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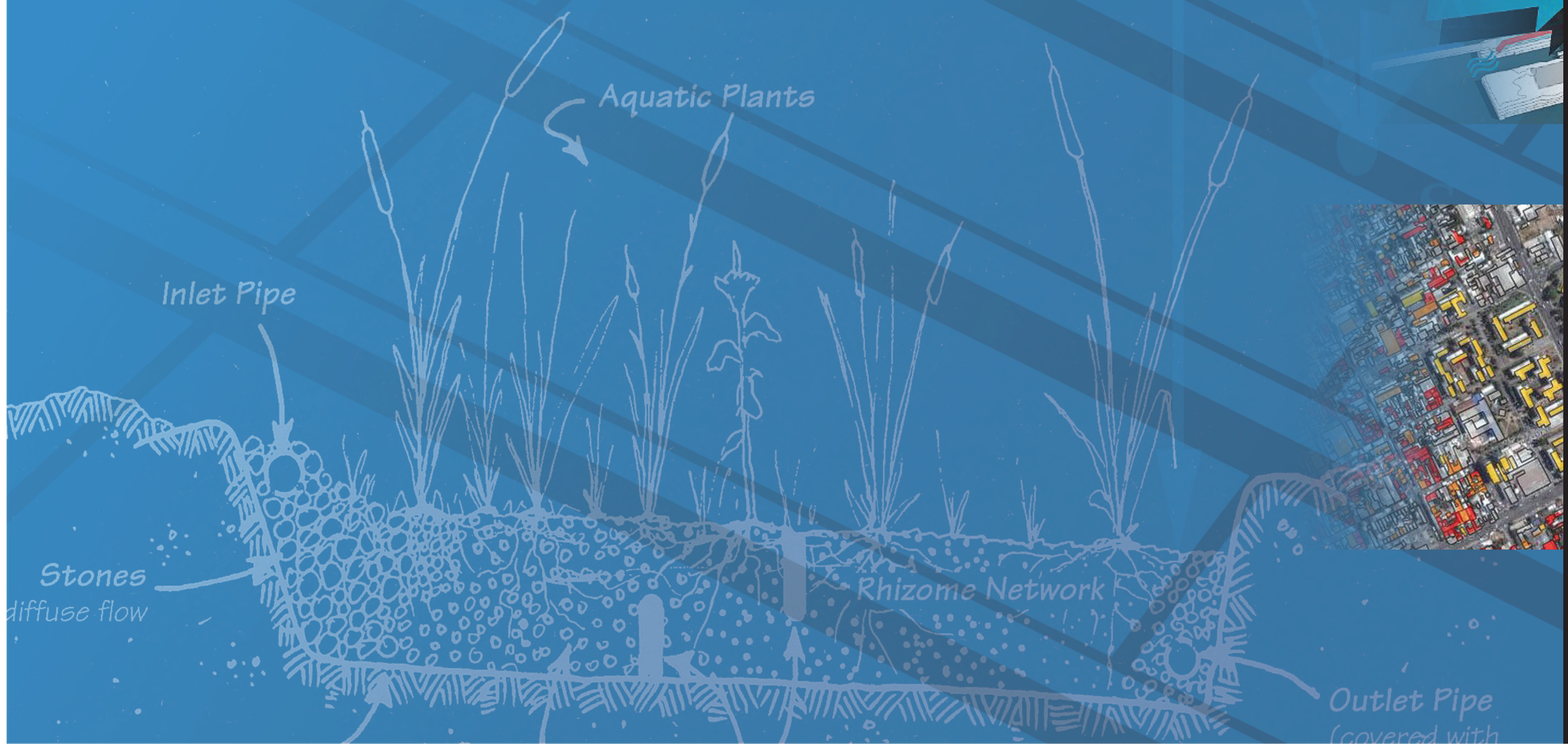

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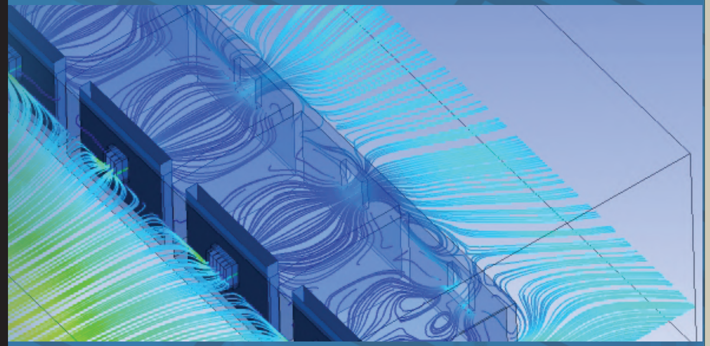

