Computational Approach in Investigating Surface and Site Radiation in the Early Phase of Designing Two-Story Wooden House in Orio District, Kitakyushu, Japan

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Along with the rise of awareness in implementing the environmentally conscious urban design, the classical process in approaching urban environmental analysis should be shifted to the performance-based considerations. In architecture and urban design, the tools developed recently holds promise to assist the decision-making process in the early phase of designing. Thus, the further performance of the intended architecture project, particularly related to energy consumption and its environmental impact, can be nearly accurately predicted. Although many studies contain the computer design process for analyzing urban energy performance, the Multi-Objective Optimization (MOO) process in the sub-tropical climate of Japan has not been widely used. This research investigates hypothetically the surface and site radiation in the early phase of designing a two-level wooden house in Orio District, Kitakyushu, Japan, through parametric and generative algorithm. The research designed to map the best possible design solution of free-form loft-twisted structure through iterating design variables related to design elements such as building orientation, base radius, twisting and scaling factor and the angle of the roof slope. The optimization targeting the minimum quantity of solar radiation both for the site and the building surface affected by the geometry. The simulation uses an EPW file of Shimonoseki as the input weather file and being scheduled for fitting the period in the extreme hot week during the summertime. The findings are successful to produce a design with better performance compared to the benchmark model even though with insignificant improvement.

Keywords: Multi-Objective Optimization, Parametric design, Urban microclimate

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1. Introduction

In the last decades, the development of digital architecture [1] has been enhancing the field of the built environment through its capability in handling complex design formulation. In architecture, advanced computational approach was revolutionized and implemented in several design and planning activities ranging from the purpose of predicting future performance of the building during the early design stage through simulation [2, 3] to the post-occupancy evaluation. This advancement brings promise in improving the design quality, particularly related to their effect on the environment. In the early phase of designing, where the uncertainty of the design aspects is happening, the building performance prediction through simulation was conducted to support the decision making process [4]. One of the advantages of its utilization is to minimize the detrimental implication to the environment where the building is built, for instance, lowering carbon from the energy consumption related to the used for cooling and heating load, comfort sensation that affects people's health [5] and urban heat island phenomena [6].

Japan is well-known in using wood as the main building material and the tradition has been inherited over generations. Besides, in architecture, wood is considered as an environmentally friendly and sustainable building material due to its availability in all over areas of this country. To be compared with concrete or steel, wood is considered more sustainable material because of its regenerative ability, which is much faster than the aforementioned two. What is more, the production of wood can be controlled by humans and the preparation tend to be cleaner and more practical [7]. Department of Architecture, The University of Kitakyushu in collaboration with Meldia Research for Advanced Wood has established a laboratory that has a specialty in wooden advanced research and construction. To fulfill one of the research agenda, the laboratory tends to design and build a two-story wooden house made entirely of wood.

Despite many studies containing computational design process for analyzing urban energy performance, the Multi-Objective Optimization (MOO) process in the sub-tropical climate of Japan has not been widely used. This research aims to investigate the outdoor microclimate in the early phase of designing a two-level wooden house in Orio District, Kitakyushu, Japan through parametric and generative algorithms platform. This research is an early design stage of the intended project and aiming to utilize the computational design which is parametric and multi-objective optimization using a generative algorithm to make environmentally friendly design considerations towards its microclimate [8]. The designated geometry will undergo the simulation and optimization of surface and site radiation and outdoor microclimate analysis using input weather data of the extreme hot week of summer in Shimonoseki, Yamaguchi, Japan [9], which is the closest available data around the city of Kitakyushu where the project is planned to be constructed. The research employed hypothetical investigation on the energy consumption efficiency using the computational definition arrangement processes. Subsequently, the result was compared to the benchmark model with no computational treatment. To achieve the objectives, a parametric design workflow was demonstrated to iterate the geometries in form-finding processes. Then, its response to the microclimate, where the radiation and the Universal Urban Thermal Climate Index (UTCI) that becomes a target analysis, was observed. Moreover, the trade-offs between design parameters and its indication toward the performance simulation was identified and compared to what the benchmark model is performing.

2. Literature Review and Related work

2.1. Computational design and Multi-Objective Optimization (MOO)

As the paradigm in architectural design shifted, the computational design has become a major topic in forming nowadays architecture. The development has changed the way the classic design process with its flexibility and capability in handling complex computation, model generation, and feedback that brings the circumstances to the greatness of freedom shape generation [10]. The distinguish difference between the classical design process and the generative design process relies on the phases that have been taken during the design process. In the classical design process, the evaluation of the model is conducted after the first targeted solution is established. The evaluation goes along until the desired solution is found. On the contrary, in the generative algorithm process, instead of making the targeted design in the early phase of designing, the source code is being made [11]. The source code is meant to formulate the design variables to generate the best possible design solution. The development challenge design rather than form, hence the design has to have four criteria such as complex, intelligible, unpredictable, and desirable [12].

Furthermore, due to its capability in formulating complex calculations, the terminology genetic algorithm from the biology and computation field has been adopted. The process of optimization is widely recognized as a process in finding the desired design alternative through genetic algorithms. The optimization is divided into single and multi-objective optimization. The Multi-Objective Optimization (MOO) within the Pareto-based approach is usually used to find the trade-offs of all objectives simultaneously [13].

2.2. Urban form and outdoor comfort

Even though many studies suggest that building typologies have strong implications for the microclimate of the site, the deployment of computational design has not been ubiquitously utilized. The evaluation of microclimate and outdoor thermal comfort are commonly conducted using a classical design process without form finding and optimization process. However, recent studies related to urban microclimate and outdoor comfort seem to have important development in mitigating the detrimental impact caused by urban heat island phenomena. Up to this point, the importance of computational design is increasing as the urban heat island phenomena transform into more vivid appearance and involve more complex parameters.

To elaborate, some projects have been conducted employing computational design to analyze microclimate subjects. For instance, Grasshopper and OpenStudio, Radiance, and EnergyPlus have been incorporated to investigate the impact of the urban canyon on the microclimate in Al Ain city, UAE [5]. The research concluded that larger ratios and North-South orientation produces more comfort space and creating wind passages could reduce the UTCI by flowing the wind. Natanian [14–17], in the range of research conducted urban environmental analysis for different type of building typology in order to see the impact of urban form towards outdoor microclimate using a parametric process . He simulates different urban typology such as courtyards, scatter, Slab NS, Slab NW and high rise with the dynamic design variables such as Window to Wall Ratio (WWR), Glazing properties, building use, Floor Area Ratio (FAR), Distance between building and Urban grid rotation in which the iteration can iterate 1920 iterations. The analysis is conducted using Ladybug, Honeybee and Colibri in the context of Mediterranean districts. The main findings of the research are the mitigation of the difference performance among the simulated typology and the potential of the workflow to assist designers in the design decision making phase.

