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Smart and Healthy within the 2-degree Limit

Rough Void:
Translating vernacular microclimates into a climate-resilient, high-density urban typology.

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ABSTRACT: Since 2015, the New York-based design studio No Architecture (NOA) has researched the history of vernacular and pre-industrial built environments in order to better understand indigenous strategies for climate-resilient development. Spatial and ecological performance analysis of our findings initially led to a catalog of vernacular outdoor microclimate morphologies, which we then translated into a higher-density proposal for an ecodistrict located in Portland, Oregon's (Csb) Mediterranean climate. The interdisciplinary study includes examinations of several dimensions of the early stages of a design process, including: underlying theoretical and historical frameworks; simulations of solar isolation and wind flow; and the elaboration of a set of flexible principles which can be adapted throughout climates with dry summer conditions. This proposal for a new "Rough Void" typology anticipates an alternate, climate-resilient trajectory for urban development.

KEYWORDS: Microclimate, Vernacular, UTCI, Design Process, Mediterranean climate.

1. INTRODUCTION

Although density is championed by environmentalists over sprawl, by many measures, our cities have exacerbated their local climates by overheating—creating the "urban heat island" effect where freeways, high-rise towers, minimal canopy coverage, and exhaust from air conditioning threaten our ability to live in close proximity [1-2]. To elaborate this paradox at the scale of housing and habitat is to question the specific configurations, the forms and fabrics of our cities today, and how they can adapt and mitigate for tomorrow. Founded in 2009, NO Architecture (NOA) is a New York-based design studio dedicated to the radical exploration of ecology and urbanism through innovative architecture. Since 2015, we have researched the history of vernacular and pre-industrial built environments in order to better understand indigenous strategies for climate-resilient housing. Spatial and ecological performance analysis of our findings initially led to a catalog of passive design strategies, which we then implemented to generate a flexible urban geometry—the "Rough Void" typology—that anticipates a climate-resilient trajectory for urban development.

2. REPRESENTING THE VERNACULAR

In the influential photographic survey *Architecture Without Architects*, Bernard Rudofsky argues, perhaps naively, that indigenous architecture achieved the comforts of floor heating and air conditioning, the efficiencies of prefabrication and standardized building components, without today's destructive reliance on fossil fuels [3]. Despite an inspiring proliferation of images, Rudofsky's survey reduces these settlements into aesthetic objects, therefore, eliding the contextual and cultural particularities of each site's builders and inhabitants. In retrospect, Rudofsky falls into the "Traditional Technology Trap," which Susan Roaf warns relies on stereotypical assumptions that vernacular builders "optimized" their design decisions for climate performance—a mistake that too often obscures the "fundamental interconnectedness that exists between technical, social, economic, and political decisions in reality" [4].

Holding both this critique and appreciation for *Architecture Without Architects*, the architectural historian Paul Oliver gave substance to Rudofsky's sketch by devoting a career's worth of rigorous scholarship to vernacular settlements. After ten years of research, Oliver and 650 contributing authors published the landmark *Encyclopedia of Vernacular Architecture* [5]. Amidst this abundant scholarship, however, there remain opportunities for further visual and quantitative supporting material. This encyclopedia, moreover, largely overlooks the relationship between vernacular settlement and the theory and practice of contemporary architecture.

Intended as a supplement to Rudofsky and Oliver, the scope of our catalog is the performance of outdoor microclimates at vernacular settlements through a methodology defined by architectural representation and climate simulation. Whereas Rudofsky and Oliver argue for Western architectural practice to respect and learn from indigenous innovations, our project reinforces their position by compiling spatial and climactic analyses to visualize and quantify the performance of pre-fossil fuel economy habitat and settlement.

2.1 Cataloging Microclimates

We have amassed twenty case studies into a catalog that cuts across climates and cultures: from the semi-private courtyards and alley ways ventilating Beijing hutongs to the shared walls mitigating solar heat gain in North African medinas. From mudbrick wind towers in Iran to stepped terraces in Greece, the catalog focuses on the outdoor microclimate between buildings as a climate positive indicator for not only outdoor space but also passive cooling and ventilation within buildings.

