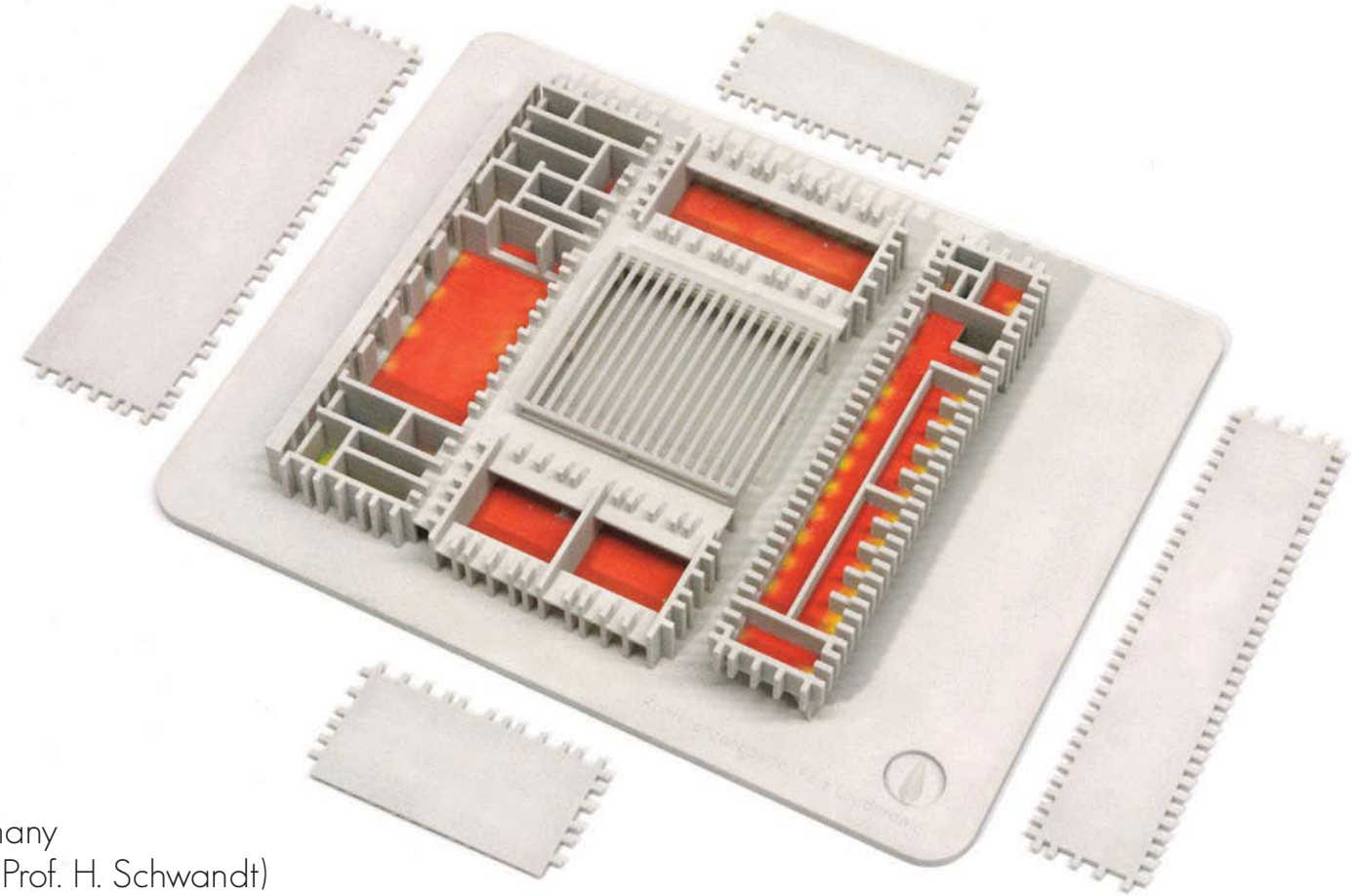
Hybrid Daylight Models in Architectural Design Education

Parametric Design Class Prototypes 2011 - 2012

Dipl.-Ing. Max Dölling [1]

Parametric Design Class
co-taught & envisioned with

Dr. Farshad Nasrollahi [2]



Opposite:
Rapid - protoyped daylight model
Mario Lucas & Stefanie Runzer
Ft. Lauderdale, USA
UDI 100 - 2000 embedded

Technische Universität Berlin, Germany
[1] Digital Processing for Academics (Prof. H. Schwandt)
[2] FG Gebäudetechnik und Entwerfen (Prof. C. Steffan)

01 Class Motivation & Background

Sustainability concerns demand simulation-driven performance knowledge to be integrated into the design process performed by architects.