The comparison between the two most used microclimatic analysis engine, Ladybug and ENVI met has been conducted in the hot arid regions of Egypt [18]. The research concluded that the workflow using Ladybug tools is more efficient for the microclimatic analysis both numerically and visually. Furthermore, a prototype digital workflow is proposed to evaluate regenerative performance in a single digital workflow [15]. The engine Ladybug, Honeybee Butterfly and Dragonfly are used to calculate UTCI and see the indicators of thermal comfort, biophilia, daylight performance and energy consumption in La Luz, Malaga. The research demonstrates the potential of applying the workflow could bring advantages due to its visual feedback for the designer to consider the decision making is made by the evidenced-based urban design process. However, the process of investigation is still open to customize the features according to the needs. The custom script has been developed to enhance the simulation run by the existing tools [19]. The research found that there are still obstacles in implementing computational microclimate analysis.

Several microclimatic studies had been carried out using Multi-Objective Optimization (MOO). For example, Delgarm et al. [20] proposed an efficient methodology called MOPSO to evaluate the effectiveness of energy consumption of a single room model situated in Teheran, Iran. The simulation involves building orientation, shading overhang, glazing ratio, and the material properties as a design variable. The results indicated that cooling, electricity decrease from 19% to 33%, while annual heating and lighting were increased by 48% and 2.6%. In addition, Azari et al. [21] utilizes MOO to explore building envelope concerning energy use impact in Seattle, Washington. The result of the research revealed that the optimum scenario with a specific percentage of the Window-to-Wall ratio (WWR). Shadram et al. [22] present MOO to explore the impact of retrofitting measures of typical 1980s residence in Sweden. The results indicated that several optimized measures could fulfil the new-build energy standard. Javanroodi et al. [23] introduce Energy Efficient Form-finder (EEF) that consist of Form-Generation, Form-Simulation, Form-Optimization and Form-solution. The results show great potential to reduce annual energy by adopting the proposed system. Camporale et al. [24] conducted the research that analyse the impact of optimization of the slab and high-rise housing's shapes towards the primary energy consumption in Buenos Aires, Argentina. The results produce a Pareto front that reflects the adoption of passive strategies in several design solutions.

2.3. Parametric and simulation tools

The entire system is arranged on the Rhino 3D and Grasshopper parametric platform [25, 26]. Ladybug is a plugin software used to analyze microclimate based on the parametric platform of grasshopper [27]. It allows importing EnergyPlus Weather data (EPW) to the data analysis and visualization according to the designer's needs. The plugin was built to facilitate designer and engineers to conduct environmental analysis related to the built environment with less time consuming. It is integrating the design process with environmental study, allowing the effective way in design and evaluation process related to environmental consideration. In addition, Honeybee complements Ladybug tools in formulating calculation related to energy analysis. This plugin integrated well-known simulation engine such as Daysim, Radiance, Therm, EnergyPlus and OpenStudio to generate the needs of energy-related analysis and visualization.

3. Research Methodology

3.1. Overview

In order to get the radiation and UTCI results and to see the impact of geometry on the urban microclimate of the intended design, the design parameters such as base radius, twisting factor, roof slope, scale factor, and orientation are based. Fig. 1 shows the parametric workflow [5, 28, 29] conducted in this research. The initial phase is the modelling of the site as the context. The next phase is the consideration of the house's parameters, sliders and it's followed by the arrangement of its parametric definitions to construct the design virtual model. Furthermore, the environmental analysis platform using Ladybug and the Honeybee is arranged. This definition is used to generate radiation and UTCI results based on input weather data. After the modelling of the site, context, building and the definition of environmental analysis are ready, the results and the iteration are being iterated and optimized in a generative algorithm-based optimization plug in called Octopus [30, 31]. The benchmark model will be analyzed separately to produce a single result as a comparison. The data obtained from the iteration and the comparison will be multiplied by per-hour electricity fare to have an image of how much money is spent to pay kWh/m^2 of the radiation result. The desired design solution will undergo a single analysis and being compared to the benchmark result to see the interval that indicates the efficiency.

3.2. Site and analysis period

The intended project is situated in Orio district 5 Chome 2 Orio, Yahata-Nishi Ku, Kitakyushu city, Japan. The site is in the coordinate 33°51'48. 9"N 130°42'29. 4"E. The topography of the site is formed with multistep terrain which has a different level of about 13 meters. The site is surrounded by detached houses with distances approximately 8 to 10 meters each, apartments, and a small area of greenery. In general, the site has covered an area of 350 m^2 with dimension 33.7 m length and 9.72 m wide. The surface area is covered by sand, gravel, and grass, and the surrounding area is covered by mostly paving and asphalt. The site and the surface have different radiation analysis.

For the analysis period, the simulation uses an EPW file of Shimonoseki as the nearest historical recorded weather data available surrounding Kitakyushu city. The period of the year that is incorporated for simulating the radiation and UTCI analysis is the extreme hot week in the summer from 5 to 11 August JST generated by Ladybug component Import Stat. The selected period has been taken on purpose to give hottest temperature to the building surface throughout the year. Thus, it could give an idea of how the condition during the hottest period is related to the surface and site radiation. The simulation prefers the hottest period in August for the radiation and UTCI simulation and the single day of August 8 for a single simulation for evaluation and comparison.

3.3. Geometry and benchmark modelling

The geometry of the house is designed to be adopting the shape of a twisted cylinder. The Reuleaux triangle [32] is designed to be the base profile if the cylinder. The geometry was built with the Grasshopper environment with several dynamic and fixed parameters as a design variable for the iteration processes. The dynamic parameters are meant to be always moving during the search for the best design solution. It is applied by deploying a number slider that is divided into several movement divisions. The dynamic parameters hold an important role in determining the alternative geometry in collaboration with the generative algorithm iterator and the result of the environmental analysis. The dynamic parameters designed in this research are building orientation, circle radius that forming the Reuleaux triangle, scaling factor to form the gradually bigger profile in the upper part of the building, twisting factor to perform twisted cylinder, and the roof slope. For the construction materials, the geometry's material has not been specifically defined to see the general tendency and only rely on the honeybee component named Honeybee_masses2zones. However, to have an insight into the maximum implication of the geometry to the UTCI, concrete was set to be the site's materials.

Table 1. Design variables.