To avoid the “Traditional Technology Trap,” Roaf advocates for methods that enable us to systematically test the actual performance of vernacular settlements, specifically citing in situ monitoring, infrared thermography, as well as thermal and daylight simulations [6]. Therefore, in compiling this catalog, our methodology included architectural drawings and 3-D modeling that simulate, quantify, and analyze for surface and ambient temperature, natural ventilation, gross floor area, and density.

We experimented with mapping climate data onto site models to produce axonometric drawings that visualize outdoor microclimate performance. As an adaptive model of thermal comfort, Universal Thermal Climate Index (UTCI) accounts for how users’ thermal expectations and preferences are modified by psychological adaptation and behavioral adjustment. In addition to its integrated and holistic consideration of both thermal history and contextual factors, UTCI involves standard requirements for weather input parameters: temperature, humidity, radiative exposure, and wind speed [7]. However, current analytical methods to assess outdoor comfort based on UTCI, such as ENVI-met and CitySim, proved too computationally heavy and time intensive for the resources of our studio, a hurdle frequently faced by designers and students [8]. Therefore, in line with this project’s resources, we selected a composite or hybrid strategy to visualize the effect of urban form on outdoor comfort. For each site, we ran simulations for solar insolation and wind flow with Computational Fluid Dynamics (CFD) to achieve a partial representation of the built environment’s impact on outdoor comfort.

With limited time during early design stages to perform advanced simulations, designers often rely on broad or inaccurate assumptions on the passive heating and cooling effects of built form. Although not a full picture of UTCI variables, coupling visualizations of solar insolation and wind flow is an efficient preliminary method for critically and quantitatively assessing outdoor comfort. Since passive design principles are most effectively implemented in the early stages of design [9-10], it is important to continue to rethink and streamline climate simulations that are not only reliable, but also accessible for designers and students without specialized training.

3. HIGH-DENSITY TRANSLATION

With an FAR of 3.45, the 16th century walled city of Shibam, Yemen achieves a similar built density to the Downtown Manhattan condition typified by Greenwich Village, which Jane Jacobs influentially championed as a model for urbanism [11]. Reviewing our existing catalog, it was surprising to learn that several additional case studies achieved a built density comparable to modern urban development, including the Medina of Marrakesh, Morocco; Cerro San Cristobal in Lima, Peru; and Sana’a also in Yemen. Although simulations of these case studies confirmed that built form can enhance outdoor comfort and, in some cases, achieve density—as is, these vernacular settlements are not solutions for our current climate crisis. Culturally-speaking, the inhabitants of 21st century urban centers have different programmatic requirements for the use of outdoor public space, and expectations around comfort. Economically, developers and home-owners understandably prefer to invest in housing built with modern comforts including electrical lighting, plumbing, and indoor climate control. Therefore, the problem remains: How can these vernacular passive design strategies be translated to serve the realities of our increasingly overpopulated and overheating urban centers in the 21st century?

To demonstrate this process of translation, below is a review of our studio’s early design stages for a high-density ecodistrict in Portland, Oregon intended to achieve carbon-neutrality. As one of the last underdeveloped contiguous parcels within Central Portland, the six-acre industrial site interrupts the fine-grained street pattern of two residential neighborhoods to the north and south with 2.5 FAR. Time-specific temperature readings collected at Portland State University indicate that the proposed ecodistrict’s site trends 1.6 to 1.8°C warmer, according to the Sustaining Urban Places Research Lab [12-13]. In Oregon, the hottest days in the 2000s approximately tripled the rate of heat-related illness compared with days 12.2°C cooler (Dalton et. al). Furthermore, the ecodistrict’s mission to mitigate the Urban Heat Island Effect via comfortable outdoor microclimates intends to positively effect social equity by increasing access to green spaces [14] and potentially create safer and healthier neighborhoods [15]. All day and year-round, a core aspiration for the ecodistrict is the design of public green spaces that define places to gather for work and leisure not only for the district’s tenants and residents but also surrounding communities.

