A Generative Approach to Social Ecologies in Project [Symbios]City

Hao Wen(✉), Pengcheng Gu, Yuchao Zhang, Shuai Zou, and Patrik Schumacher

Design Reaserch Lab, Architectural Association, London WC1B3ES, UK
hao.wen@aaschool.ac.uk

Abstract. The following paper talks about the studio project [Symbios]City, which is developed as a design research project in 2020–2021 Schumacher' studio on social ecology of the graduate program in Architectural Association's design research lab. The project aims to create an assemblage of social ecologies through a rich but cohesive multi-authored urban district. The primary ambition is to generate an urban area with a characterful, varied identity, that achieves a balanced order between unity and difference avoiding both the sterile and disorienting monotony of centrally planned modernist cities and the (equally disorienting) visual chaos of an agglomeration of utterly unrelated interventions as we find now frequently. Through a thorough research process, our project evolves mainly out of three principles that are taken into consideration for the development of our project: topological optimization, phenomenology, and ecology. By "ecology", we understand it as a living network of information exchange. Therefore, every strategy we employ is not merely about reacting to the weather conditions, but instead it is an inquiry into the various ways we can exploit the latter, a translation of the weather conditions into spatial and programmatic properties. [Symbios]City therefore aims at developing a multi-authored urban area with a rich identity that achieves a balance between the various elements. [Symbios]City began formally from topological optimization, developed based on studies on ecology, and concluded the design following our phenomenological explorations, aiming at a complex design project that unifies the perception of all scales of design: from the platform to the skyscrapers.

Keywords: Structural optimization · Social ecologies · Phenomenology · Generative design

1 Introduction

The studio extrapolates from recent urban concentration processes, assuming a further intensification. Ecological challenges like climate change in general and rising sea levels in particular also point to the wisdom of further urban densification because a sprawling urbanization is much harder to protect. Densification is also mandated by the transformation of cities from industrial centres to knowledge and innovation centres where

The work of Wen and Gu are equal.

P. F. Yuan et al. (Eds.): CDRF 2021, *Proceedings of the 2021 DigitalFUTURES*, pp. 13–25, 2022.
https://doi.org/10.1007/978-981-16-5983-6_2

the collaborative integration of self-directed, creative labor processes mandates the full exploitation of colocation synergies in hyper-dense, permeable urban fabrics.

The proposal is a part of the studio project developed by Schumacher Patrik in AADRL 2020–2021. It envisions a new high-rise district between the City of London and Canary Wharf, straddling both sides of the river. Four teams, each with four architects, simulate the potential for a multi-author urbanism that generates a legible order and unity across a highly differentiated 3D urban fabric. The project assumes the hegemony of tectonism as a precondition for achieving the required density of differentiation and correlation. At the same time, the proposal serves as a highly synthesized testing ground for several important theorems in the realm of architecture, including bendsoe and his predecessors' studies on topological optimization, lovelock's argument for the concept of Gaia and ecophysiology as well as Schumacher's parametric semiology.

The development of the project focuses on several important environmental and social parameters. Wind, a strong environmental factor for skyscraper designs, is implemented in the early stage of the design. Lateral forces in coordination with the primary wind direction in London crucially influence the shape language of the structure benchmarks. Flood, another potential hazardous environmental condition, is responded with hydraulic generated ground conditions. Sunlight, a dynamic parameter throughout the day and year round, shapes the groupings of the building façade and their overall performances. The proposal also aims to optimize within itself and the nearby neighborhoods, creating social clusters for versatile interior experience and moments of integration and fragmentation according to principles in phenomenology.

Although it is hard to summarize a 12-month project in a 10-page paper, we intend to document the thought process, important milestones and the design development of the project in the following article.

