

Integration of Outdoor Thermal and Visual Comfort in Parametric Design

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ABSTRACT

Parametric modeling tools are increasingly adopted in design practice. Various plug-ins for Grasshopper – the most widely used parametric tool – allow the creation of mathematically originated geometries from environmental data such as solar geometry, wind direction and velocity, radiation intensity, illuminance levels, etc. However, a critical look at the application of parametric methods in the practice of design reveals that their use is still predominantly based on aesthetical, structural and fabrication criteria. The opportunities that these tools offer to design strategies and components that are responsive to outdoor and indoor comfort conditions are starting to be explored at research level, but are rarely comprehensively integrated in the education and practice of architecture. To investigate the links between parametric form-making and outdoor comfort, a workshop at the Royal Danish Academy – aimed at the design of shelters – combined Parametric and Environmental Simulation Tools (ESTs) with the use of the most recent Grasshopper's plug-ins. In search of thermal and visual comfort optimization, the students employed these parametric design tools to achieve responsive geometrical design solutions.

KEY WORDS:

Parametric Design, Environmental Simulation Tools, Outdoor Comfort, Design Creativity.

INTRODUCTION

The past decade has seen the emergence of intricately-articulated surfaces whose design and production were enabled by the capacity of parametric tools. However, the way in which these design solutions have contributed to human comfort (e.g. thermal) has often not been analyzed in detail. This is particularly evident when looking at the parametric design (PD) of urban shelters. Complexly shaped forms have typically responded to fabrication and aesthetical principles, without holding careful consideration of users' comfort conditions (Turrin et al., 2012). Yet, the potential is there: their geometry and materials could positively affect thermal and visual comfort. To explore the missing link between PD and comfort, a series of “parametric shelters” were designed by students of the CITA Master at the Royal Danish Academy (Cita.karch.dk, 2014). In a period of two weeks, design teams composed by 2 to 4 people approached climatically “challenging” urban sites in New York, Berlin, Honk Kong, Shenzen, Singapore, Reykjavík, and Madrid, a rural site in Barcelona, and a desert area in Iran. Each of these locations presented climatic conditions that limited their usability. The design of the shelters was optimized through

the parametric control of their overall shapes. The rationalization and modularization of their geometry was obtained with the integration of Environmental Simulation Tools (ESTs).

Design Comfort by Architectural Means

The design of shelters should mitigate external climate influences and facilitate, among other functions, the thermal comfort and daylight quality (Fig.1) of the spaces below and those adjacent. Several studies showed the influence of comfort on the ratio of utilization of outdoor spaces and on users' behavior (Nikolopoulou and Lykoudis, 2006). Outdoor climate studies indicate that the conditions expressed by the Physiological Equivalent Temperature (PET) – one of the most accepted models for outdoor comfort – are dependent on the radiation exposure and on wind velocity (Hoppe, 1999). Thermal comfort studies conducted by Bouyer et al. (2007) on envelopes of stadia showed the importance of geometry with respect to such parameters. For instance, designing the porosities of stadia (i.e., the capacity of the envelope and of the structure to control wind flow penetration) and the sky-opening factor (i.e., the sky view from the spaces sheltered) determines relevant differences in PETs (Turrin et al., 2012).