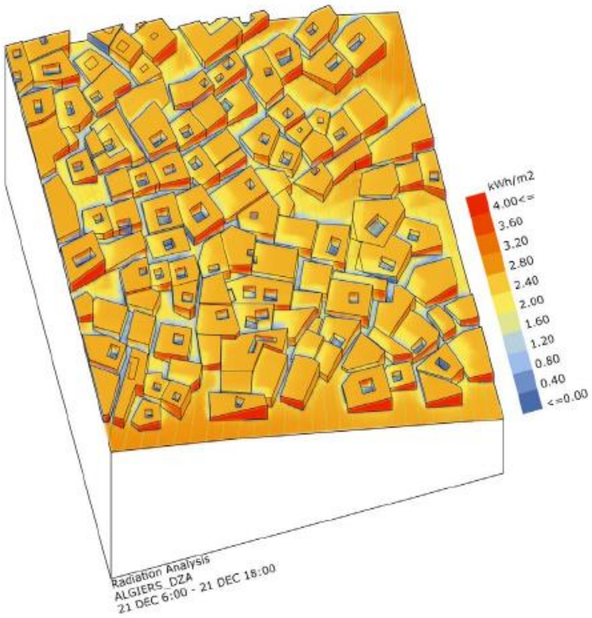

Figure 1. Casbah of Algiers: winter solar insolation analysis.

In the Willamette Valley 80 miles west of the Pacific Ocean, Portland receives summer breezes from the northwest, downstream from the Columbia River and winter winds from the east up the Columbia River Gorge [16]. The Koppen-Geiger climate classification for Portland is Csb: a Mediterranean climate with a cool dry-summer that receives almost all precipitation during the mild winter season. In Portland, the average temperature is 19.3°C in summer, and 5.9°C winter. Due to high ambient temperature and strong solar radiation, the most challenging issue for Mediterranean climates is cooling buildings. During summer months, there is considerable potential for night-time ventilative cooling due to the large daily temperature fluctuation [17]. In combination with interior thermal mass and decreasing heat losses, the most relevant passive design strategies for this location are aimed at increasing natural ventilation in warmer months and solar gains in cooler months.

3.1 Mediterranean Vernacular

From our existent catalog, five vernacular case studies share Portland's classification under the Koppen-Geiger's parameters of a Csb "cool dry-summer" climate: the Algerian Casbah of Algiers; the Greek island of Hydra; and the Italian towns of Alberobello, Anticollo Corrado, and Positano. The five case studies share a network of narrow pedestrian streets and self-shading alleyways punctuated by open public plazas, creating a hierarchy of outdoor public space diverse in not only scale and geometry, but also program. While framing culturally-specific activities—mosques in Algiers, Orthodox churches in Hydra, Catholic in Italy—these plazas feature an additional dimension of flexibility: time. Marketplaces, for example, convert easily into formal civic centers on days of public celebration. At all five sites, a collection of diverse and flexible plazas hosts comfortable microclimates for public gathering.

Unlike Portland's classic street grid, all five settlements feature an irregular street pattern rotated off the north-south axis. Urban microclimate depends not only on the type of city (in regards to size, geographic location, density, and land use) but also street design features, including the height of buildings, street widths and orientation [18]. A study conducted in Ghardaia, Algeria concluded that pedestrian comfort conditions are indeed improved by rotating the street to a northeast-southwest or northwest-southeast orientation [19]. In summer, our catalog's solar insolation simulations showed an increase in the shading effects of walls in comparison to east-west oriented streets; while in winter, an increase in solar access in comparison to north-south oriented streets (Fig. 1).

Deliberately integrated topographic conditions benefit microclimate performance at each of the five sites, which are all elevated on sloping hillsides and oriented to capture sea breezes. For example, in the case of Algiers, the orientation of the Casbah stimulates natural ventilation in summer by capturing the prevailing northeast summer winds. In winter, the Bouzareah massif blocks the prevailing northwest winds, mitigating their intensity [20]. At all five locations, variations on a dominant housing flex with the terrain [21], compounding the urban fabric's distinctive quality of roughness in both plan and section. This intimate integration with the landscape further stimulates natural ventilation since building facades align with the sites' contour lines, allowing fresh air to stream through the street pattern. It is important to note, however, that these vernacular strategies likely respond not only to the natural topography or local geomorphology, but also to considerations including local building skills and traditions as well as the social, economic, and historical evolution of each settlement (Roaf, 2008).

Whereas the twin conditions of proximity to the sea and mountainous topography benefit these case studies' natural ventilation performance, East Portland is inland and relatively flat. The process of translating passive design techniques into the proposed ecodistrict, therefore, calls for the innovation of a new urban typology that increases the urban fabric's degree of roughness in plan and section via its intrinsic built form. In other words, an example of "landform building," which Stan Allen suggests, "no longer occupy a given site but instead, construct the site itself" [22]. This new typology will examine the multiple intersections of landscape and ecology in contemporary architectural practice as a source for new formal strategies and design techniques applicable for Mediterranean climates.