2 Topological Optimization as a Method of Parametric Semiology

As Schumacher argues, "all design is communication design. The built environment, with its complex matrix of territorial distinctions, is a giant, navigable, information-rich interface of communication. Each territory is a zone of communication. It gives potential social actors information about the communicative interactions to be expected within its bounds."[1] Parametrcism speaks to this level of semiology from its rule-based generation process and the overall part-to-whole relationships. Architectural elements communicate one-anther at the initial geometrical development and are gradually into spatial environments that correspond. However, it is crucial to be aware of how a semiotic system should demonstrate both syntax and semantics. As his criticisms on the postmodern architectural approach suggests, Schumacher argues, "Eisenman's work had no semantic dimension, and Jencks had no syntax."[2] Topological optimization (TO) approach, on the other hand, naturally fit in the agenda of parametric semiology. As our design research suggests, in the later paragraph of the paper, TO processes have the capacity to generate a catalogue of varied yet similar (varied due to differences of input parameters

[1] Patrik (2012).
[2] Patrik (2012).

and mathematical principles; similar because of geometrical generation algorithms as well as TO's unique design language) of structural benchmarks. These benchmarks are grouped by tectonic similarities and potential spatial behaviors and are later translated into typical building materials of skyscraper designs as well as a field of interconnected neighborhoods.

2.1 Background

To this day, in lieu of the development of computation aid design and revitalization of mathematical structural principles since the design of Antonio Gaudi, simulation and optimization methodologies has become an indispensable part of structural design. TO methods for structural design were first introduced and developed in Bendsoe's Topological Optimizations: Theory, Methods and Application. As stated in the book, "The typology optimization algorithm returns a structural layout describing mean load path in the form of a density distribution on the design domain."[3] Different TO methods (SIMP, ESO, BESO and so on) have since integrated with different CAD software, providing designers with ready-to-use interfaces that allow somewhat intuitive numeric and geometrical input and outputs benchmark models as readable geometries to the software environment. TO was first applied to the structural design of automobiles, where strong torque force and tight building spaces ask for materials with high levels of structural performance. As it develops, TO process starts to influence the structural design of mega structures, especially the main structure support for skyscrapers, and thus making its impact in the architectural built environment. Namely, in the competition entry of citic financial centers by SOM and the One thousand Miami by Zaha Hadid Architect, a new type of tower design that is supported by TO algorithms demonstrates a new paradigm of super-tall towers that are lightweight, coreless, structurally expressive and spatially informed.

Our proposal therefore uses TO software as a driver for architectural semiology, achieving a multi-author district that reads as a difficult and complex whole, generating characterful tower identities on the urban, cluster and individual level, and creating interconnected neighborhoods as well as different moments of tower clusters based on principles of phenomenology.

2.2 TO Software and Its Potential to Achieve Tower Semiology

The design research is embedded in three TO grasshopper plug-ins, Topos by Sebsastian "archiseb" Bialkowski, Peregrine by LimiState and Ameba by Mike Yimin Xie. These three software each offer a unique benchmark generation process based on the differences in algorithmic approach and geometry interpolation. Each software takes input such as geometric domain, load and support conditions as well as nodal divisions and material density from the geometry set-up interface and calculates optimized load paths through numerous generations, and then interpolates the load path into meaningful geometry outputs. Yet due to the differences of each software, even with the same input, the output benchmark is going to be different.

[3] Bendsoe and Sigmund (2003).

Topos uses the ESO (SESO) method (evolutionary structural optimization or single directional structural optimization) which was first proposed by Mike Xie and G.P. Steven in 1993.[4] During the interactive calculation process, load path remains static. The more iteration it runs, the more resolution the final load path gains. Topos also uses density distribution of voxels to translate the calculated load paths into geometrical elements following the marching cube algorithm.[5] The resulting benchmark model is a holistic mesh with unevenly distributed density values according to the load path.

Peregrine also uses the ESO method, and in terms of mathematical principles, it only has minor differences with that of Topos. However, for the geometry interpolation, it uses discrete element piping to assign different thickness value to each load path. At the same time, it recognizes the calculated load path as either element in tension or elements in compression.