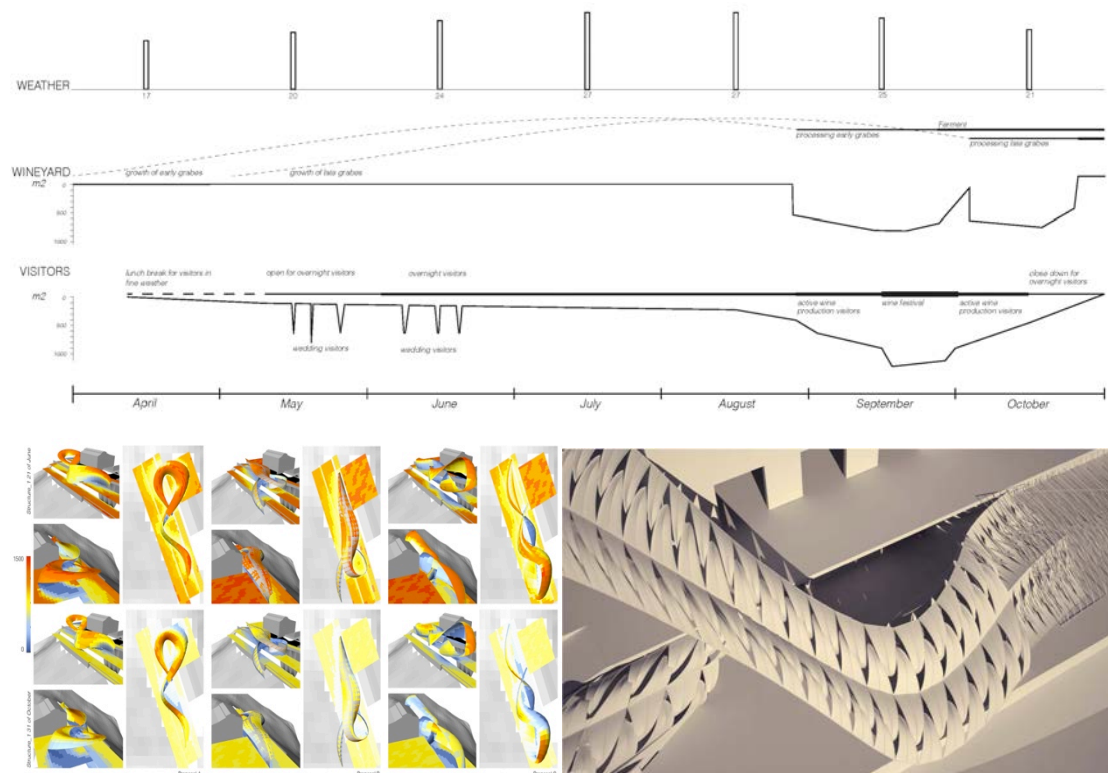


Figure 1. Valldaura (Barcelona). (a) The site, which includes a vineyard, hosts various activities and is exposed to continuously changing weather conditions. (b) First phase of the design exercise, when various shapes are studied according to optimal protection or exposure, depending on instantaneous radiation. (c) The structure is parametrically defined in order to enhance or impede wind flows and solar penetration as a function of comfort. Comfort number hours are predicted to be extended by 40% from April to October (Students: Ida Katrine Friis Tinning, Inès Klausberger, Tadeas Klaban).

TEACHING CONTEXT

Integration of Design and Analysis in a Parametric Environment

The workshop was centered on the use of Grasshopper, one of the most popular parametric platforms (author's article, 2014). There are several plugins that have been developed for Rhino/Grasshopper (Table 1). Some of the most recently available plugins allow an interface with validated Environmental Simulation Tools (ESTs), such as EnergyPlus, Radiance and Daysim (Roudsari, Pak, 2014). These plugins and tools are free and open source, and users can customize them based on their needs.

In the CITA Master workshop, a single model was used for design and comfort analysis, facilitating a smoother, more integrative, and efficient workflow (Roudsari, Pak, 2014). The benefits of integrating ESTs into the design process have been often discussed in previous studies (Weytjens et al, 2012). At the time of writing, however, discussion by non-developers of the actual application of such tools in the design process has rarely been documented (plugins such as Ladybug and Honeybee, used in the workshop, are very recent).

Table 1. Parametric Comfort Workshop: Design Process and Tools

Design Phase	Design Action	Parametric Modeling Tools (PMTs)
Climate Analysis	Weather file information was overlaid to digital models	Grasshopper - Ladybug
Performance Goals	Selection of one or more coupled performances goals (e.g. reduction of radiation when temperatures is over 24 degrees and wind is limited)	Outdoor Comfort Diagrams, Physiological Equivalent Temperature (PET)
Geometry design and performance behavior assessment	Design of a variety of geometrical shelter massing based on the repetitions of modules and assessment of their performances. Specific design of one component and analysis of its performance	Grasshopper - Honeybee, Ladybug
Inverse computing for design adaptability	Dynamic behavior of modules are determined on the basis of instantaneous weather conditions and user activity	Grasshopper
Verification	Design Solution are simulated for verification of their performances	Grasshopper - Honeybee, Ladybug,

DESIGN METHODS AND PROCESSES

Climate analysis

The design was founded on a thorough understanding of the weather data from the part of the students. Students learnt how the climatic conditions of their site transform over time in order to define adaptive design responses (Fig. 2). Even if the weather files were provided to students, it was considered that sites may have different microclimatic conditions than the one represented by the available data due to local factors such as urban fabric, materials, colors, soft/hard-scapes, etc. The use of the Ladybug plugin allowed to relate weather data to contextual characteristics (Grasshopper3d.com, 2014). This plugin to the parametric platform Grasshopper facilitates the graphical exploration of connections between the data available and geometries and materials designed. Multiple climatic variables (e.g., radiation and temperature) can be represented, overcoming limitations of tools such as Ecotect and Vasari.