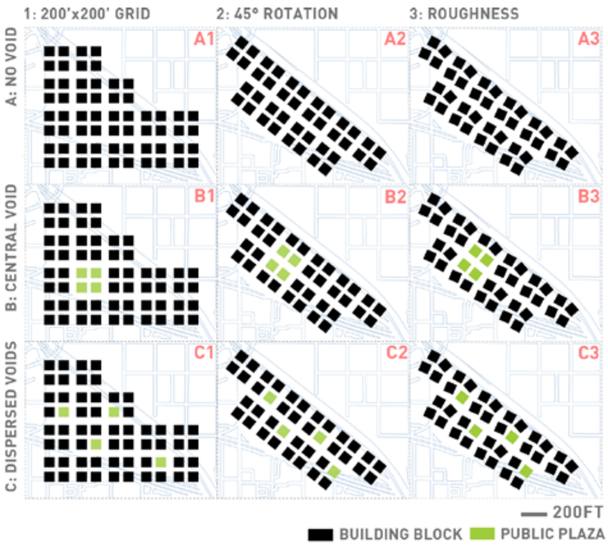

Figure 2. Above spatial operations each tested at both uniform and varied building heights for a total of 18 design iterations.

3.2 Simulations

We arrived at the Rough Void typology through an iterative testing of three design principles: street rotation, void condition, and volumetric roughness. The principles were tested in isolation and combination on an abstracted base model derived from Portland's 200'x200' cartesian street grid with uniform building massing (GFA: 1,260,000sf) at 3.5 FAR. The street rotation principle relies on a solar access angle adjustment determined by latitude: in the case of Portland, 45° NW-SE. Void condition was tested in two applications: 1) a single 279x279' central plaza; 2) four 145x145' dispersed plazas. Two applications also tested the principle of volumetric roughness: 1) rotating the 70x70' building footprints 2) varying building heights. In total, eighteen iterations of proposed urban morphologies were modelled and simulated (Fig. 2).

Drawing on discussions for generating faster microclimate maps, this study approached UTCI from its two most important parameters—sky heat exchange and wind speed—simulating each individually [23]. Maps generated in Grasshopper simplified UTCI by privileging sky heat transfer, or the spatial effect of sun on outdoor comfort. Sunrise to sunset on the summer equinox (June 21) represented summer daytime conditions: air temperature (Ta) at 19.21°C, mean radiant temperature (Tmrt) at 35.32°C and relative humidity at 59.73%. As spatial maps of UTCI, the simulations only describe thermal diversity driven by the presence of direct sun or shade. These maps account neither for spatial differences in surface temperature across the urban area nor for spatial differences in wind speed.

The study accounts for the effect of urban form on wind speed with CFD simulations run in ANYSYS Fluent. Portland TMY data provided the summer average wind speed and direction (3.4m/s at NNW 112.5°). An SST *k-ω* turbulence model replaced the *k-e* model. No-slip conditions were used to simulate wind tunnel walls. Chamber dimensions were x=2090.6m, y=776.6m and z=65.0m with resolutions dx = dy = dz = 1.98m in space. This domain grid resolution was adequate for the required scale, namely the interaction of wind patterns between 70x70ft building volumes.