Yet as a relatively novel practice, no proven set of design methods or cognitive framework has yet been established.

In teaching, simulation and design classes are still often divorced, separating formal from building science concerns.

Our class "Parametric Design" instead investigates the integration of thermal and daylight simulation into the early stages of architectural design on a building science and design research level.

M. Arch. Students are asked to create a 800 m^2 community center with a complex spatial programme, using Radiance/ Daysim simulations (DIVA for Rhino) and EnergyPlus (DesignBuilder) as continuous design decision aids.

Lectures on building physics and simulation principles guide students in developing own workflows. Results are analyzed from a design process and optimization perspective.

Student Rafael Canihuante presenting daylight simulations, summer 2012

02 Design Context & Optimization Implications

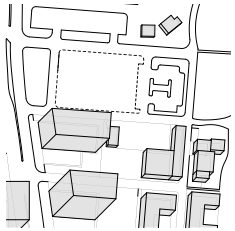
To elucidate how design factors influence energy and daylight performance, sites in different climate zones are chosen, allowing morphological differences to emerge. All optimizations are primarily to be achieved by varying parameters of architectural form.

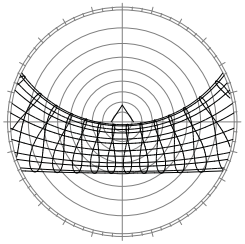
The climates pose individual challenges for combined thermal and daylight optimizations:

Ft. Lauderdale: *high summer temperatures & humidity (shield from solar gains); very high yearly direct & diffuse sky luminance, high solar angles (bounce, diffuse & redirect light)*

Hashtgerd: *high summer temperatures, cold winters (seasonal control of solar gains: needed in winter, exclude in summer); usually clear skies & high luminance year-round (provide alternate glare-free light paths for required winter gains)*

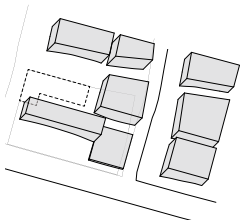
Östersund: *generally cold climate (solar gains required all year); extremely low luminance & sun angles in winter (tune aperture sizes & positioning, avoid glare from direct light)*

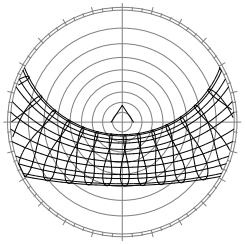




Avrg. annual dry bulb temp.: 25°C
Cumulative annual global horizontal irradiation: 1792 kWh/m²

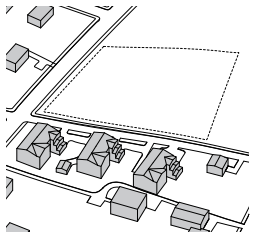
Ft. Lauderdale, Florida, USA
Tropical monsoon climate
Humid & hot summers, dry winters

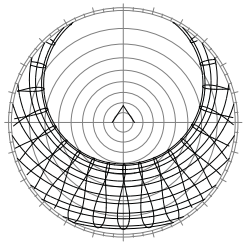




Avrg. annual dry bulb temp.: 15°C
Cumulative annual global horizontal irradiation: 1951 kWh/m²

Hashtgerd, Iran
Semi-arid continental climate
Cold winters, hot & dry summers





Avrg. annual dry bulb temp.: 3 °C
Cumulative annual global horizontal irradiation: 889 kWh/m²

Östersund, Sweden
Subarctic continental climate
Cool summers, extreme winters

03 Decision Metrics & Procedural Challenges

Design decisions are guided by a variety of metrics:

1. UDI 100 - 2000 lux Climate-Based Daylight Metrics for all spaces; seasonal & yearly occupancy schedules
2. Irradiance images (seasonal & yearly)
3. Point-in-time falsecolor luminance & evalglare images
4. Total and primary energy demand of idealized best-practice cooling, heating & lighting systems (via E+)

Students face several key challenges in class:

1. Complex sites, challenging climates & spatial programme
2. Ill-defined & project-specific workflows
3. Time constraints (we are not a design studio per se)
4. Usually limited building science, sustainability and software tools knowledge; we teach all software, simulation and building science basics from scratch, in a single semester.

Our class terminates with the schematic design phase and results in geometrically pre-optimized buildings.

Opposite: USA (1st column), Iran (2x upper right), Sweden and Berlin (old site) daylight models

04 Design Process & Multi-Domain Decision-Making I

Three design phases are generally completed in class:

1 Heuristic Design Phase (rules-of-thumb, sketch models)
2 Initial Simulations (massing E+, partial daylight sim., rad. maps)
3 Detailed Simulations (whole building E+ & daylight sim.)