Ameba, on the other hand, uses the BESO method (bi-directional evolutionary structural optimization). It is an extension of the ESO method, also proposed by Mike Xie, which allows for efficient material to be added and inefficient material to be subtracted from the geometry domain.[6] Therefore, for each iterative calculation, load path becomes dynamic, different from the previous iteration of the load path calculation. Finally, it uses marching cube method as geometrical mesh generation, the same as Topos, for its benchmark output.

Through a painstaking research of trial-and-error, we managed to generate a series of benchmark catalogues that looks at tower structure in a typical 200-m skyscraper under the condition of self-load and dynamic wind load. Although the workflow and design principle for these three algorithms yield a similar process, each software adapts best to different values of input parameters. For Topos, the structure benchmark become most legible when we spread load zones evenly on each different level; for peregrine, the structural members have the highest performance with load conditions mirrored on two halves of the tower; for ameba, we use repetitive surface support to adhere different parts of the mesh results.

As shown in the Fig. 1, the differences and similarities of configurative voids in each structure study can later be interpreted as semiology in architectural language and the built environment.

Depending on their configurative void behaviors, we categorized the benchmarks into four tower clusters. Type Y towers that are generated by topos and have mostly branch structural moments. Type H towers that are generated by ameba, which uses strong mid-level floor plates to connect the two half towers. Type X towers that use large cross bracing to support the half towers. Type Z towers that have small cross bracing moments all over the tower (Fig. 2).

[4] Xie and Steven (1993).
[5] Lorensen and Cline (1987).
[6] Huang and Xie (2007).

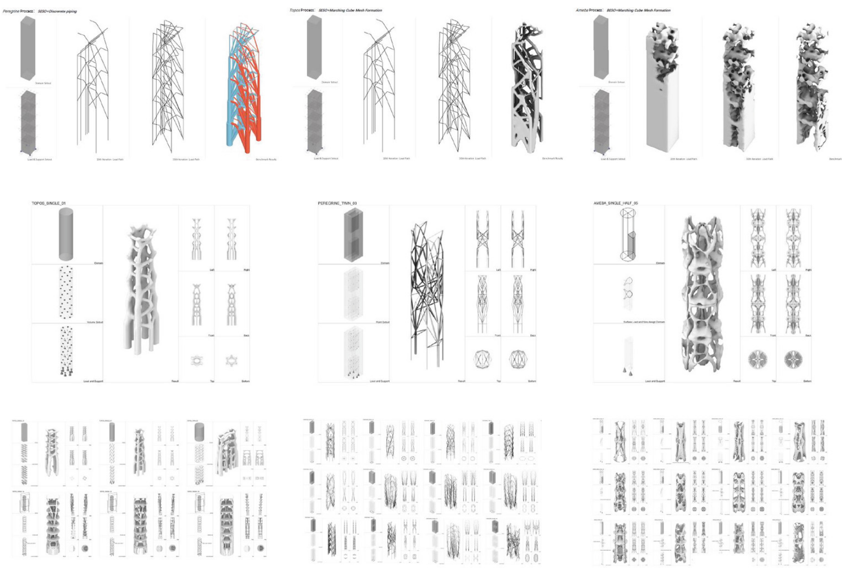

Fig. 1. Top part shows software differences between topos, peregrine and ameba. Bottom part shows the benchmark catalog.

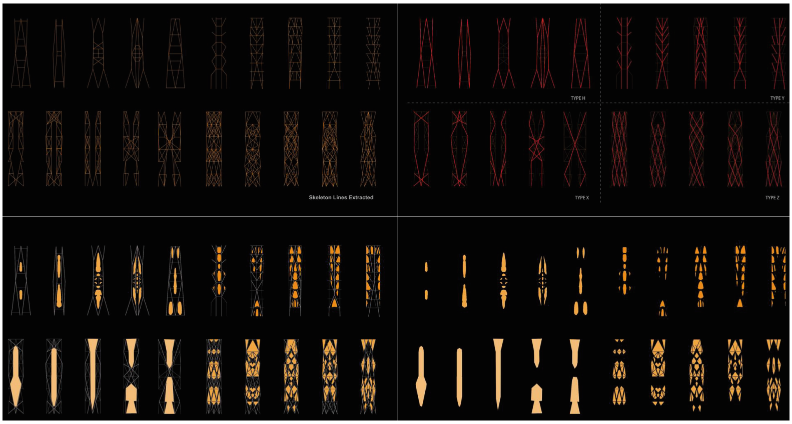

Fig. 2. Figure is composed of four diagrams, each studying different aspects of benchmark configuration.