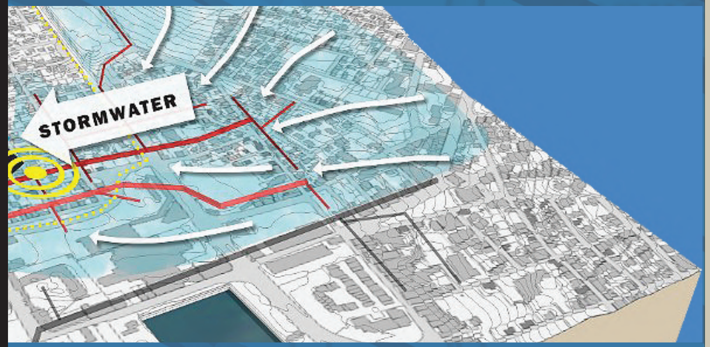

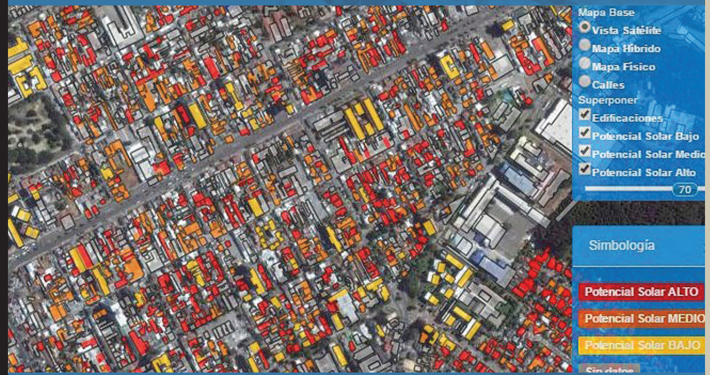

I

RESEARCH ARTICLES

ADAPTIVE BUILDING AND SKIN: AN INNOVATIVE COMPUTATIONAL WORKFLOW TO DESIGN ENERGY EFFICIENT BUILDINGS IN DIFFERENT CLIMATE ZONES

Monica Rossi-Schwarzenbeck[1] and Angelo Figliola[2]

ABSTRACT

This research aims at developing an innovative methodology and the related computational workflow to design energy efficient buildings equipped with climate responsive building skins able to respond dynamically to environmental conditions changing over the time. This methodology, called Adaptive Building and Skin (AB&S), is applicable in different climate zones and consists of a computational form-finding method, which supports architects and engineers in the buildings' design process resulting in buildings with optimized energy performance and a high level of indoor and outdoor comfort under changing environmental conditions. The innovativeness of AB&S lies in the fact that it includes the entire design process and considers several internal and external inputs to find the best solutions at all scales of a project: starting from the micro urban-scale with the design of the site and of the building shape, down to the building-scale and finally the skin-scale.

Applicability and functionality of AB&S has been tested and improved in the design of office buildings located in specific cities located in different climate zones (cold, temperate, tropical and subtropical). Results of the application in Berlin, Germany, are presented in detail in this paper.

KEYWORDS

adaptive building and skin, performance-based form-finding, data-driven approach, parametric design, indoor and outdoor comfort, different climate zones.

1. CLIMATE-ADAPTIVE BUILDINGS: STATE OF THE ART AND INTENT OF THE RESEARCH

The development of highly energy-efficient buildings, able to dynamically respond to the change of external climate conditions in order to minimize the energy demand for heating and cooling and to achieve a high level of comfort has already been a very popular research topic over the last decades but is nevertheless very current. The energy efficiency of a building is the result of a series of "design choices" at different scales such as orientation, position and geometric shape of the building, window-to-wall-ratio and building skin characteristics.

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Because the performance of the building skin plays a particularly important role in this context [1], several recent research works take into account only this part of the building with the intent to develop a climate-adaptive building skin. This approach aims at having *"the ability to repeatedly and reversibly change some of its functions, features or behaviour over time in response to changing performance requirements and variable boundary conditions and does this with the aim of improving overall building performance"* [2]. The adaptability of building skins can be realized pursuing two different strategies. The first one refers to "kinetic envelopes" [3], which implies that the building skin can change its configuration via moving parts (solar shading, moving panels, lamellae etc.). In the second case the adaptability is realized via changes in thermo-physical or optical properties of building components and materials (shape-memory or temperature-responsive polymers, phase changing materials PCM, photo-chromatic glasses etc.). In this case, the building skin does not have a changing form, but is characterized by an optimized (for a specific climate zone) geometry able to maximize the dynamic properties of the used materials and components.