Design variables (Parameters)	Unit	Range	Unit per step	Steps
Orientation	°	5−180	5	36
Base radius	m	2−3	0.1	10
Twisting factor	-	-125−125	5	50
Scale factor	-	-25−25	5	10
Roof slope	°	0−30	5	12

Fig. 2 illustrates the position and movement of the parameters and Table 1 describes steps of each design attributes. The first designated dynamic parameter is the orientation translated in the rotation of the base profile toward the center points of its area. The rotation angle is set to have 36 parameter's movements with 5° for each movement ranged from the minimum 5° to 150°. The second variable is the radius of the base profile of the geometry formed by the Reuleaux triangle which is the subtraction of three identical circles with dynamic diameter ranged from

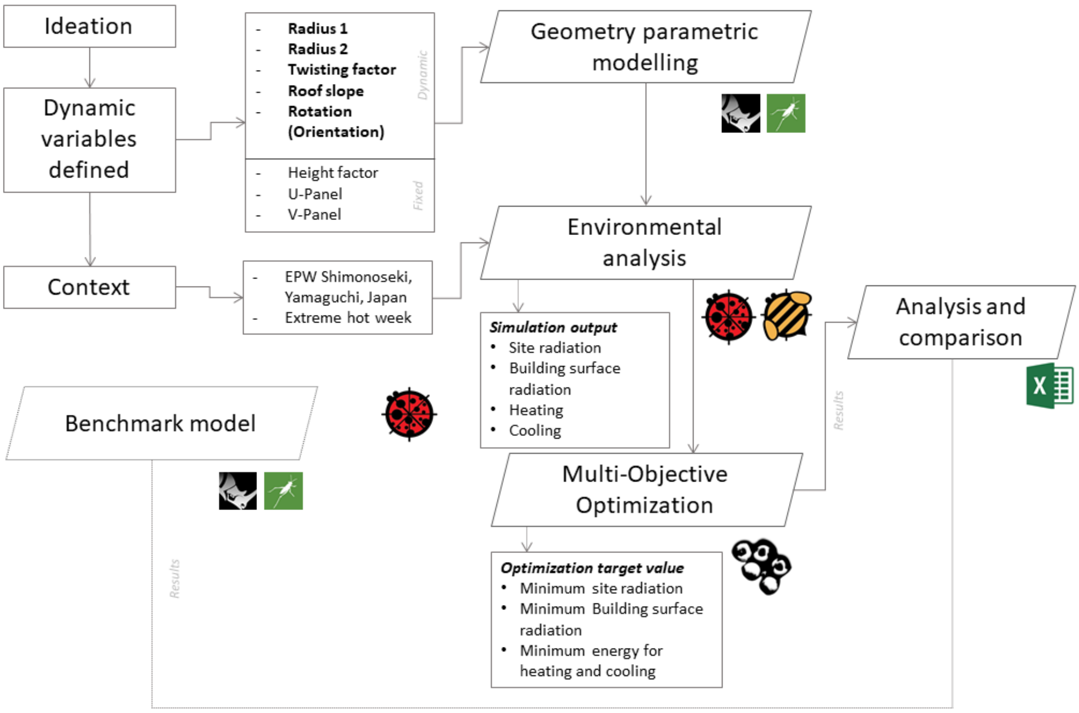


Fig. 1. Research workflow.

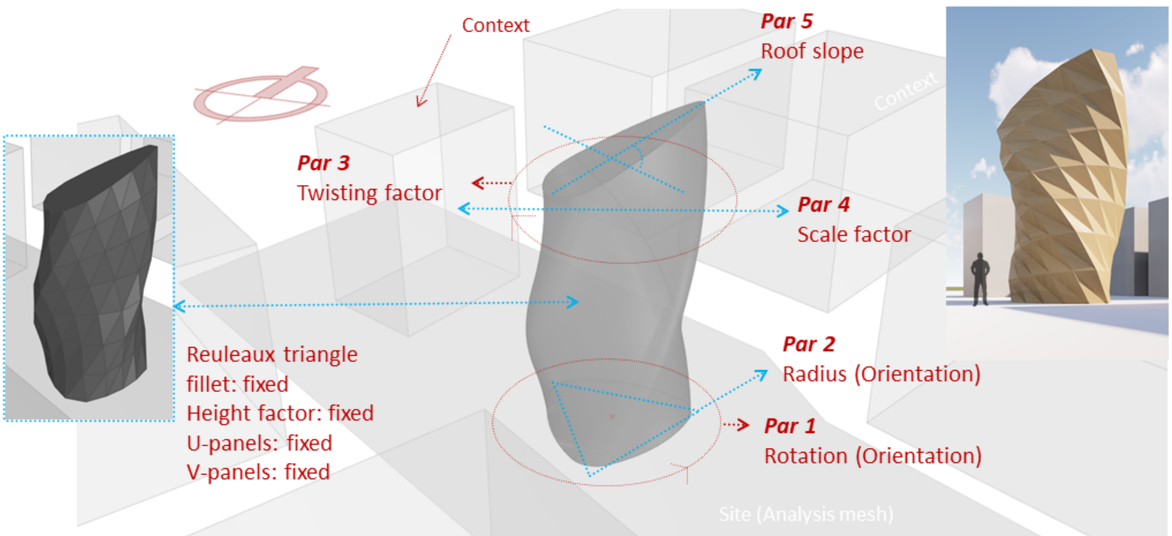


Fig. 2. Design parameters.

minimum 2m to 3m with 10 movements, 0.1m for each step. The third variable is the twisting factor which has 50 variable movements with 5 units for each step, the factor ranged from the minimum value of -125 units to 125 units. The fourth variable is the scale factor with 10 movements with 5 units for each step. The variable ranged from -25 units to 25 units. The last design variable is the roof slope. This variable has 12 variable's movements with the 5° unit for each step. The parameters ranged from a minimum angle of 0° to 30°. Besides the dynamic parameters, the fixed parameters are set. The fixed parameters are the triangle's fillet, height factor, U and V axis for planar paneling. From, the number of several design movements contributed by each design parameter, the system could iterate 2.160.000 design solutions. However, not all the design variables will undergo the simulation due to the limitation of the engine hardware and optimization process.

3.4. UTCI and radiation

The radiation simulation and analysis are conducted entirely in the parametric platform of Grasshopper. The model of the geometry driven by the design parameters, the site, and context as an input parameter will further be simulated using plugin Ladybug and Honeybee [27]. The Non-uniform rational basis spline (NURBS) geometry that is generated in Grasshopper firstly being penalized using a plugin called the Lunchbox. The closed brep geometry merged with the brep of the site and the context becomes a test point to spread the results points. In terms of climatology data, the component of the Ladybug Radiation Analysis is used. It is supplied by the data of the selected sky matrix obtained from the component Ladybug Export Stat. For the site radiation, the process taken is similar to the geometry surface radiation. Both use the same analysis period of the extreme hot week of the year.

Besides the arrangement of radiation analysis, the UTCI parametric definition and analysis uses the component of the Outdoor Solar Temperature Adjustor that calculates data input of sky matrix, radiation diffuse, base temperature, horizontal infrared radiation, and analysis period. After the data calculated in the Outdoor Solar Temperature Adjustor, UTCI is computed in the component of the Outdoor Comfort Calculator with the wind speed, mean radiant temperature, and relative humidity as additional input data. Fig. 3 illustrates the building model and simulation workflow in which situated in the middle of the site and being iterated and simulated simultaneously to obtain the site and surface radiation results and the value of UTCI during the hottest week of the year.