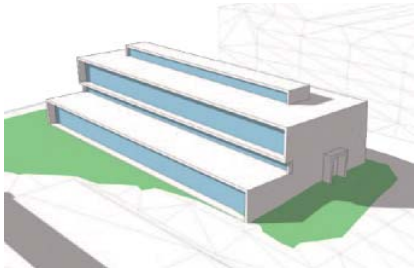
How can design, a non-linear, goal-oriented synthesis process, contain analysis paradigms that require stable boundary conditions and rational procedures?

Representations that relate form to performance (e.g., DIVA daylight & radiation maps) mediate between different domains of reasoning *(A^n etc., right)*; they are "multivalent".

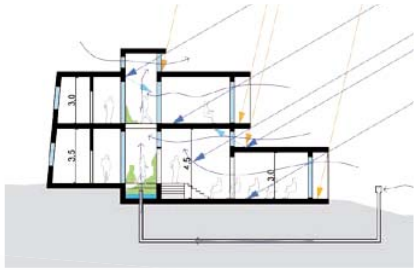
Multivalent representations articulate domain overlap and update global design intent *(N)*, which feeds back into the contributing source domains.

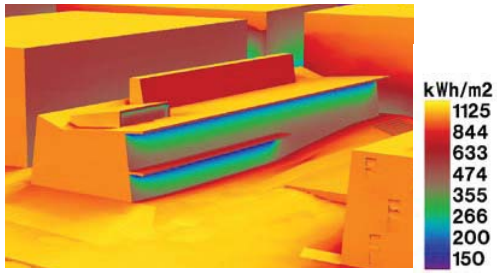
In this model, "the" overall design/optimization process appears as a dynamic field, not a linear pathway; iterative schemes are contained within it.

Heuristic design/performance knowledge is steadily constructed, reinforced and updated by domain crosstalk.

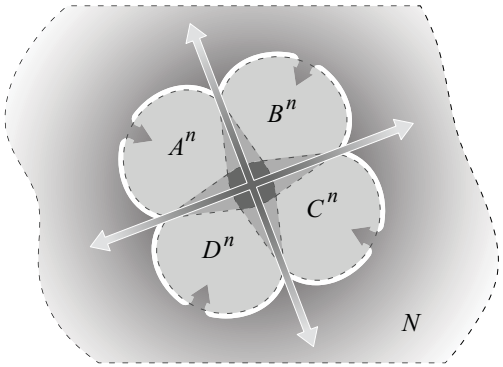


Iran design sketch model (left), initial variant performance section, modified massing summer irradiance map (below); all images taken from the first two design phases

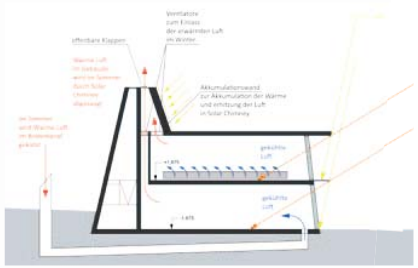


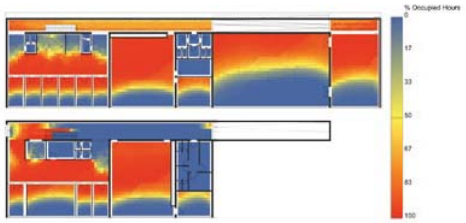


Domains of inquisition and representation in design synthesis



Pre-final design variant: Performance section (below), corresponding DIVA UDI 100 - 2000 lux metrics (on floor plans)



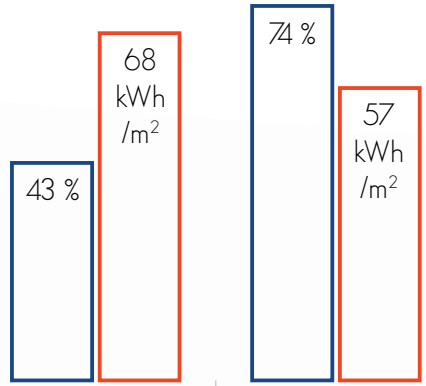


05 Iran Design Adaptation Process (~final phase)

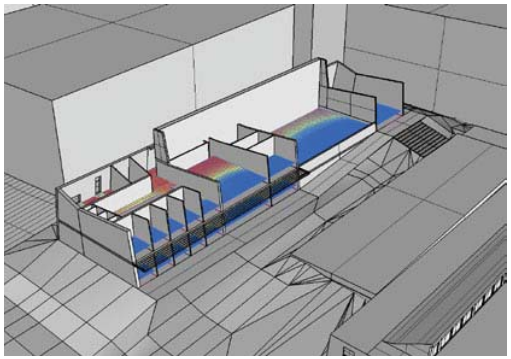
Concurrent thermal and daylight analysis resulted in overall morphological and facade modifications of increasing overhang depth and adding side fins. The results show a simultaneous increase in daylight utilization and reduction of total energy demand; this is a common trend in successful designs.