2.3 Benchmark Post Processing and Materialization

The initial benchmark generation only present optimized structural studies in an ideal scenario. To complement the real-life conditions, we employed structural evaluation software to test the benchmark's performances under real-life conditions. We used Karamba 3d as the primary parametric engineering software. For each benchmark evaluation, we used the anticipated floor load and wind load as the load input and simplified the benchmark into simplified stick models for analysis. The simulation of the stick model behavior allows us to add structural members to stabilize the overall structure.

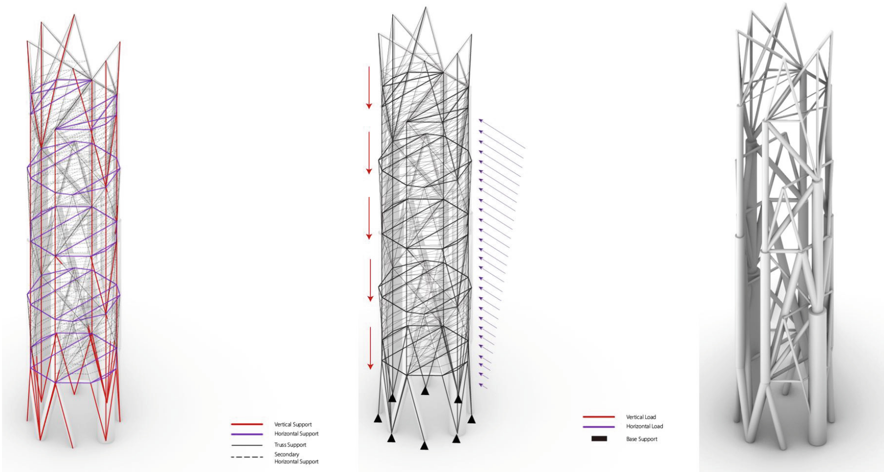

Fig. 3. Figure shows the post evaluation process.

During the simulation, we also used real-life material data for typical skyscraper design, wood, concrete and steel, allowing the structural studies to gain resolution in terms of buildability and materiality. The tri-material approach therefore adds another level of urban reading in addition to the configurative clusters Y, H, X and Z. The resulted structural studies after their material translation form an urban matrix of dual

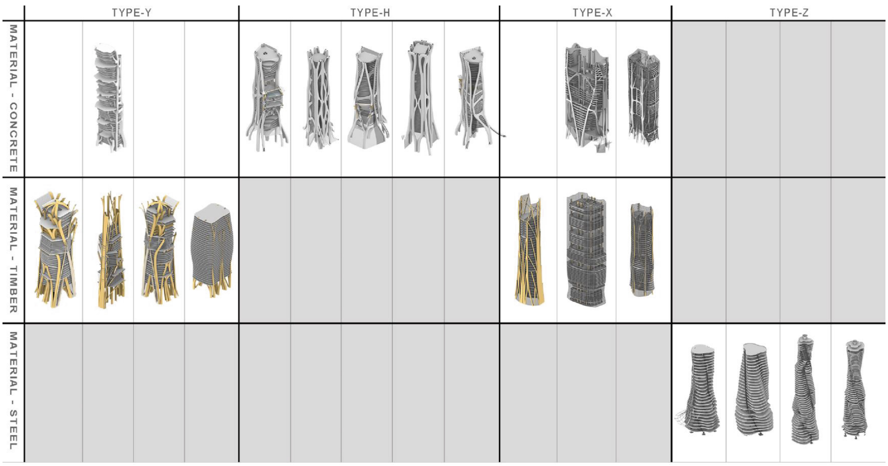

Fig. 4. Figure shows tower matrix, horizontal represents configurative differences; vertical shows material differences.

readings (Fig. 3). These two layers of clustering intertwine with one another, following the principles of phenomenology, forming a complex and variegated order (Fig. 4).