3.5. Optimization and benchmark model comparison

The optimization phases are conducted utilizing the plugin called Octopus. This plugin works with the parametric platform Grasshopper. It allows the solution to find a process with multiple objectives at one-time optimization running. The optimization process is based on SPEA-2 [13] and Hype algorithm [33]. The feature uses the default setting, which is elitism 0.00, Mutation probability 0.1, Mutation rate 0.1, cross-rate 0.8, population size 100, and maximal generation 100. After the alternative solutions being spread on the Octopus population field, the desired solution will be selected with a reinstate solution. Furthermore, the solution will be simulated according to the fare for electricity and be compared to the performance of the benchmark model. The benchmark model is the virtual typical two-story house box with the dimension of 5 meters long, 4 meters wide, and 8 meters height. The model facing north, south axis and it is fixed and has no dynamic parameters.

4. Results

The results are organized according to the sequences that previously explained. First, the general findings of the optimization process from the Octopus will be described. Second, the findings and analysis of the benchmark model and the two preferred solutions will be explained. Third, performance-related energy consumption is described, and the last, the results of each model performance will be generally compared.

4.1. Genetic Algorithm optimization processes

The optimization processes were conducted in Octopus incorporating the dynamic design variable as a genome and the results of the site and surface radiation, UTCI, volume's gap and area's gap, as the Octopus's phenotype. The simulation was run with a maximum of 100 populations with no maximum generation. The simulation tends to minimize all the phenotypes entered into the engine and will be spread in a 3D population field. In Figure 4, the elite of the spread individual, indicates the distribution of the explored design solution in which each design solution containing the information of the calculated analysis results (phenotype). The population field has five axes, which are the average surface radiation (X-axis), average site radiation (Y-axis), average UTCI (Z-axis), volume's gap (color axis), and the Surface area's gap (Scale axis). The scale of each axis is provided according to the minimum and maximum results of each phenotype. The three X, Y, Z-axis measured according to the value that goes along the axis. For the color axis, gradual color from red to green represents the value of the volume gap. Red color represents a more significant gap, and the green represents the opposite, while brown represents the gap in between. For the scale axis, the small area gap presented in bigger mesh size and smaller surface area's gap presented in small mesh size.

The targeted solution is in the minimum X, Y, Z-axis, with small mesh scale and in green color. The two desired solution is highlighted in the yellow circle (Fig. 4). The solutions selected are categorized in the minimum UTCI model and minimum surface radiation model. The minimum UTCI model is located in the minimum axis of Z and X, and the minimum surface radiation model is located in the minimum axis of Y. Accordingly, based on the distri-

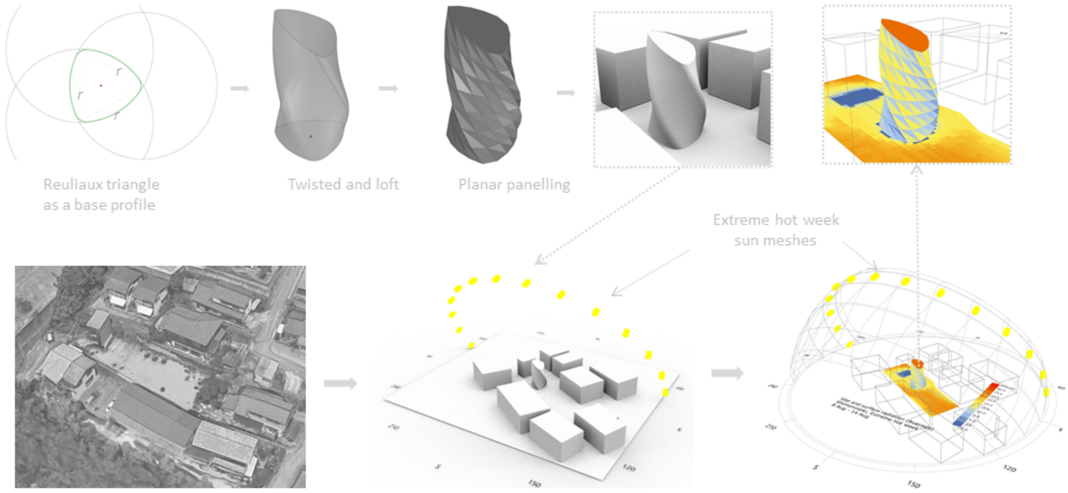


Fig. 3. The site and context, modeling, and analysis.

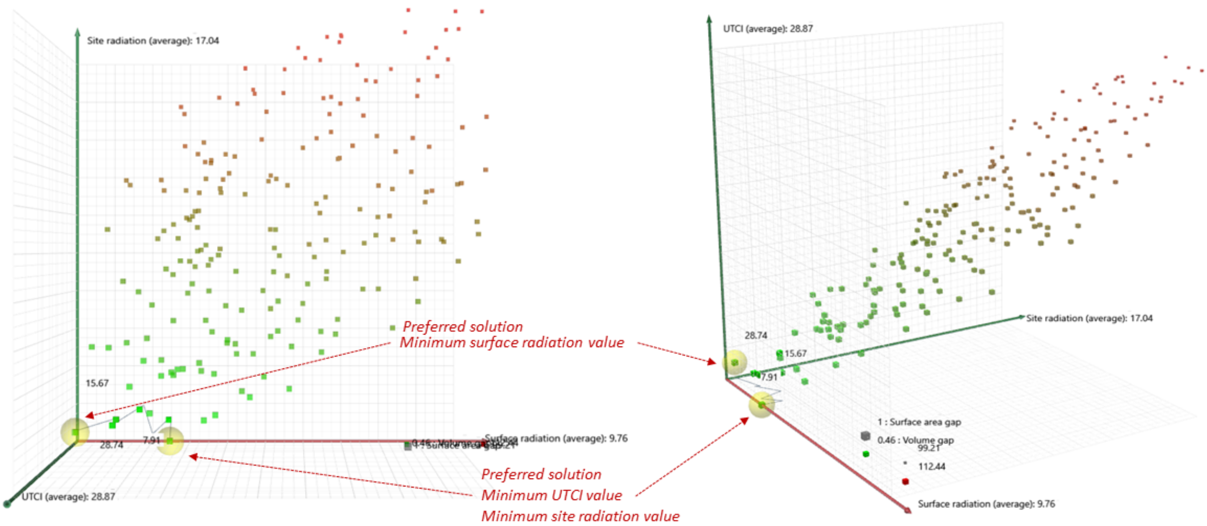


Fig. 4. 3D population field of the optimization result, top and perspective view.

bution in the population field, the targeted model for the minimum site radiation is the same as the minimum UTCI model. Hence, there are only two desired solutions will be reinstated and compared with the benchmark model's performance. Each value will further be investigated through reinstating solution process from a single simulation.