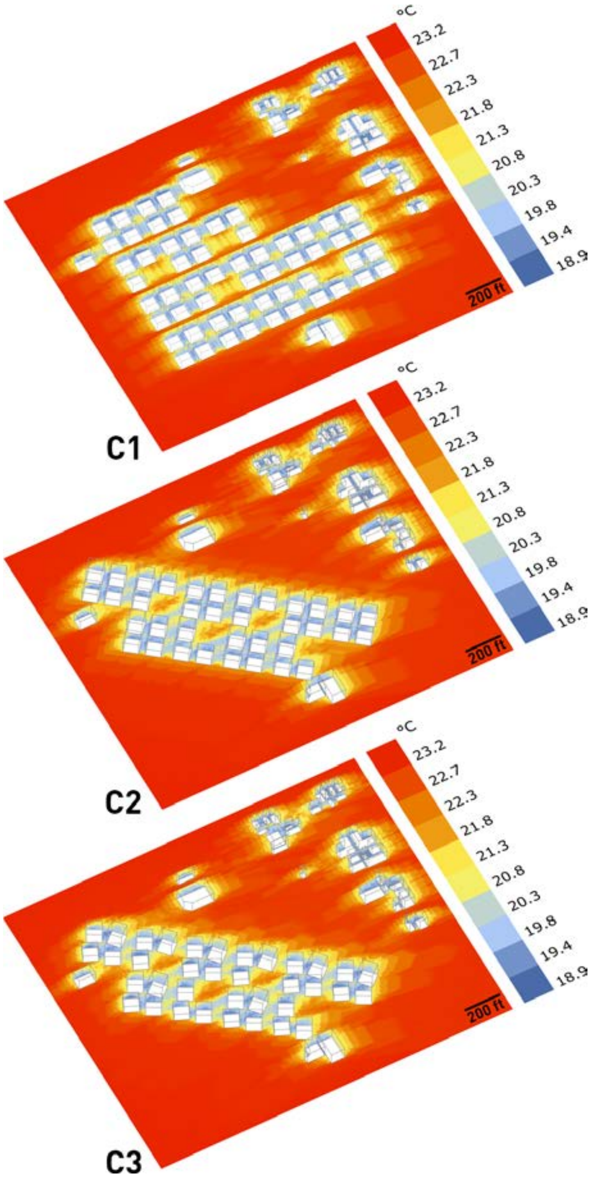

Figure 3. Sky Heat Transfer spatial maps of UTCI for three iterations of spatial operation series C—dispersed voids—with NS aligned grid (C1); with 45° grid rotation (C2, C3); and rotated building footprints (C3). All three iterations tested with varied building heights.

	Plaza 1			Plaza 2			Plaza 3			Plaza 4		
Design Iteration	**C1**	**C2**	**C3**	**C1**	**C2**	**C3**	**C1**	**C2**	**C3**	**C1**	**C2**	**C3**
Avg UTCI: (°C)	22.1	22.9	22.0	22.6	22.7	22.0	23.2	22.7	23.0	21.9	23.4	23.1
Avg Vorticity Magnitude	0.12	0.15	0.80	0.45	0.24	0.35	0.63	0.72	0.68	0.98	0.47	0.47

Table. 1: Comparison of wind effects within dispersed plazas.

Results from the Sky Heat Transfer simulations confirmed that grid rotation increases an urban fabric's self-shading properties. For example, whereas the main east-west thoroughfares are exposed to the sun in iteration C1, every street canyon receives shade in iterations C2 and C3 (Fig 3). By rotating the grid, shaded areas along plaza perimeters widened and cooled ≅1.5°C along the eastern plaza boundaries. By rotating building footprints, thermal contrast between the center and periphery of plazas increased by ≅1°C. Although the plazas in iteration C3 were the hottest (22.7°C) of all iterations, its street canyons were also the coolest, reaching a low 18.2°C UTCI absent from plaza iterations without both grid and building rotations. In future design iterations, land- and water-scaping can mitigate the relative heat stress observed at the centers of the plazas (Fig. 6). Landscape designs need not only respond to and learn from the completed simulations, but also be subject to subsequent sky heat transfer and CFD analysis that weigh the shade benefits of tree canopy coverage against potential negative effects on wind turbulence.

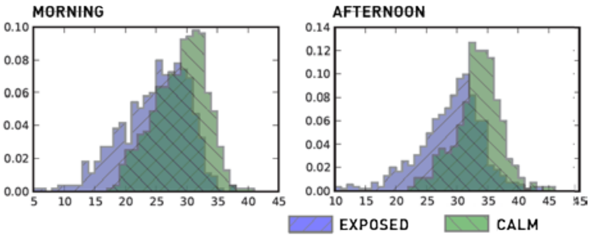

Figure 4. Frequency of UTCI with and without wind in Portland during summer months (source: klimaat.ca).