Design variant comparison: Projected total energy demand of heating / cooling / lighting (kWh/m², annual) and Useful Daylight Illuminance 100 - 2000 lux (%), annual

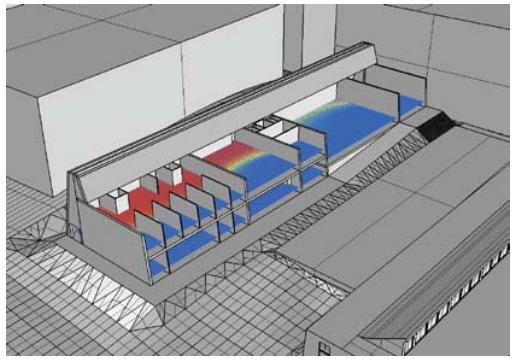
Below: Summer / winter facade insolation studies showing seasonally selective performance



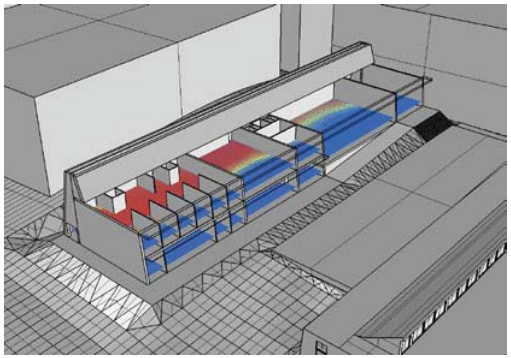
Initial Variant 01 *Final Variant 04*



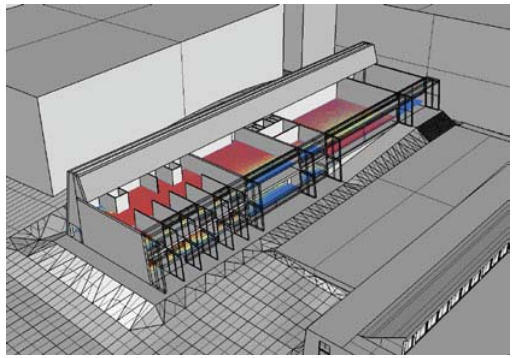
Variant 01, UDI 100 - 2000: 43%



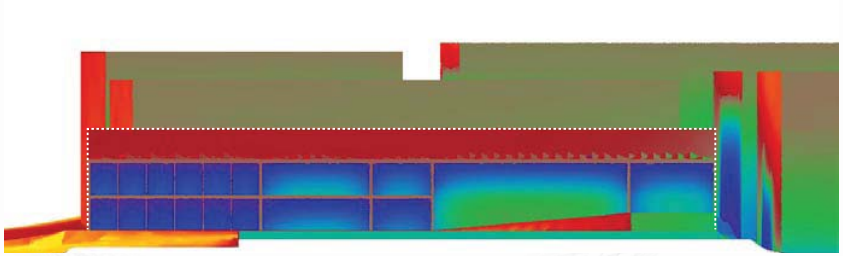
Variant 02, UDI 100 - 2000: 32%

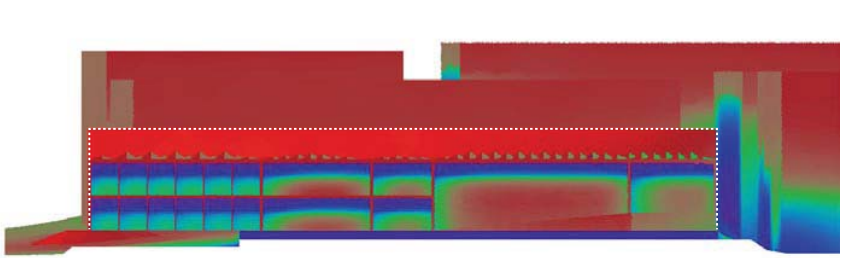


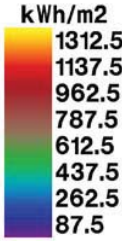
Variant 03, UDI 100 - 2000: 41%



Variant 04, UDI 100 - 2000: 74%





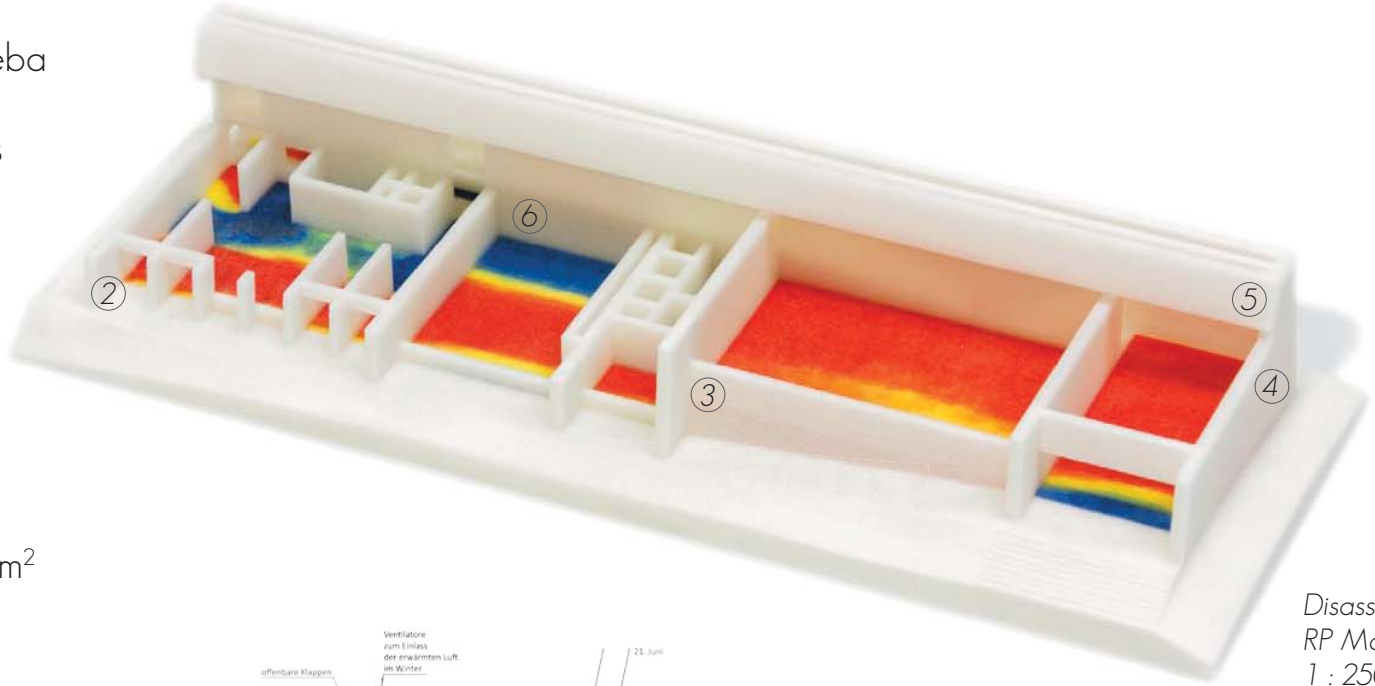