4.2. Benchmark model

The single simulation for the benchmark model has been carried out using the extreme hot week analysis period from the EPW file data of Shimonoseki. It is simulated without incorporating genetic algorithm processes and incorporated fixed parameters. The results show that the 8 meters experimented box performs several outcomes for the site's UTCI, site radiation and its surface radiation. The outcomes of average UTCI stated 28.74 °C on average. In the other analysis, the benchmark model resulted value of the average site radiation of 15.706 kWh/m^2 and the surface radiation of 9.008 kWh/m^2.

Fig. 5 shows the results visualization of each targeted results for the benchmark model. From the result's legend in the site, both UTCI and site radiation analysis recorded almost equal data dominated by a high range of temperature and radiation. In UTCI result, the site is almost covered with the average temperature of about 29.2 °C to 29.6 °C. Small parts of the site recorded the colder temperature, affecting by the context, of 28.2 °C to 28.9 °C. For the site radiation, the site is dominated by the spots valuing 18 kWh/m^2 to 24 kWh/m^2. In the surface temperature analysis, the building stated quite prevalent distribution of 12 kWh/m^2 to 18 kWh/m^2.

4.3. Minimum UTCI model

Different from the simulation of the benchmark model, the minimum UTCI and Radiation model are the manifestations of MOO processes. The geometry produced from the form-finding process is consist of the design variables as follows: 115° rotation, 3 meters of the base's radius, 85° twisting factor, 15 units scaling factor and 0° of the roof slopes. For the performance, the minimum UTCI model results show that the outcomes of average UTCI of 28.74 °C on average. In the other analysis, this model resulted in a value of the average site radiation of 15.67 kWh/m^2 and the surface radiation of 8.36 kWh/m^2.

Fig. 6 shows the results visualization of each analysis result from the minimum UTCI model. From the result's legend in the site, both UTCI and site radiation analysis recorded almost equal data dominated by a high range of temperature and radiation. In UTCI result, the site is almost covered with the average temperature of about 29.2 °C to 29.6 °C. Small parts of the site recorded the colder temperature, affecting by the geometry, of 28.4 °C to 28.5 °C. For the site radiation, the site is dominated by the spots with radiation of 18 kWh/m^2 to 24 kWh/m^2. For the surface temperature analysis, the surface building distributed value of 9 kWh/m^2 to 18 kWh/m^2 and a small area under 9 kWh/m^2.

4.4. Minimum surface radiation model

For the minimum surface radiation model, the geometry produced from the form-finding process consists of the design variables as follows: 70° rotation, 2.9 meters of the base's radius, 5° twisting factor, 25 units scaling factor and 25° of the roof slopes. For the performance, the minimum radiation model results show that the outcomes of average UTCI of 28.74 °C on average. In the other analysis, this model results in the average site radiation of 15.71 kWh/m^2 and the surface radiation of 7.91 kWh/m^2.

Fig. 7 shows the results visualization of each analysis result from the minimum radiation model. From the result's legend in the site, both UTCI and site radiation analysis recorded almost equal data dominated by a high range of temperature and radiation. In UTCI result, the site is majorly covered with the average temperature ranged 29.2 °C to 29.6 °C. Small areas of the site resulted in colder temperature, affecting by the geometry, of 28.2 °C to 28.5 °C. For the site radiation, the site is dominated by the spots with the value of 18 kWh/m^2 to 24 kWh/m^2 and a small area under 18 kWh/m^2. For the surface temperature analysis, the surface building distributed majorly value of 9 kWh/m^2 to 18 kWh/m^2.

4.5. Energy consumption

The simple calculation has been conducted parametrically on grasshopper platform using the components Honeybee export to OpenStudio regarding energy simulation. The simulation resulted in the outdoor and indoor surface temperature that furthermore will be multiplied by the fare per-kWh of the electricity. The simulation calculates the per-month bill for the input geometry that's being converted into Honeybee Zones. The period is taken for this calculation in a whole year from the EPW file of Shimonoseki.

The first simulation was conducted to the benchmark model. The results produced are the six months of normalized cooling and heating electric energy for the building. The graphic both for cooling and heating are fluctuating along the year. Fig. 8 illustrates the monthly utility cost, which is the bill of the cooling and heating spent on the electricity of the benchmark model. In May, the bill for cooling is ¥ 8.47, and it is going up to ¥ 39.54 in the next month. The peak is in August with the expense for electricity reach ¥ 178.16. The bill drops more than half in September and set the lowest amount after the peak of ¥ 10.89 in October. For the heating needs, January is the peak that set for ¥ 176.50, and it slightly goes down in February to about ¥ 151.94. The following two months the bill is set for ¥ 90.60 and ¥ 26.23. In May and October, the bill is a sphere between heating and cooling needs.

Fig. 9 illustrates the monthly utility cost for the minimum surface radiation model. The cooling electricity bill appears in April with the cost of ¥ 0.21. In May, the cost increases to about ¥ 8.4, and there is a significant increase for ¥ 110 to reach ¥ 150.49. In August, the cost is reaching

Design variables

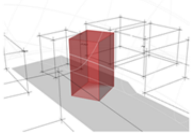
Rotation: -

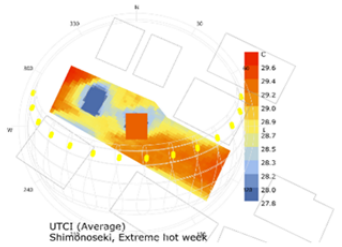
Base radius: -

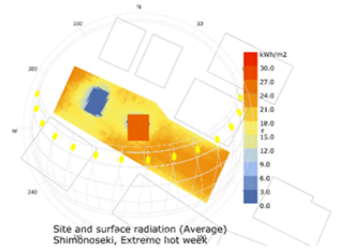
Twist: -

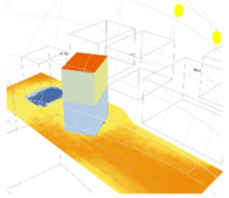
Scale: -

Roof slope: -









*UTCI (average): **28.74° C***

*Site radiation (average): **15.706 kWh/m²***

*Building surface radiation (average): **9.008 kWh/m²***

Fig. 5. Analysis results for benchmark model.