CFD results met expectations on the degree to which wind benefits UTCI, coinciding with Portland TMY data, and both suggesting an ≅7°C UTCI difference between calm and exposed wind conditions (Fig. 4). Although average wind speeds for the plaza iterations demonstrated a surprisingly thin variance (1.1-1.6m/s), results confirmed that increasing volumetric roughness by rotating building footprints dramatically increased wind turbulence (Table 1). For example, the vorticity magnitude increased 433% from C2 to C3 in the case of Plaza #1, and thus, is model on which to refine the geometries of iteration's other plazas (Figure 5). The effect of wind turbulence on outdoor comfort deserves closer study under a CFD method that accounts for "air age" pattern and distribution, which is a relative indicator of outdoor air quality [24]. With results firmly within the UTCI "no heat stress" category, the C3 morphology now becomes the base for further study.

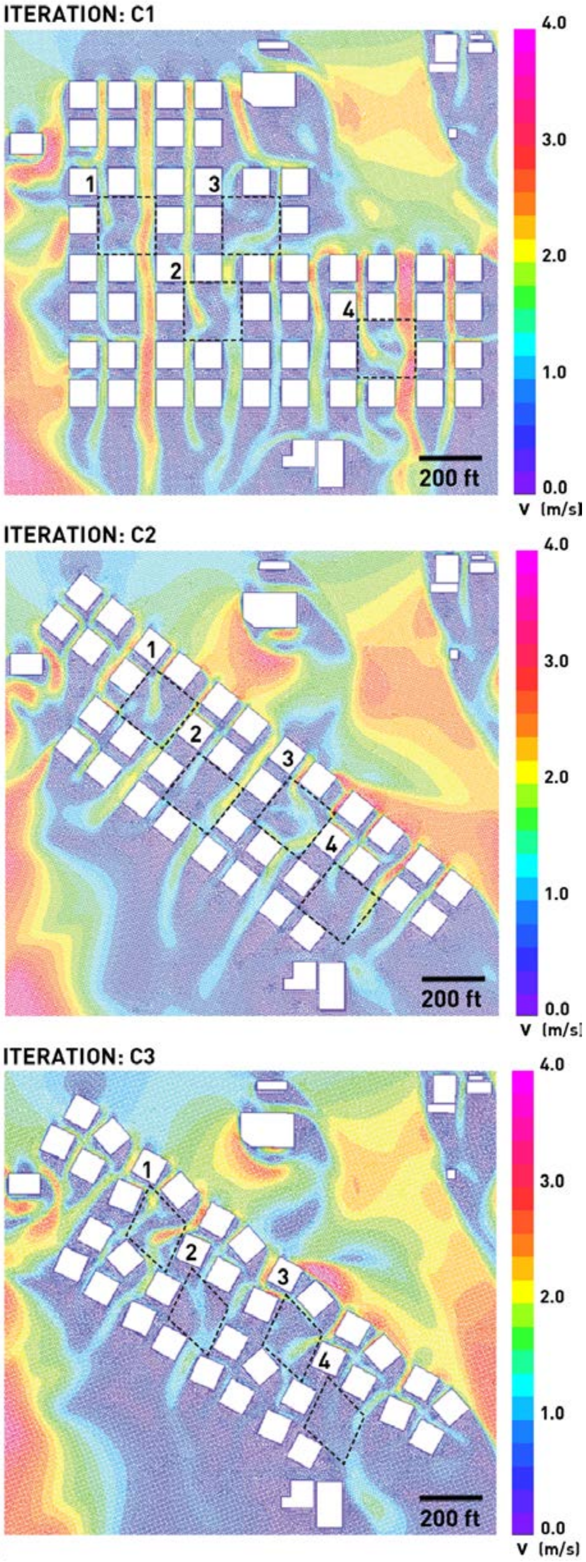

Figure 5: CFD simulations for spatial operation series C, iterations C1-C3 with dispersed courtyards outlined and numbered in black.

Figure 6. Rendering of plazas with tree canopy coverage.

4. CONCLUSION

Advancing the trajectory pioneered by Rudofsky and Oliver, this study corroborates indigenous precedents as both inspiring and useful in practice, yet at the same time, insists that quantitative methods are critical for moving beyond the assumption that form follows climate in the traditional and vernacular. Our process demonstrates how a hybrid approach to UTCI, where sky heat transfer and wind velocity are simulated independently, provides time- and cost-efficient results for students and architects who wish to integrate climate analysis into the early stages of their design process. Emerging from a series of flexible principles intended to scale and re-program according to local constraints, the Rough Void is a typology that is at once site-specific and replicable.

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