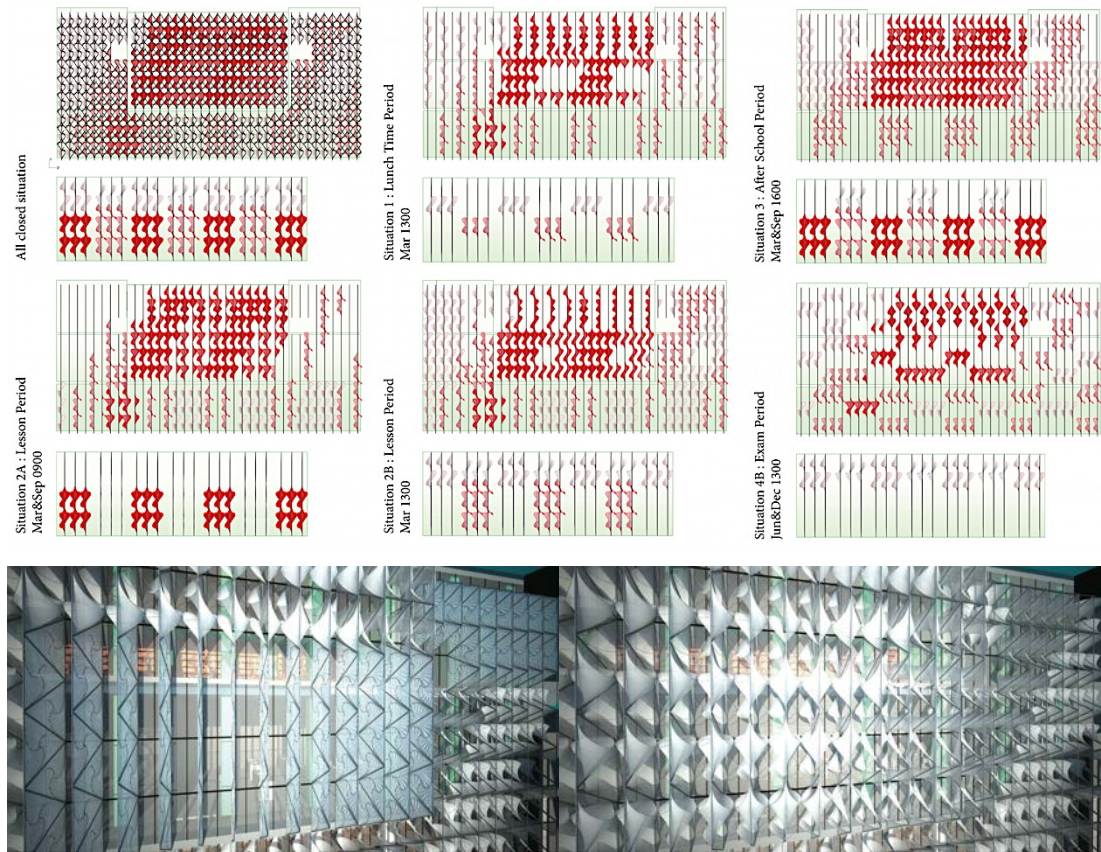


Figure 2. The design aimed to bring daylight in, and guide it through, a narrow court in Honk Kong. Indoor and outdoor illuminance levels controlled the position of façade reflectors. The courtyard, with the addition of the reflective components, receives an increases amount of daylight. Indoor rooms receive a well-calibrated light (a) The different positioning of the reflective components is based on sky conditions and users activities' requirements (c) Rendering of two configurations offered by the system (Student: Chan Chun Yin).

Setting numerical and time based performance goals

Multi-functionalism was considered as one of the design drivers: shelters had to be flexible and with open plans. The students envisaged final users' behavior, as it determined the comfort goals with measurable and meaningful indicators. Accordingly, and in order to contain the shelter design within achievable boundaries, a selection of numerical performance goals was made. The selection comprised two groups of indicators, respectively for thermal and daylight comfort. Each team started the design by setting time dependent performance goals for:

- Thermal comfort: PET or isolated factors influencing the heat-balance models of the human body were used (e.g., temperature, mean radiant temperature, shadows' hours, radiation, air direction and velocity, etc.).

- Daylight comfort: Illuminance and luminance values were adopted as design generators (Fig. 3)