Design variables

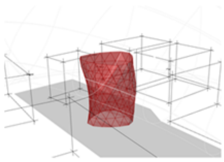
Rotation: 115

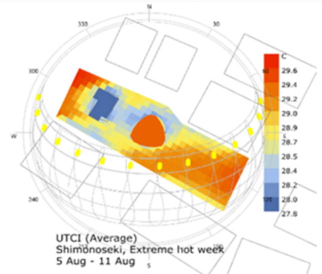
Base radius: 3

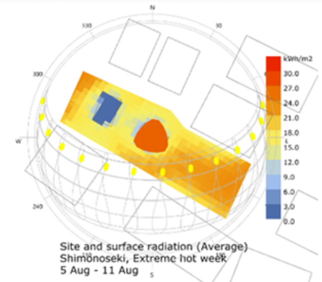
Twist: 85

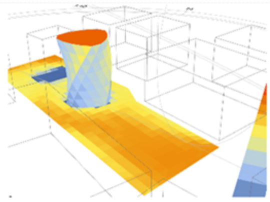
Scale: 15

Roof slope: 0









*UTCI (average): **28.74° C***

*Site radiation (average): **15.67 kWh/m²***

*Building surface radiation (average): **8.36 kWh/m²***

Fig. 6. Analysis results from minimum UTCI model.

Design variables

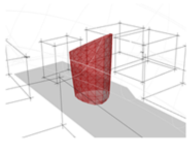
Rotation: 70

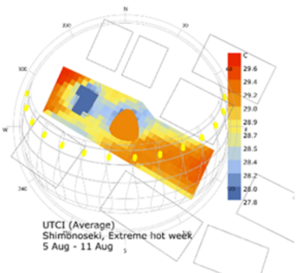
Base radius: 2.9

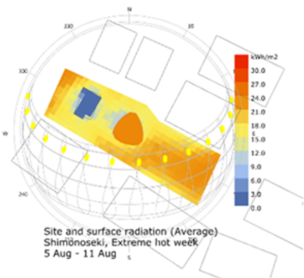
Twist: 5

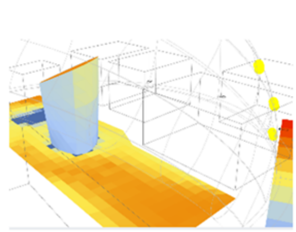
Scale: 25

Roof slope: 25









*UTCI (average): **28.74° C***

*Site radiation (average): **15.71 kWh/m²***

*Building surface radiation (average): **7.91 kWh/m²***

Fig. 7. Analysis results for minimum radiation model.

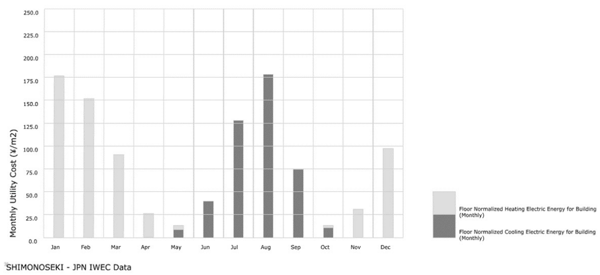


Fig. 8. Monthly utility costs for minimum benchmark model.

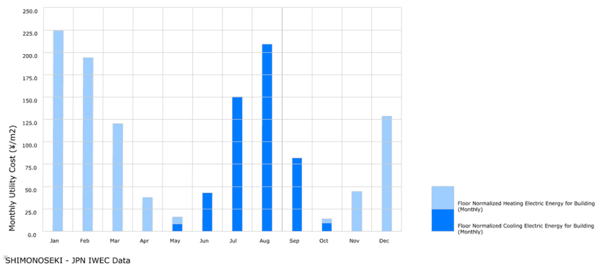


Fig. 9. Monthly utility costs for minimum surface radiation model.

a peak with a value of ¥ 209.16. After reaching the peak, for the following month (September), the cost is drastically decreasing to the value of ¥ 81.9. Moreover, the last month to cover the electricity bill for cooling is in October with ¥ 9.4. For the heating electricity bill. January, February, and December stated the three highest costs for cooling within one year. The cost of three respective months is ¥ 224.33, ¥ 193.8 and ¥ 128.82. The lowest electricity bill for cooling is recorded in two months of July (¥ 0.095) and October (¥ 4.50).

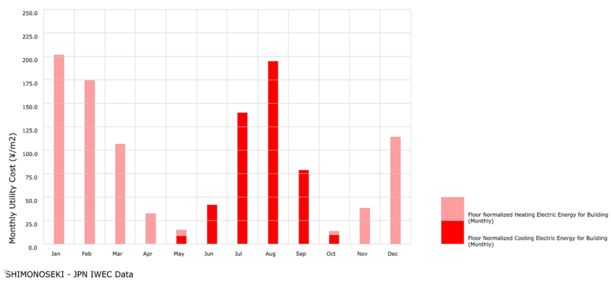


Fig. 10. Monthly utility costs for minimum UTCI model.

For the next electricity expense calculation, model the OpenStudio calculation is based on the selected model that considered to have minimum average UTCI among the distributed solution. The cost for the electricity of cooling and heating needs are fluctuating along the year. Fig. 10 shows the cost of the utility bill of the minimum UTCI model. The cooling cost in started to appear in April sharing the portion with heating load cost ¥ 0.23. In the following months, the cost is increased by ¥ 8.82 in May, ¥ 41.94 in June, ¥ 139.98 in July and it is reaching the peak in August with the cost of ¥ 194.96. The cost is gradually decreasing for September and October with ¥ 79 and ¥ 9.89 respectively. For the heating cost, January, February and December stated the highest cost within one year (¥ 201.73, ¥ 174.23 and ¥ 114.34). From March to June, the cost is gradually decreasing from ¥ 106.53 to ¥ 0.07.

5. Discussion

From a series of parametric and optimization process, the results show several tendencies and exciting findings. The two selected solutions produced by the genetic algorithm optimization tend to perform better performance related to the designated objectives with an insignificant difference. This considered as a lack of not enough iteration process and observation. However, from the comparison of each model that is simulated with a single simulation on the hottest day on August 8 at 14.00 JST, the findings confirm the hypothesis of the improvisation through parametric and generative optimization in several aspects such as minimum surface and the site radiation and the UTCI. Besides, there is an interesting finding indicate that better performance in radiation and UTCI analysis is not equally a better expense related to the electricity cost for heating and cooling. Each phenomenon will be described in the following explanation.

Fig. 11 illustrates the performance of each model's designated target performance simulated, which are the UTCI, Site and surface radiation of the benchmark model, minimum UTCI model and the minimum surface radiation model in the hottest day of August 8, at 14:00 JST. From the calculation of UTCI, the targeted performance does not set the desired gap in temperature. The average value of 28.74 °C (in the extreme hot week) is stated in all the models. In a single simulation, the performance almost shares a fluctuate calculation. The better UTCI of the two models only performs better after 13:00 with insignificant different from 33.84 °C to 33.77 °C. In the site radiation, similar to the UTCI, better radiation appears after 13:00 and continue in between 16:00 to 18:00 again with insignificant different from 0.62 kWh/m^2 to 0.61 kWh/m^2. In terms of building surface radiation, better calculation stated better performance from 11:00 to 20:00 with slightly significant amount compared to the other two objectives with the improvement of 0.2 kWh/m^2 to 0.18 kWh/m^2.

