It would be nice to have the possibility to see the volume (m3)

8. When comparing the two different approaches (Stages / Complete) which one do you prefer?
- Stage division ☐
- Complete ☒

9. For which phase of the project would you think this strategy would be more helpful?
- Conceptual ☐
- Development ☒
- Documentation ☐

- More specifications in the parameters table
USERS VALIDATION

WHICH ONE WAS MORE HELPFUL

USEFULNESS SCALE

PROJECT PHASE APPLICATION

WORKFLOW COMPLEXITY

STAGE DIFFICULTY

SEQUENTIAL VS INTEGRATED
DISCUSSION & CONCLUSIONS
CONCLUSIONS

1. There is no one **ideal optimization** workflow (flexibility, available data & company).

2. The most critical part of the entire process is the beginning, **designing the problem** defining what will change or not, besides clarifying the specific needs and having the right **information** at the right **time** is a fundamental consideration.

3. It is necessary to work **together** with the **specialists** of the diverse fields to define the different parametric models and set up the **performance** simulations.

4. Computers can effectively work as **design decision supporters** and as **educational tools** for architects and designers. Specifically when talking about cost and energy, it can help in finding good **balanced solutions** based on **performance** analysis in combination with **aesthetic** aspects. In this process, it is crucial also to involve the designers **intuition** and **expertise**.

5. Technology is already there we just only need to **change** and **improve** the way we use it and apply it.
THANK YOU