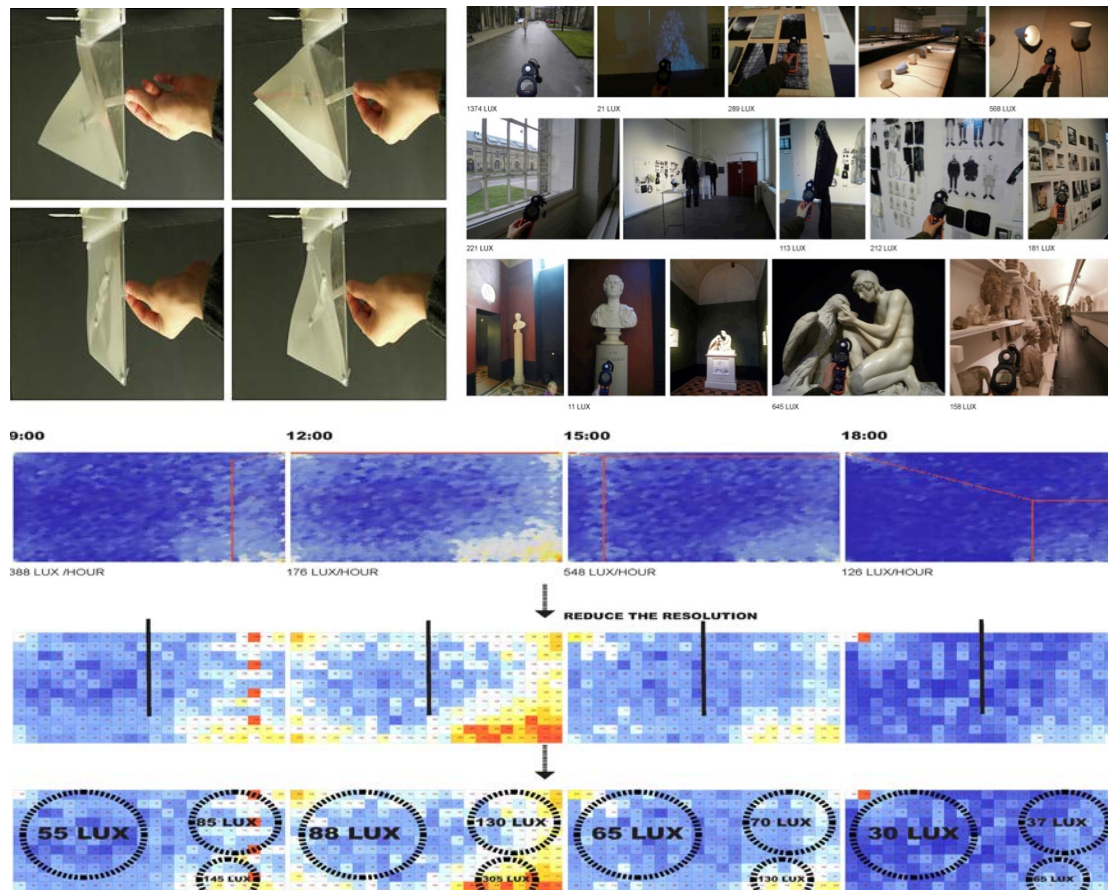


Figure 3 Design of an envelope system in Shenzhen. The open-space hosts exhibitions (a). The facade opens depending on the type of exhibition light requirements. (b) Illuminance values were recorded in museums in order to study performance goals. (c) Possibility of illuminance variations were controlled by the façade system during a winter day (plan views) (Student: Wenyu Wu).

Geometric design and assessment of performance behavior

In this phase, Ladybug was extensively used to consider the implications of radiation and sunlight-hours. Integration of the plugin with Grasshopper allowed an almost instantaneous feedback on design modifications. The students created preliminary design concepts and simulated how they meet well-defined performance goals. Two key factors of their parametric system's design – geometry and material properties – highly influenced thermal and visual comfort. Another Grasshoppers' plugin, Honeybee, was integrated in the process to support detailed daylighting and radiation simulation using validated ESTs (Roudsari and Pak, 2014). Students could run several types of accurate image-based analyses to produce diagrams for luminance, illuminance or radiation.

Inverse computing for design adaptivity

A series of geometric reconfigurations were made so that shelters were able to react to climate conditions and users' thermal and daylight comfort. The focus was on components that constantly varied their configurations to adjust to weather variations and fluctuations of spatial programs. The parameterization process defined the dynamic movements of the components. Inverse computing techniques were used to determine such specific movements (Fig. 4). The systems designed are reactive to changing weather conditions and factors such as radiation, illuminance values, and wind speed and direction.