In terms of energy consumption, the improvement of

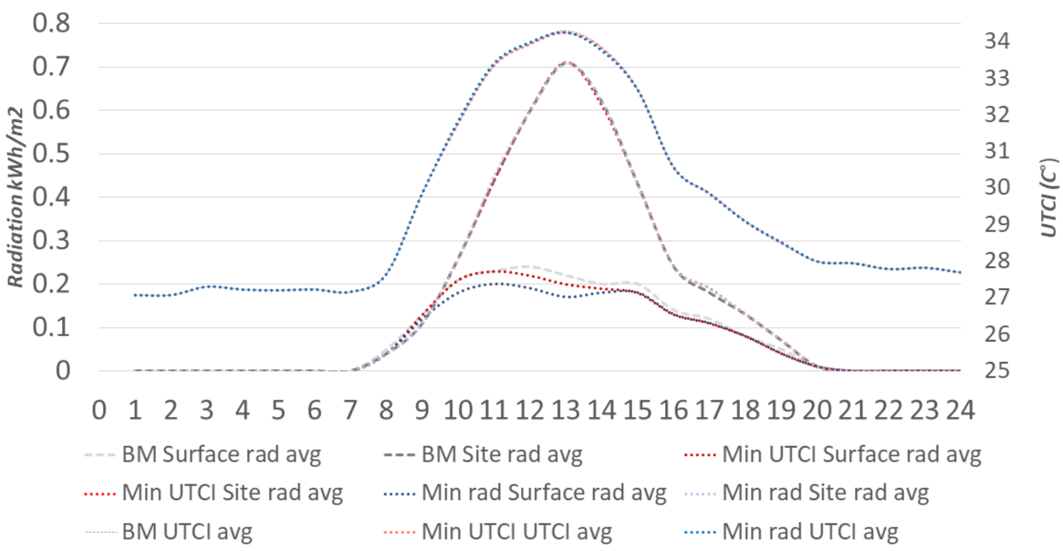


Fig. 11. Monthly utility costs for minimum UTCI model, Aug 8.

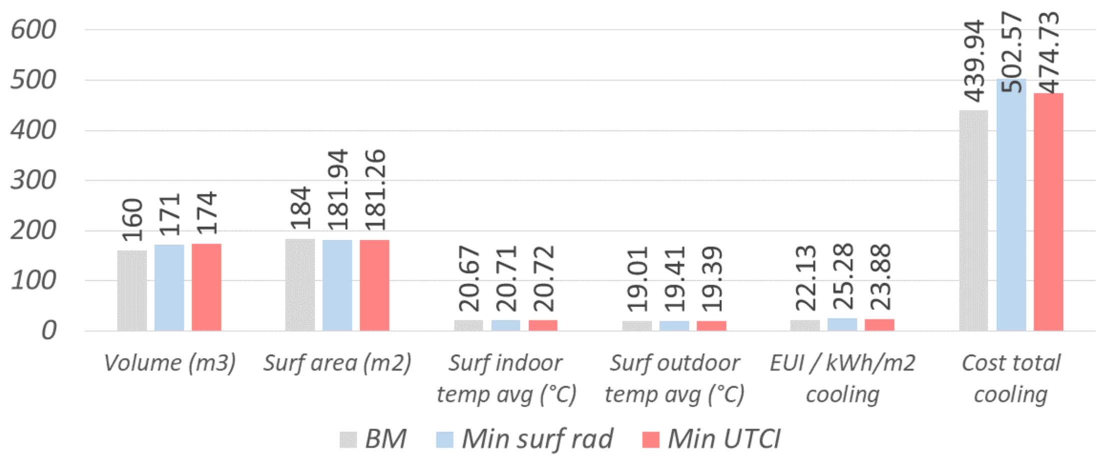


Fig. 12. Trend in energy consumption of cooling for each model.

radiation and UTCI does not follow by the decrease of utility bill within one year. The two selected model from the optimization process set more expensive cost compared to the benchmark model. The estimation gap between the benchmark model electricity cost in August (the peak) is ¥ 31 with the minimum radiation model and about ¥ 16 with the minimum UTCI model. It is indicated that the minimum surface radiation and the area did not guarantee a lower electricity bill for the cooling needs. In general, the tendency and trade-offs of the dynamic design parameters with the targeted design performance are not visible. First is because of the lack of generation number in the iteration process, and second is because it is Multi-Objective Optimization deploying multiple parameters (genotype) and objectives (phenotype). Fig. 12 illustrates the calculation in OpenStudio simulation. From the data presented in the chart, interestingly, the cost is depending on the EUI, yet it has no relation to the volume and the surface area. The finding contradicts the assumption that the area of the building surface and the volume of the building would affect energy consumption and its cost.

6. Conclusion and further works

This paper describes the parametric and Multi-Objective Optimization approach in investigating the building form toward the outdoor thermal comfort in Orio district, Kitakyushu city, Japan. Comprehensive parametric calculation of the dynamic parameters-driven geometry design, environmental analysis for UTCI, and radiation had been conducted parametrically. The arrangement of parametric operation produces two selected design solutions that match the preferences. The results show minor improvement in the three designated design objectives, which is confirming the hypothesis. However, the opposite results appear in the annual utility bill for cooling and heating needs within one year. In general, the research guides the design consideration related to the variables to build the geometry of the house according to the targeted goals using the site's weather data.

The research is limited to the relation between geometry and its impact on the radiation and UTCI. The simulation does not include the properties of the material for the site and the building. The iteration in genetic algorithm optimization is still considered lacking due to the hardware and optimization setting's limitation. Thus, it needs more investigation in validating the information provided above. Despite the limitation mentioned above, the simulation has successfully come up with a design solution that performs better than the benchmark model. It opens the possibility of sharpening the improvement by addressing the shortcomings. Further works are encouraged to set more generations in the optimization process to get better validation and observation.

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References

[1] Rivka Oxman. Thinking difference: Theories and models of parametric design thinking. *Design Studies*, 52:4–39, 2017.

[2] Jingyu Zhang, Nianxiong Liu, and Shanshan Wang. A parametric approach for performance optimization of residential building design in Beijing. *Building Simulation*, 13(2):223–235, apr 2020.

[3] Riccardo Talami and J Alstan Jakubiec. Early-design sensitivity of radiant cooled office buildings in the tropics for building performance. *Energy and Buildings*, 223, 2020.

[4] Shady Attia, Jan L.M. Hensen, Liliana Beltrán, and André De Herde. Selection criteria for building performance simulation tools: Contrasting architects' and engineers' needs, 2012.