High-performance building skins cannot be designed separately from an appropriate and holistic design of the building at all design scales: micro-urban, building and skin.

At the micro-urban scale, parameters that have great influence on the energy demand for cooling and heating are for example building form, orientation towards the cardinal points, positioning on the lot and/or relationship with other buildings and/or with green outdoor spaces. These parameters influence the level of inhabitants' outdoor comfort and consequently can be used to create well-tempered outdoor common spaces and to mitigate the urban heat island effect. These research topics are investigated in academia usually at the neighborhood/urban scale or sporadically in the design of building complexes [4] [5]. Specific software used for the outdoor comfort analysis (e.g. EnviMET, TownScope or Urbanwind) are not able to investigate and optimize the energy performance of the buildings and of the building skin components.

Choices at the building scale have also strong influence on the level of energy performance of buildings. In particular, the window-to-wall ratio and the orientation of the windows towards the cardinal points affect the thermal solar gains and the thermal dispersion. To verify energy performance at the building scale, Computational Fluid Dynamics software (like Energy+, Design Builder, TRNSYS and IDA) are appropriate tools. However, most designers check only the parameters for the mandatory energy certification (e.g. EnEV in Germany or APE in Italy), without evaluating dynamic parameters or the level of thermal comfort. The design of important elements like size and orientation of windows is frequently based on esthetical rather than functional criteria.

At the skin scale, the most important elements are skin geometry and materials. The skin geometry can optimize the energy flow between outside and inside (and vice versa) and consequently improve the level of inhabitants' comfort indoor. The design of this (changing or optimized) geometry is usually supported by computational design tools (e.g. Grasshopper combined with different appropriate plug-ins) in order to find the perfect form able to meet a predefined performance [6] [7]. This topic usually characterizes the academic works or some applications in specific experimental buildings. The use of (innovative or traditional) materials—able to adapt their energy performance under changing environmental boundary conditions by means of phase change, thermal mass activation, etc.—can reduce the energy demand for heating and for cooling of a building. Research in this field, oriented at commercializing a specific material or component, is often conducted by the chemical or building industry and does not consider the whole building [8] [9].

The above-mentioned three design scales, despite their strong influence on each other, are usually considered separately and often by different research/design organizations that do not communicate with each other.

Another growing research area is the so-called "data-driven design." The possibility to access an almost unlimited quantity of data, the growing ability to refine the data to extract information useful for problem-solving processes inevitably change design processes. The use of data becomes the "fuel" to feed the creative process and increase the quality of the choices made by decision makers [10]. The application of this strategy in architectural practice is favored by use of generative and parametric design techniques in which qualitative and quantitative data are the pillars of multi-criteria optimizations. As well represented in MacLeamy's curve: the "information of the design process" in its early stage allows maximizing the impact of design choices in terms of performance and decreased costs related to their application [11] [12]. Performance-based designed architectures have led to the development of numerous researches [13] [14] mainly focused on the exploration of the relationship between form and energy performance, in relation to different climate zones.

Based on the above-mentioned research works and examples of best practice design processes, this work aims to develop an innovative design methodology based on a data-driven approach to design energy efficient buildings able to integrate appropriate site organization, an energy saving building form, climate adaptive building skins, reacting materials and a high level of environmental comfort indoor and outdoor.

2. ADAPTIVE BUILDING & SKIN (AB&S): AN INNOVATIVE METHODOLOGY AND THE RELATED COMPUTATIONAL WORKFLOW TO DESIGN ENERGY EFFICIENT BUILDINGS

Several medium sized and big design studios, attentive to the problems of energy efficiency and environmental comfort, have developed over time design workflows able to manage complex processes with software interoperability methods. Often small studios or students do not have the staff, the ability or the budget to manage complex processes with many different software (e.g. one for the urban scale, one for the building scale and one for the skin scale).

For this reason, one single design methodology, called *adaptive Building & Skin* (AB&S), was developed in this work. AB&S aims at systemizing the methods (already used in the buildings' design sector) in a computational workflow (tool) that starts from the micro-urban scale and arrives at the level of systems and components creating a strong synergy between the various design phases and actors

The goals of AB&S are:

- To support architects, engineers and students in the design of energy-performance-oriented buildings, characterized by climate-responsive building skins. "Climate-responsive building skins" intends not only kinetic skins, but also building skins with an optimized, but fixed geometry that are realized with performance changing materials.
- To define a "path"—computational workflow—that can be "run" from the beginning (micro-urban scale) to the end (skin scale) of the design process but which can also

be used only in one part or can be "run" in the opposite direction to verify specific design choices

- To develop a performance-based form-finding instrument that is easy to use. An easy pre-defined computational workflow can very well be used by small architectural studios, which often are not able to invest time and manpower in complex computational design processes.
- To create a "common action field," through which experts of outdoor comfort, designers and manufacturers can communicate with each other.
- To generate a tool that can be used for the design of buildings located in different climate zones.