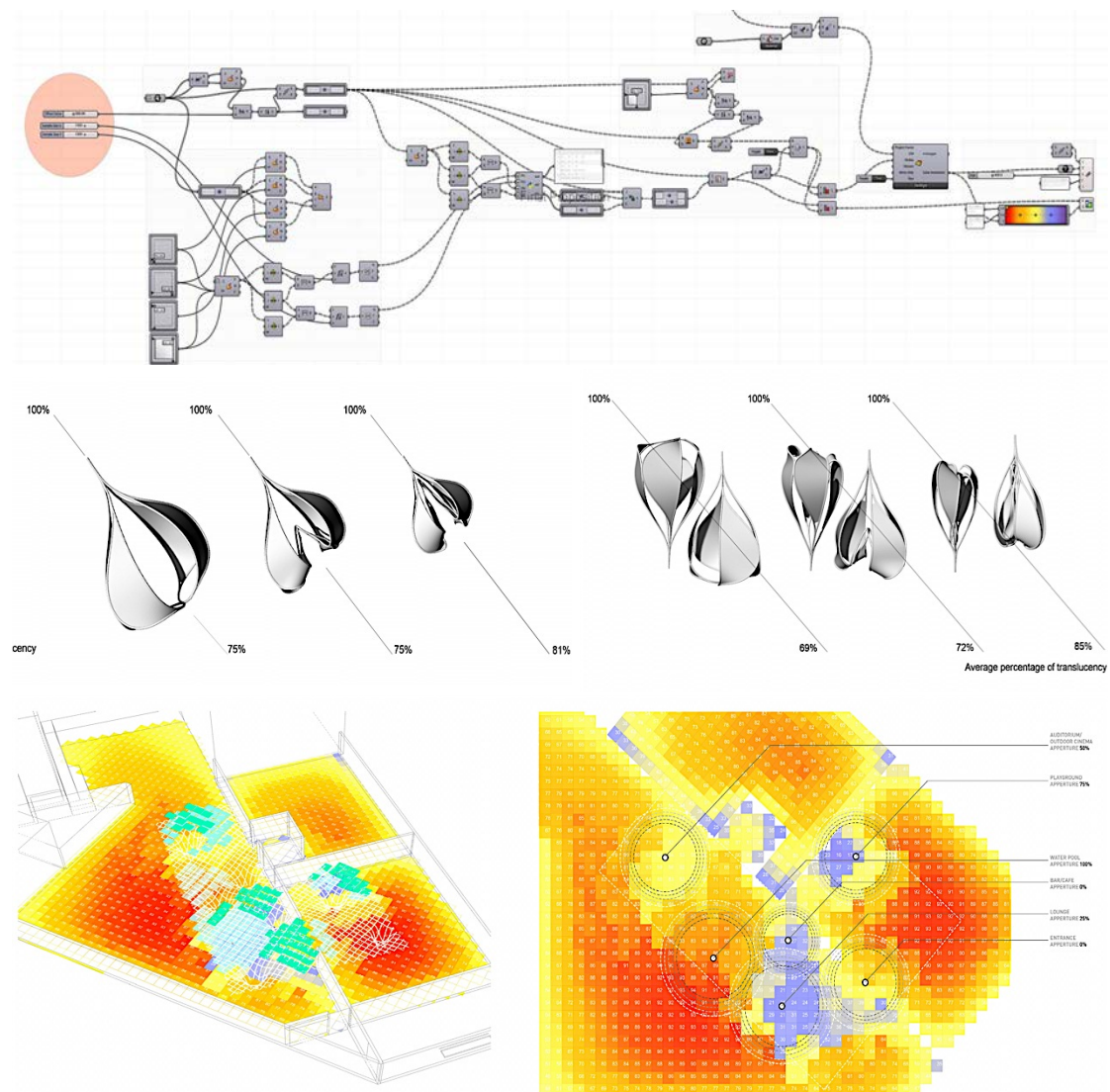


Figure 4 Design of a shelter in New York. (a) A Grasshopper “recipe”. (b) Determination of the degree of opening of each parametric module. (c) The opening is function of solar irradiance and activities. (Students: Hulda Jonsdottir, Lukasz Włodarczyk and Olga Krukovskaya)

DESIGN RESULTS

The qualities of all the shelters designed stemmed from their inherent link to the site. Projects located in New York, Madrid (Fig. 5), Barcelona, and Singapore (Fig. 6), experienced overheating. It was assumed that the air temperature of the spaces underneath was largely affected by the solar exposure of the spaces. The focus was therefore on reducing radiation when excessive. In opposite climates, with significant wind loads, such as the desert in Iran (Fig. 7), and the Icelandic city of Reykjavik (Fig. 8), protection from wind was considered crucial. Airflows in the spaces adjacent to the shelters depended on the incoming wind velocity, which is affected by their shape and openings. Finally, projects located in dense sites in Berlin (Fig. 9), Shenzhen, and Hong Kong, focused onto creating visual comfort, while saving artificial lighting. The use of daylight as a primary light source enhanced environmental quality. Similarly to the principles informing the achievement of passive thermal comfort, daylight-oriented passive strategies aimed at reducing the use of artificial lighting with variable forms and reflectivity of materials.