06 Iran Design Daylight Model & Strategies

Design / Simulations (validated):
Tereza Měřičková, Maciej Potrzeba

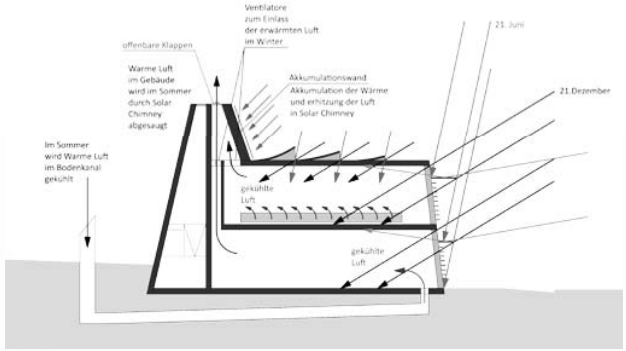
1 Seasonally selective skylights
2 Deep overhangs & side-fins
3 Partial glazing reduction
4 Solid East / West facades
5 Solar chimney
6 Circulation in North facade, as thermal buffer

UDI 100 - 2000 lux: 74%
H/C/L energy demand: 57 kWh/m^2
Initial variant: 68 kWh/m^2



Disassembled RP Model, 1 : 250

Assembled RP Model



Solar control, earth pipes & solar chimney conceptual section

07 Florida Daylight Model & Strategies

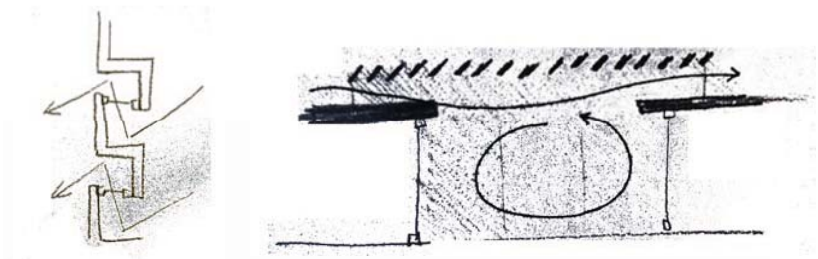
Design / Simulations (validated):
Irene Vera Crego, David Cepeda del Toro