3 Ground Design and Flood Simulation

In order to accommodate for the 3 mm sea level rise and the 6-m daily tidal differences in London, the design tries to create a hydraulic-driven ground condition. The rise of water planes acts as gestalt switches for the ground. At relative sea level 0 m, 4 m and 7 m, the shape language of the ground transitions from a continuous landscape to shattered islands. The connectivity between different tower cluster changes from ground to high-rise bridges respectively. The ground design also implements a hierarchy of river paths which reflects the flooding pattern of the Thames River. These river paths act as means to drive the water flow, mitigating and containing the flooding.

3.1 Flood Simulation

To study the flooding condition, we did a series of simulations in Maya and Houdini, using particle systems. Parameters were set in speed, viscosity, density, friction of particles to test different conditions. An outcome which mostly corresponding to the reality was finally filtered and adopted.

Two negative factors were found during the simulation experiment: In reality, there will always be some other factors affecting the result and cannot be specifically predicted by software. Specific trails of particles are quite random and complex, which are hard to be used. As a solution, we summarize the general movement trend of particles to get a more instructive image result.

3.2 Tower Arrangement

The advantage of current arrangement is that in the secondary turns of simulation with towers on the site, the particle trails are more in line with the previous simulation result which can be easier to do further design. Then, we make the second iteration of simulation with towers as obstacles and get the second graph of particle trend.

Water flow will not directly affect the towers. We use the final pattern for the ground design: the area closed to towers will be raised to block the flood, while the rest of the ground will be used as river paths to let flood go through, thus preventing the city area. In the outcome, the division logic of towers are based on the groups of ground by the operations set above (Fig. 5).

3.3 Podium Design and Network Theory

Related theories are studied and used in podium design in reference to ‘The Autopoiesis of Architecture’ by Patrik Schumacher, in order to find the best way of circulation for different kinds of functions.

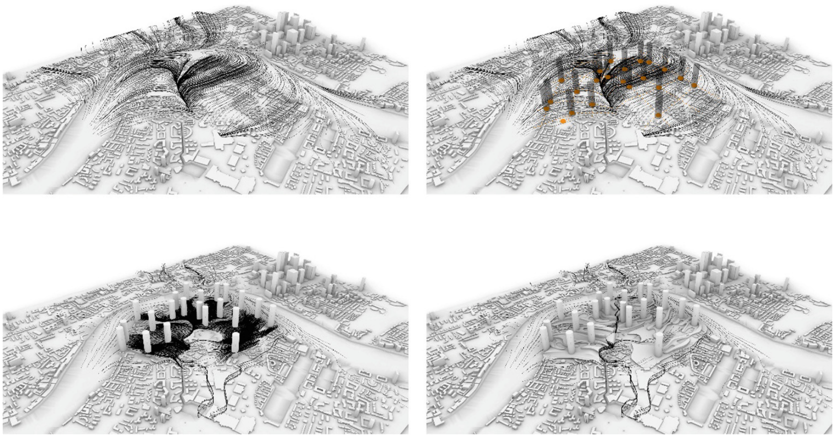

Fig. 5. Left top: the 1st iteration of particle trails; Right top: Location of towers based on trails Left bottom: the 2nd iteration of particle trails; Right bottom: ground operations result.

Network theory and space syntax theory explains the relationship between number of routes and accessibility, thus can be further used to describe the openness and privacy of functions. Set theory quantifies the level relationship between spaces, a further containment relationship can be set between different types of connections.