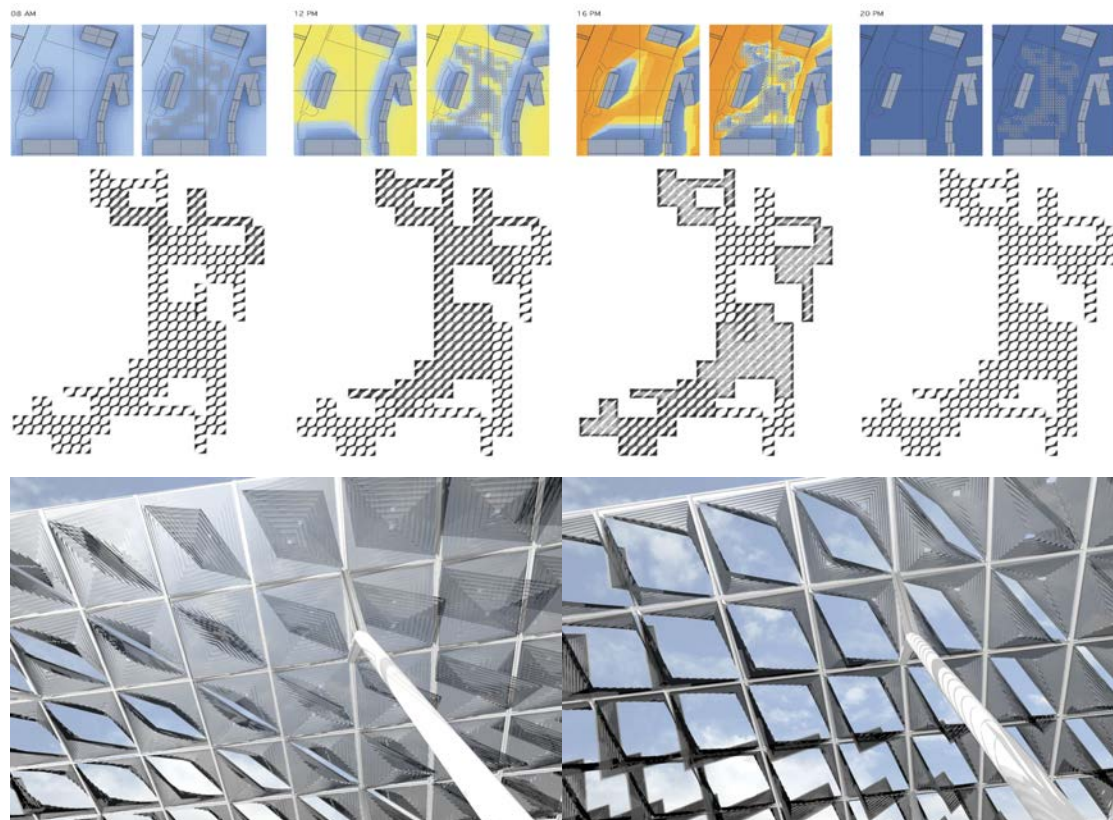


Figure 5 Radiation simulated at ground level is the parameter controlling the movement of a canopy hosting several street activities in Madrid. (a) Configurations of the system at different times of a day. Radiation is controlled only when necessary (i.e. when temperatures are above 24 to 30 degrees, depending on wind velocity) (Students: Huen Cheying, Lo Chen-Chi, Annika Nora Richmond).