1 Large protective roof canopy
2 Louvred "Luminous Courtyard"
3 Deep, light diffusing facades
4 Openable, shielded glazing for yard cross-ventilation

UDI 100 - 2000 lux: 73%
H/C/L energy demand: 94 kWh/m^2
Initial variant: 119 kWh/m^2

Disassembled RP Model, 1 : 250

Assembled RP Model



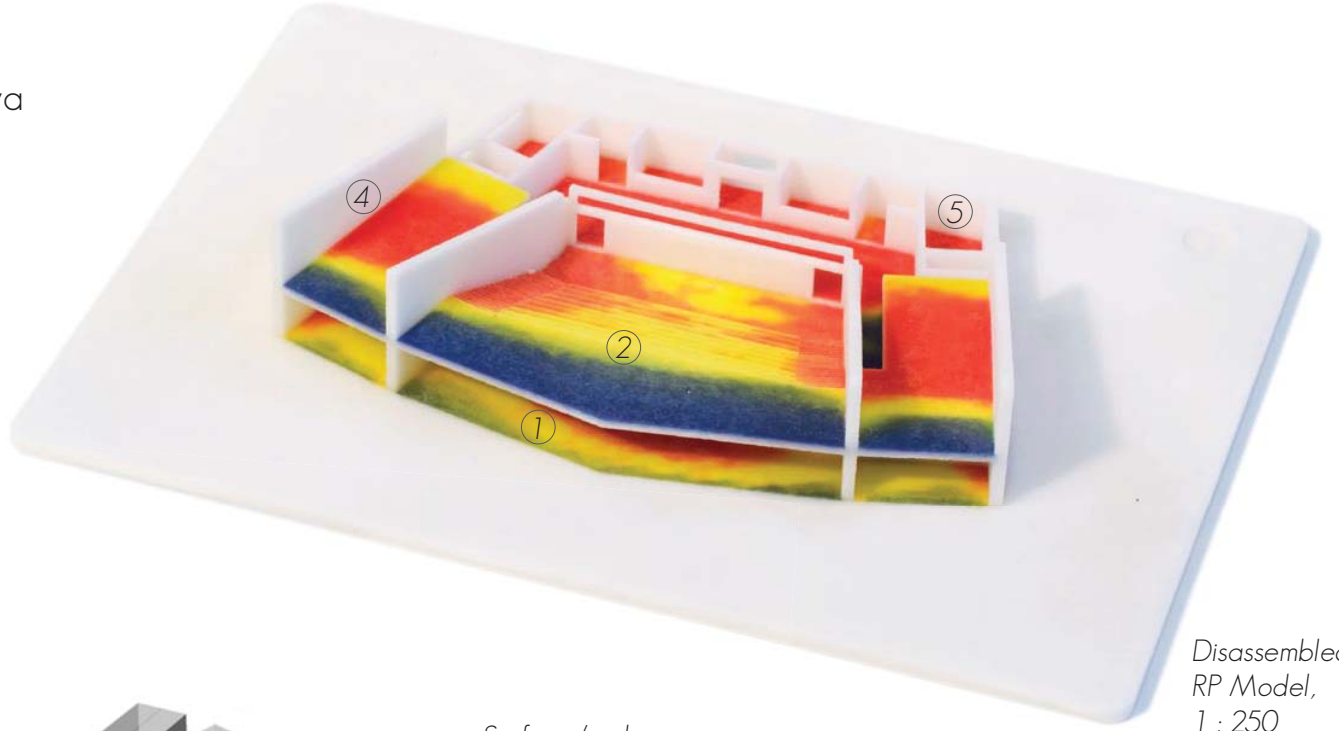
Light-diffusing facade & courtyard conceptual sketches

08 Sweden Daylight Model & Strategies

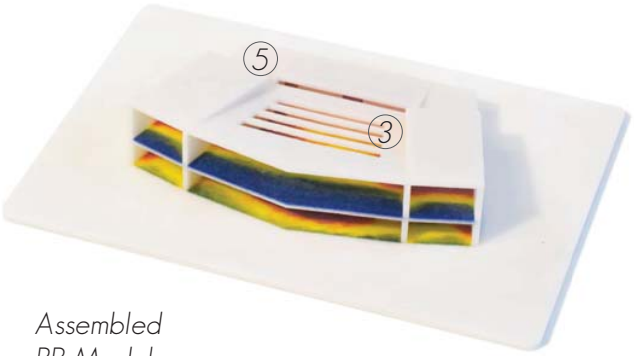
Design / Simulations (validated):
César Castillo Alberola, Ralitsa Georgieva