The arrangement of towers based on particle trails in the previous part of this article proposed an aspect of network relationship when the towers being regarded as nodes and the network produced (which is in parallel and perpendicular to the particle trend lines) being regarded as circulations to connect nodes. Therefore, different connectivity prototypes are proposed and applied to different functional areas in the site. Podiums were designed on the basis of the circulation relationships.

At this stage, the base of the design project is determined. Responses to external environmental conditions such as wind, flood and land topography blossom into various identities and points of exchange. These points of exchange take place where one transition from one cluster to another, whether it is from one shape language to another, or one material to another, or through the different water levels of the day. However, spatial and neighborhood experience is still the determining factor of an architectural/urban planning project. From this point of view, the following part focus on the exchange of neighborhoods and spatial performances of the design.

4 From Programmatic Distribution to Neighborhood Ecologies

Our proposed neighborhood experience is a criticism of the modernist architectural paradigm raised by Le Corbusier.[7] In the modernist approach of urban planning, program districts are segregated into city zonings with stretched-out communication facilities. To accommodate for the current habits of living and principles of the 15-min city, we purpose a hyper-dense urban area with program overlays and interconnected neighborhoods. We achieve it on several important architectural scales. In the individual towers, coreless voids which are generated by TO benchmarks host numerous programmatic sub-environments. On the cluster level, towers are grouped by dual readings of either configurative behaviors or material behaviors, resulting in zones of different program specificities or different levels of activity intensity. On the city scale, our purposed area, together with the other three proposed urban designs in the studio, bridges two separated densified urban developments in London, Canary Wharf and the city of London.

4.1 Typical Program Classification and Distribution

After case studies and research on a catalog of skyscraper design, we categorized the main program functions in a typical tower into four major groups: Residential use which includes apartment housing, student housing, hotels and residential facilities; Corporate use which includes open offices, small offices, conference rooms and rest areas; Commercial use that includes shopping centers, open markets, restaurants and cinemas; Facility use that includes park areas, gymnasiums, libraries and galleries. These programs are further distributed according to the urban matrix of structural studies.

For program distribution, we first assign the four major function groups to the four configurative groups. Y towers have large openings and large floor plates, so they are assigned to commercial usage; H towers have smaller openings and are assigned to residential usage; X towers have the largest voids and are assigned to facility usage; Z towers have small floor areas but many opportunities for interconnectivity and are assigned to corporate usage. Next, the level of hybridity of program overlays are assigned to each material group. Steel clusters and concrete clusters are separated so they have less hybridity whereas timber clusters bridge the urban connection between steel group and concrete group and have more levels of program hybridity. The dual urban reading of the initial tower design is therefore translated into a variegated yet orderly neighborhood ecology.

4.2 Dynamic Programs and Micro-structures

In addition to the standard static program planning for each tower, to accommodate the ever-changing need for activities, we proposed a second layer of dynamic programs. These programs take advantage of the porous structure as a result of TO's unique design language. They are supported by another layer of microstructure, affiliated by the main tower structure. Depending on different times of the day, or different needs of user activity, these programs have movable parts and thus can change their shape language

[7] Corbusier (1920).

as well as their primary functions. Take the dynamic residential tower for example (Fig. 6). It is supported by shelf-like structures which inhabit the main void of the residential towers. The shelf structures have removable floor plates and shear walls and can thus accommodate different types of residential usage. The combination of the microstructures and main structures allow the overall urban design to become more adaptable. Neighborhood relationships also become dynamic, changing itself according to either time differences or population needs.