3. INSTRUMENTS AND METHODS

After an in-depth study of the state of the art of parametric building design, and several years of experience in the field of energy efficient building and building skin, a design workflow has been defined. This is developed based on real standard design processes and is organized in three steps corresponding to the above-mentioned scales. Inputs, objectives to reach and the related parameters; design choices and outputs were identified for each of the three scales. Outputs of one design scale are inputs of the next scale (Figure 1).

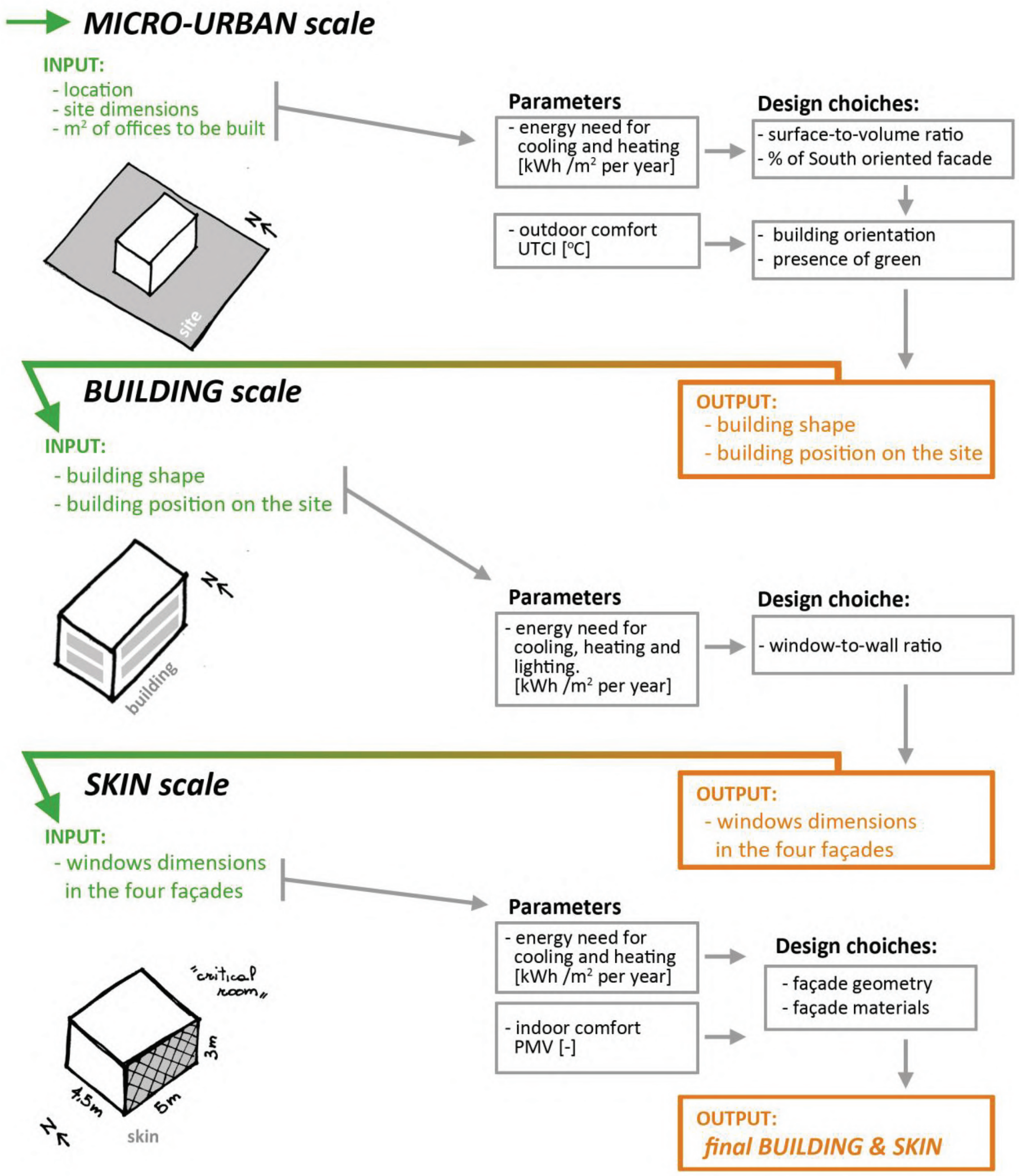
Micro-urban scale: At the micro-urban scale, inputs are the initial data that normally are known at the beginning of a design project: location (as weather data), dimensions of the site and the total floor space (in square meters) of the building that has to be built. The outputs are building shape and position of the building on the site. In this step of the design process, urban planning codes and regulations of specific cities can help in the definition of design constraints such as maximum building height, floor area ratio, and mass configuration [15].