1 Extensive South apertures
2 Sunspace to capture gains
3 Skylights for deep daylighting
4 Small or no East / West windows
5 Reduced North surface area

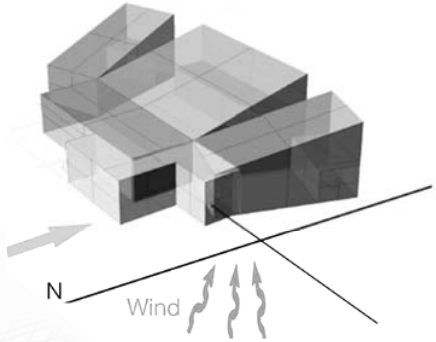
UDI 100 - 2k: 40% (yearly, dbl. glazing)
H/C/L energy demand: 112 kWh/m^2
Initial variant: 171 kWh/m^2



Disassembled RP Model, 1 : 250



Assembled RP Model



Surface / volume ratio control & buffer spaces sketch

This model is an outlier; students used triple-glazed Krypton-insulated glazing for simulations. Metrics show summer only due to low winter illuminance.

09 Multi-Domain Decision-Making II : Simulation & Intent

How can it be assured that multivalent representations, which encode knowledge states during given design phases, are accurate in what they show?

Representations are derived from models, which are produced under different epistemological regimes (e.g., design vs. engineering) but refer to the same object (building).[1]

Individual epistemes need to be valid internally, but also attuned to intersect by managing three key variables:

1. Process (e.g., heuristic vs. analytic workflows)
2. Scope (e.g., design intent vs. its simulation encapsulation)
3. Representability (e.g., knowledge presentation and production in science vs. design domains)

This is work-in-progress thinking! [2]

see [1] Doelling and Nasrollahi, "Building Performance Modeling in Non-simplified Architectural Design", Proceedings of the 30th eCAADe conference, Prague 2012, pp. 97 - 106 and [2] Doelling and Nasrollahi, "Parametric Design: a Case - Study in Design - Simulation Integration" (forthcoming, 2013)

Opposite: USA (1st column), Iran (2x upper right), Sweden and Berlin daylight models, disassembled

Max Dölling, Dipl.-Ing., Assistant Professor
DigiPro @ 3d-Labor (Prof. H. Schwandt)

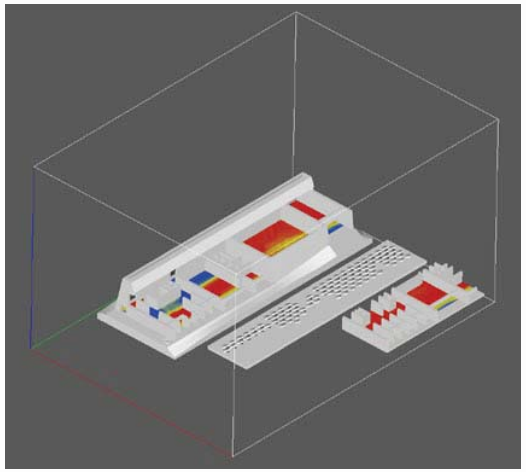
10 Physical Daylight Model Production

Simulation models are translated into "water-tight" 1:1 scale polygon geometries, manually textured with the UDI metrics and laid out in the printer software (Zprint).

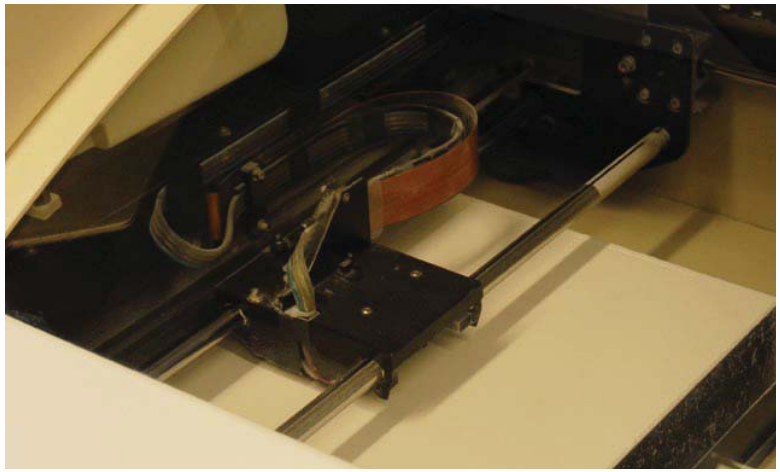
The Zprinter deposits colored binder on a gypsum-based substrate, building up the model layer by layer.

Finally, the extracted model is sealed with clear epoxy resin, required for extra stability, and cured.