[5] Dana Mohammad Ahmad Hamdan and Fabiano Lemes de Oliveira. The impact of urban design elements on microclimate in hot arid climatic conditions: Al Ain City, UAE. *Energy and Buildings*, 200:86–103, 2019.

[6] Roberta Cocci Grifoni, Simone Tascini, Ernesto Cesario, and Graziano Enzo Marchesani. Cool façade optimization: A new parametric methodology for the urban heat island phenomenon (UHI). In *Conference Proceedings - 2017 17th IEEE International Conference on Environment and Electrical Engineering and 2017 1st IEEE Industrial and Commercial Power Systems Europe, EEEIC / I and CPS Europe 2017*, 2017.

[7] Atsuko Tani. Interdisciplinary Discussions on Sustainable Use of Wood Structure and Fire Risk - Situation in Japan and Austria. In *Proceedings of the enviBUILD 2019*, pages 202–207. 2020.

[8] Beta Paramita, Hiroatsu Fukuda, Rendy Perdana Khidmat, and Andreas Matzarakis. Building configuration of low-cost apartments in Bandung-its contribution to the microclimate and outdoor thermal comfort. *Buildings*, 8(9), 2018.

[9] Ladybug EPW Map.

[10] Andrea Zani, Michele Andaloro, Luca Deblasio, Pierpaolo Ruttico, and Andrea G. Mainini. Computational Design and Parametric Optimization Approach with Genetic Algorithms of an Innovative Concrete Shading

Device System. In *Procedia Engineering*, volume 180, pages 1473–1483, 2017.

[11] Rendy Perdana Khidmat, M. Shoful Ulum, and A. Dwi Eva Lestari. Facade Components Optimization of Naturally Ventilated Building in Tropical Climates through Generative Processes. Case study: Sumatera Institute of Technology (ITERA), Lampung, Indonesia. In *IOP Conference Series: Earth and Environmental Science*, volume 537. Institute of Physics Publishing, aug 2020.

[12] P. Janssen and J. Frazer. Generative Evolutionary Design : a Framework for Generating and Evolving Three-Dimensional Building Models. 2005.

[13] Sunisa Sansri and Somlak Wannarumon Kielarova. Multi-objective shape optimization in generative design: Art deco double clip brooch jewelry design. In *Lecture Notes in Electrical Engineering*, volume 449, pages 248–255. Springer Verlag, 2017.

[14] Jonathan Natanian, Or Aleksandrowicz, and Thomas Auer. A parametric approach to optimizing urban form, energy balance and environmental quality: The case of Mediterranean districts. *Applied Energy*, 254, 2019.

[15] Emanuele Naboni, Jonathan Natanian, Giambattista Brizzi, Pietro Florio, Ata Chokhachian, Theodoros Galanos, and P. Rastogi. A digital workflow to quantify regenerative urban design in the context of a changing climate. *Renewable and Sustainable Energy Reviews*, 113, 2019.

[16] Jonathan Natanian, Patrick Kastner, Timur Dogan, and Thomas Auer. From energy performative to livable Mediterranean cities: An annual outdoor thermal comfort and energy balance cross-climatic typological study. *Energy and Buildings*, 224, 2020.

[17] Jonathan Natanian and Thomas Auer. Beyond nearly zero energy urban design: A holistic microclimatic energy and environmental quality evaluation workflow. *Sustainable Cities and Society*, 56, 2020.

[18] Ibrahim Elwy, Yasser Ibrahim, Mohammad Fahmy, and Mohamed Mahdy. Outdoor microclimatic validation for hybrid simulation workflow in hot arid climates against ENVI-met and field measurements. In *Energy Procedia*, volume 153, pages 29–34, 2018.

[19] Jonathan Graham, Umberto Berardi, Geoffrey Turnbull, and Robert McKaye. Microclimate analysis as a design driver of architecture, 2020.

[20] N. Delgarm, B. Sajadi, F. Kowsary, and S. Delgarm. Multi-objective optimization of the building energy performance: A simulation-based approach by means of particle swarm optimization (PSO). *Applied Energy*, 170:293–303, may 2016.

[21] Rahman Azari, Samira Garshasbi, Pegah Amini, Hazem Rashed-Ali, and Yousef Mohammadi. Multi-objective optimization of building envelope design for life cycle environmental performance. *Energy and Buildings*, 126:524–534, 2016.

[22] Farshid Shadram, Shimantika Bhattacharjee, Sofia Lidelöw, Jani Mukkavaara, and Thomas Olofsson. Exploring the trade-off in life cycle energy of building retrofit through optimization. *Applied Energy*, 269, 2020.

[23] Kavan Javanroodi, Vahid M. Nik, and Mohammadjavad Mahdavinejad. A novel design-based optimization framework for enhancing the energy efficiency of high-rise office buildings in urban areas. *Sustainable Cities and Society*, 49:101597, aug 2019.

[24] Patricia E. Camporeale and Pilar Mercader-Moyano. Towards nearly Zero Energy Buildings: Shape optimization of typical housing typologies in Ibero-American temperate climate cities from a holistic perspective. *Solar Energy*, 193:738–765, nov 2019.

[25] Rhino - Rhinoceros 3D.

[26] Scott Davidson. Grasshopper Algorithmic Modeling for Rhino, 2015.

[27] Mostapha Sadeghipour Roudsari and Michelle Pak. Ladybug: A parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design. In *Proceedings of BS 2013: 13th Conference of the International Building Performance Simulation Association*, pages 3128–3135, 2013.

[28] Jonathan Natanian, Or Aleksandrowicz, and Thomas Auer. A parametric approach to optimizing urban form, energy balance and environmental quality: The case of Mediterranean districts. *Applied Energy*, 254, 2019.

[29] Jonathan Natanian and Thomas Auer. Balancing urban density, energy performance and environmental quality in the Mediterranean: A typological evaluation based on photovoltaic potential. In *Energy Procedia*, volume 152, pages 1103–1108, 2018.

[30] Eleftheria Touloupaki and Theodoros Theodosiou. Optimization of Building form to Minimize Energy Consumption through Parametric Modelling. *Procedia Environmental Sciences*, 38:509–514, 2017.

[31] Ahmed Toutou, Mohamed Fikry, and Waleed Mohamed. The parametric based optimization framework daylighting and energy performance in residential buildings in hot arid zone. *Alexandria Engineering Journal*, 57(4):3595–3608, 2018.

[32] Giuseppe Conti and Raffaella Paoletti. Reuleaux Triangle in Architecture and Applications. In *Lecture Notes in Networks and Systems*, volume 88, pages 79–89. Springer, 2020.

[33] Francesco Demarco, Francesca Bertacchini, Carmelo

Scuro, Eleonora Bilotta, and Pietro Pantano. The development and application of an optimization tool in industrial design. *International Journal on Interactive Design and Manufacturing*, 14(3):955–970, sep 2020.