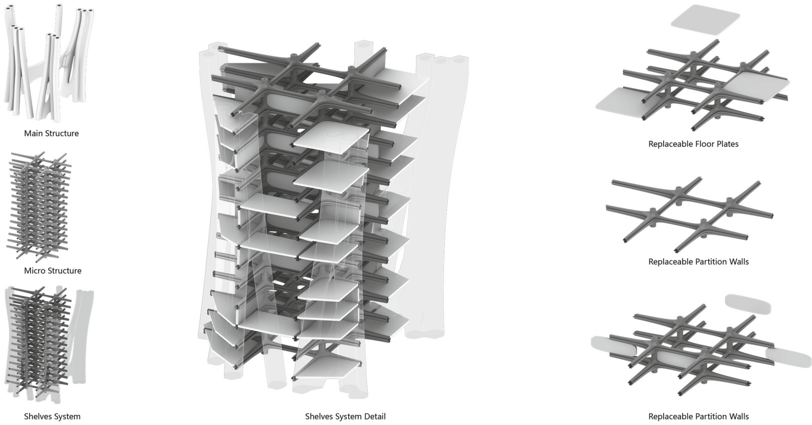

Fig. 6. Figure shows the design of microstructures for dynamic living.

5 Façade Development and Sunlight Optimization

The façade system on the one hand is the climate interface of buildings playing a role of shading and ventilation. On the other hand, the façade also reflects the internal functional activities.

We firstly set up specific façade types for different directions: according to different sunshine conditions, the northeast direction (yellow part) is mostly small balconies used in residences; the southwest direction (blue part) uses shading skin structure, while the transition part (green part) uses public places like outdoor platforms.

In terms of dynamic skin design, we summarized 6 kinds of façade units with different activities and then studied their specific shading capabilities. After that, we define the shading ability to a certain figure between (0, 1) that can give the performance of different kinds of façade systems in a more direct way. The lower the value is, the weaker the shading ability it has, while it does not mean this kind is useless. Another parameter of openness was also set to text if the façade can provide more eye contact between spaces which can be then used for functions in large spaces like public stages and indoor gardens (Fig. 7).

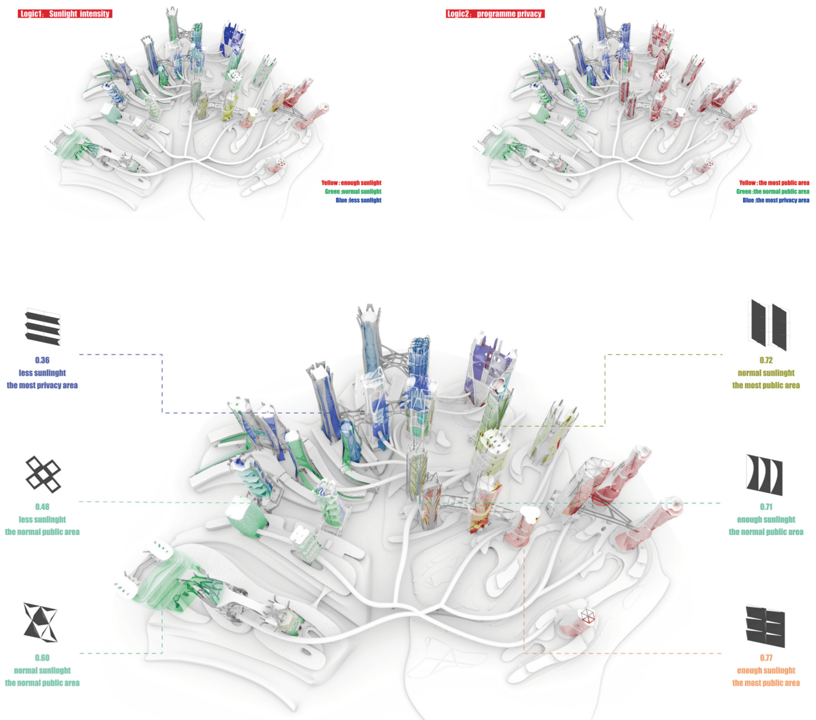

Fig. 7. Figure shows the final layout the operable facades.

6 Conclusion

Our proposal attempts to challenge the traditional design process of an urban development, where extremes of oversimplification and overcomplicated urban scene coexist at the same time. For instance, fast-developed cities have large zones of copy-pasteable buildings displaying a highly monotonous identity and a city center with project of different developers and designers that creates a highly differentiated scene.