Model part during extraction from build space



Model laid out in Zprint software



Printhead depositing binder layer on substrate bed

Zprinter at 3d-Labor, printing yet another model (vintage Contex Designmate)

11 Physical Daylight Model Properties

The daylight models have unique properties as artefacts:

Daylight behavior is shown in conjunction with its root geometry, which encodes all performance design decisions.

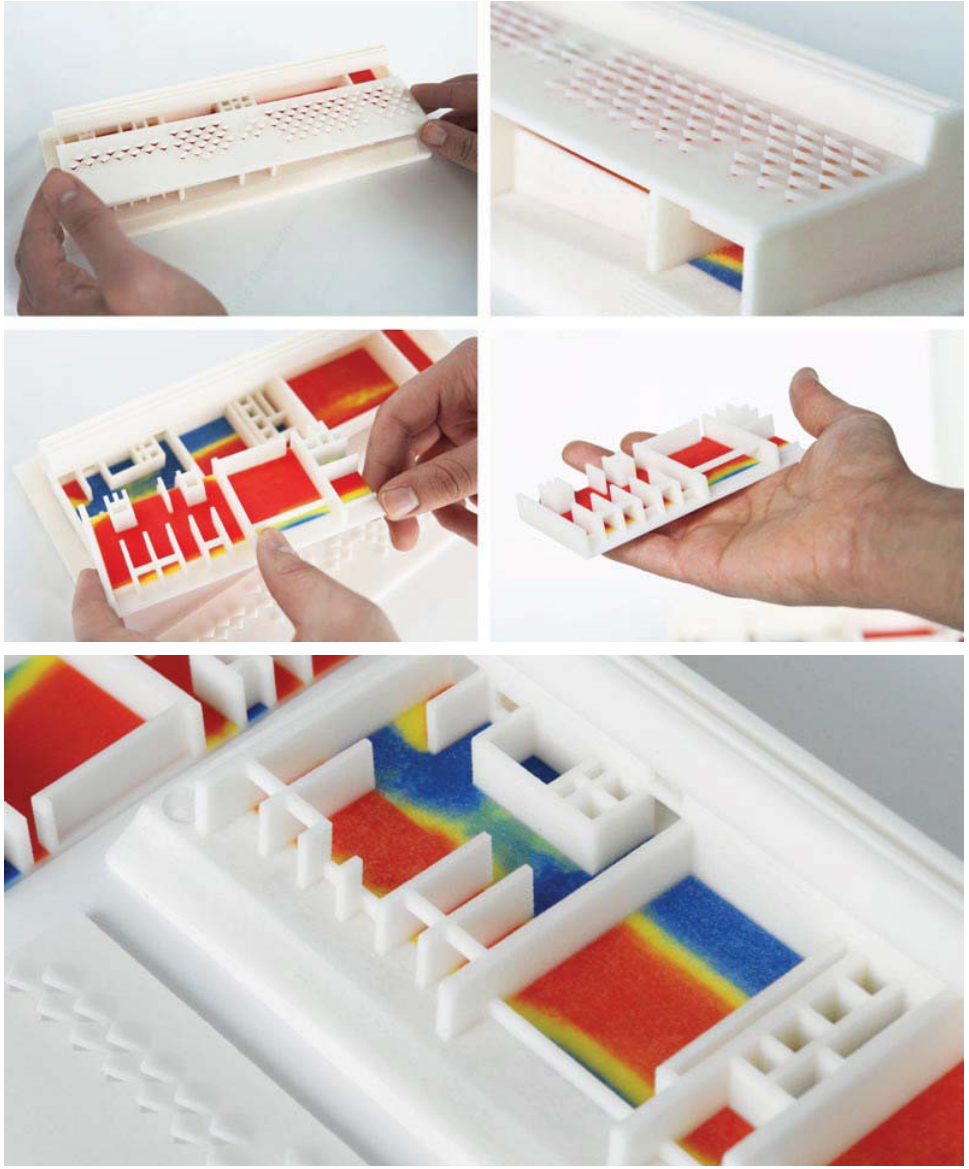
Models are three-dimensional and the source data trans-temporal, rendering the objects four-dimensional and objective, since no special glazings or dynamic shading devices, which could not be shown in the models, are used.

Process variables of scope and representability are aligned, lending the models great descriptive precision. They are multivalent representations and reflect a field state of design thinking at the end of the schematic design phase.

What do we use them for?

The models make the interplay of daylight performance and geometry literally graspable for new students, summarize optimization and design research results in a physically manipulable form and serve as a typological library.

Opposite: Teheran design hybrid daylight model disassembled & handled; detail of printed metrics



Thank you, DIVA DAY!

Off-conference questions?

max@spacesustainers.org

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Special thanks to Cecilia, Jürgen, Laura, Carmen & Irena.

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