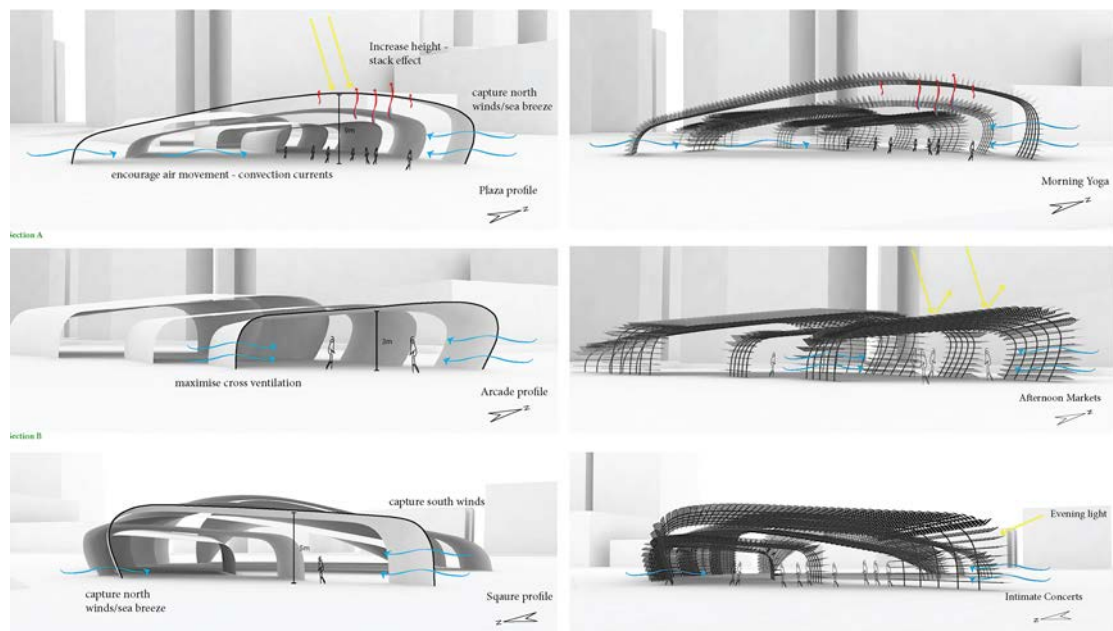


Figure 6 Parametric shelters in Singapore. (a) A series of sections shows how natural ventilation, radiation, and reflected light from surrounding buildings are integrated in one model where massing and components act as a system that increase thermal and visual comfort (Students: Mattias Lindskog, Lyn Poon, Karoline Wæringsaasen, Thyge Wæhrens).

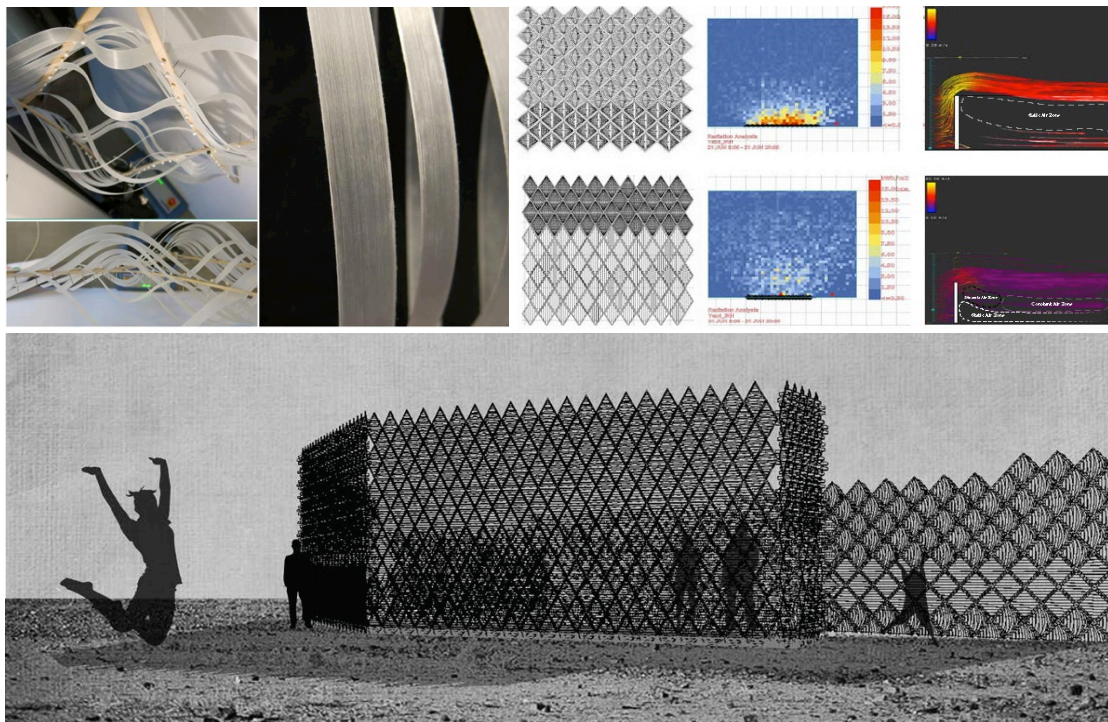


Figure 7 Iran. (a) Simulated wind flows and solar radiation are the parameters controlling the mechanic movement of flexible strips inserted into rhomboidal components. (b) These are hosted within a series of vertical wind shelters (Students: Zeynab Zaghi, Jens Jacob Jul Christensen).