Combining research-based design methodologies using catalogs and simulation and generative design methodologies which allow TO semiology to develop into an interwoven built environment, we aim at creating a new paradigm for urban design. This new type of urban development is able to resolve different design parameters as shown. Identities of the architecture is overlapped and intertwined. A variegated urban order of echoing identities seems to be the middle ground between the monotonous mundane and the eye-soring, competing complexity.

The final project adopts multiple design principles of parametricism. The ground topography is generated by hydraulic patterns based on the natural river flow and changes its connectivity in reaction to the rising of the water level. The platforms, as another iteration of the same hydraulic pattern, interface between the tower volumes the ground circulation. The skyscrapers are clustered based on the performative qualities of the topological optimization and material explorations and provide flexible zoning opportunities and coreless programmatic distributions. Finally, the design of the kinetic façade is optimized based on a series of sunlight studies, differentiating the articulation of any south-facing and north-facing openings.

To conclude, [Symbios]City began formally from topological optimization, developed based on studies on ecology, and concluded the design following our phenomenological explorations, overall aiming at a complex design project that unifies the perception of all scales of design (Fig. 8).

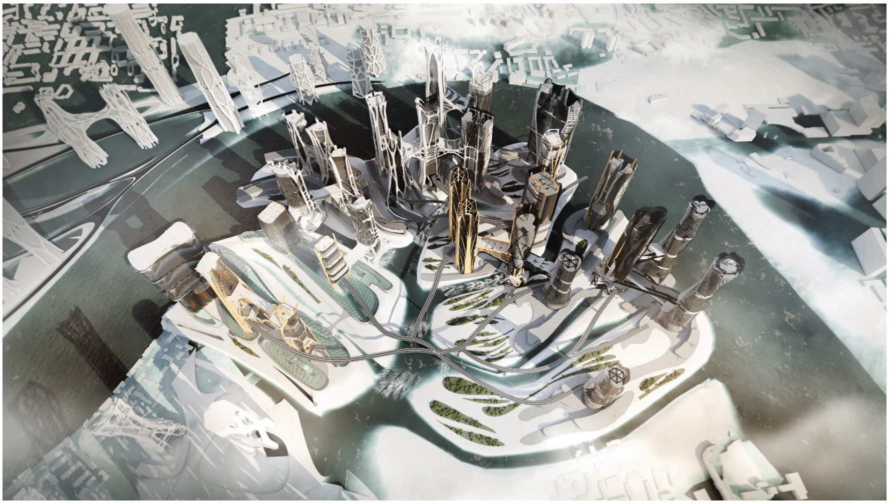

Fig. 8. Figure shows the final rendering of the project.

References

Patrik, S.: Parametric Semiology – The Design of Information Rich Environments (2012). https://www.patrikschumacher.com/Texts/Design%20of%20Information%20Rich%20Environments.html

Bendsoe, M.P., Sigmund, O.: Topological Optimization: Theory, Methods and Application Springer Heidelberg (2003).https://doi.org/10.1007/978-3-662-05086-6

Xie, M., Steven, G.P.: A simple evolutionary procedure for structural optimization. Comput. Struct. **49**, 885–886 (1993)

Huang, X., Xie, Y.M.: Convergent and mesh-independent solutions for the bi-directional evolutionary structural optimization method (2007). Available via Science Direct. https://reader.elsevier.com/reader/sd/pii/S0168874X07000777?token=A321626F94F939FFC0ACF8C61F23FBB163273A9C4ACF8FB0AC372F9E9FF42CED4885EC5B79E0375B21815766127A17D6

Lorensen, W.E., Cline, H.V.: Marching Cubes: A Higher Resolution 3D Surface Construction Algorithm (1987)

Corbuser, L.: Radiant City (1920)

Lovelock, J.: Geophysiology, the science of Gaia. Rev. Geophys. **17**, 215–222 (1989)