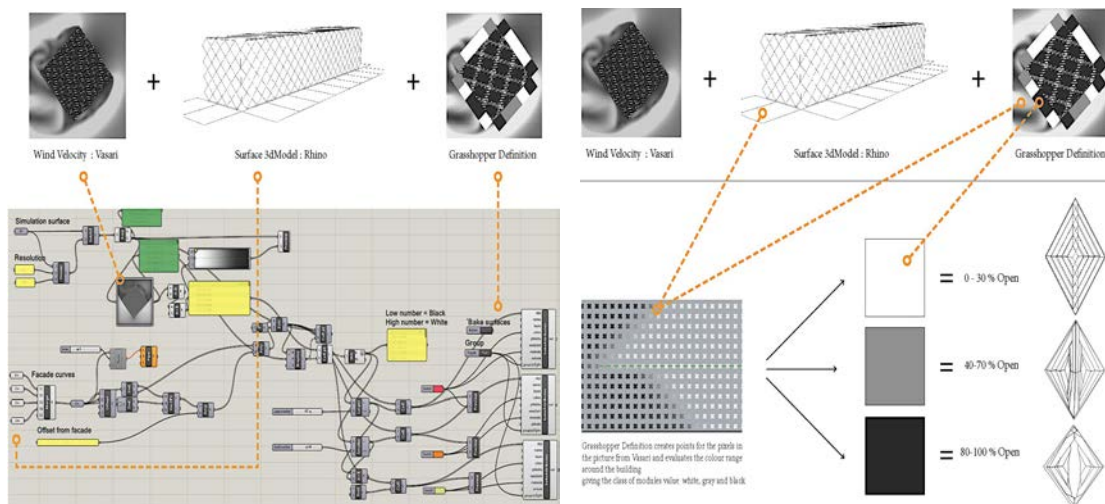


Figure 8. Due to high wind frequency and velocity, outdoor spaces in Reykjavik are quite uncomfortable for a large part of the year. The project looked at controlling wind flow in a public market. Pressure coefficients from rudimentary CFD models were used to control the façade permeability to air (Student: Kristjana Sigurdardottir).

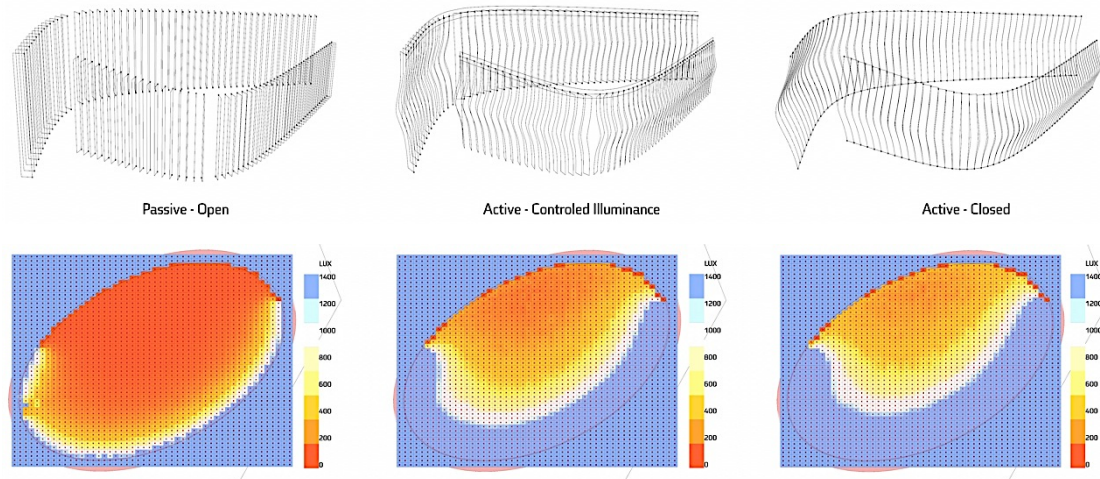


Figure 9 Berlin. A series of vertical fins were parametrically controlled linking their elastic deformation to targets of illuminance levels. Since the site is a large open space, creating differentiated visual conditions was seen as a stimulus for users' wellbeing and engagement (Student: Anders Per-Kristian Hansson).

CONCLUSIONS

Parametric modeling significantly increases the opportunities for climatic design.

The workshop attempted to break the mono-disciplinarity of most teaching approaches to parametric design where geometric inverse computing are often solely based on fabrication or structural roles, for which a larger tradition of conceptual morphogenesis exists. The series of designs elaborated by students illustrated how relations between structure, shape, and materials can be efficiently integrated with environmental considerations related to thermal and luminous comfort.

The findings indicated that it is possible and beneficial to integrate emerging parametric tools into the digital architectural and environmental design. These tools allow a 'transversal' approach to design information, and facilitate a decision making process based on the feedback loop between formal and functional relationships. Parametric design must be released from the constraints of 'parametricism' applied without any variations to all climates (however impressive its effects could be) and exploited to produce intelligent designs that embrace the full complexity of the environment.

A guided use of parametric tools seems to grant the opportunity to foster climatic awareness, intuition, and design skills in support of the students' decision making. At the workshop, students gained key insight into the microclimate conditions at play, and into capitalising locally available resources. They learned how the built environment is a highly complex system that involves many interdependent sub-systems.

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