The objectives that are to be reached are energy efficiency of the building and outdoor comfort level at the outdoor spaces on the site. The first objective, measured as energy need for heating and cooling [kWh/m^2 per year], will be achieved by acting on two design choices: surface-to-volume ratio and percentage of South-oriented façade. The second objective, measured with the UTCI, Universal Thermal Climate Index [°C], will be achieved by acting also on two design choices: position of the building on the site and presence of vegetation (green outdoor spaces, trees etc). For each design choice, a range of acceptable values, based on the literature, is defined in order to speed up the initial computing process. These ranges are different for different climate zones. The parameters that have to be optimized have a periodization (processing order): the surface-to-volume ratio and the percentage of South-oriented façade are simultaneously considered to define the building shape. Then, when the building shape is already defined, the level of outdoor comfort is used as a parameter to place the building on the site and to determine the quantity of vegetation on the site.

Building scale: Inputs at the building scale are the outputs of the micro-urban scale: building shape and position of the building on the site. The objective is the energy efficiency of the building, measured as energy need for heating, cooling and lighting [kWh/m^2 per year], that will be reached by acting on one design choice: the window-to-wall ratio in the four facades of the building. As in the previous step, ranges of values are also defined.

Skin scale: At the skin scale, a standard room is defined and tested. In this case, inputs are also the outputs of the previous scale. Objectives are energy efficiency of the building, measured as energy need for heating, cooling and lighting [kWh/m^2 per year] and indoor comfort level

FIGURE 1. Workflow schematization.



measured as PMV, Predicted Mean Vote, [-]. These objectives will be achieved by acting on two design choices: façade geometry and façade materials.

4. COMPUTATIONAL WORKFLOW: APPLICATION AND TESTS IN OFFICE BUILDINGS

This workflow was translated into a computational workflow with the support of Grasshopper and some of its plug-ins in order to obtain an instrument that can be used throughout the design process by all the involved actors (architects, engineers, building physicists and industries). Grasshopper is an open source, node-based graphical algorithm editor tightly integrated with Rhinoceros 3-D modelling tools [16] [17]. Many different possible plug-ins are available to expand or specify the skills of Grasshopper. In this work, Ladybug and Honeybee—two open source plugins for environmental performance evaluation—are used [18]. Ladybug imports standard EnergyPlus weather files (.EPW) into Grasshopper and provides a variety of 3D interactive graphics to support the decision-making process during the initial stages of design. Honeybee connects the visual programming environment of Grasshopper to validated simulation software packages, particularly EnergyPlus, Radiance, Daysim and OpenStudio for energy, comfort and daylighting simulations.

The developed tools have been tested in different cities and climate zones. In this paper the results for Berlin, Germany, are presented.

4.1 Micro-urban scale

The test began with the definition of starting data at the micro-urban scale:

- location (Berlin, Germany),
- site dimensions and surface (80 m × 60 m = 4800 m^2),
- orientation towards the cardinal points of the site (the long dimension of the site is parallel to the east-west axis)
- total floor space of offices that have to be built (about 6400 m^2).

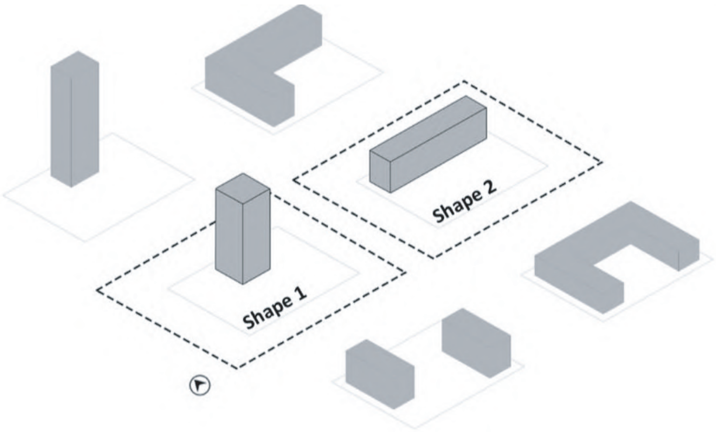
Furthermore, a height of 3.30 m had been decided on for all floors of the building and the maximization of South-facing building skin surface was defined as a priority.

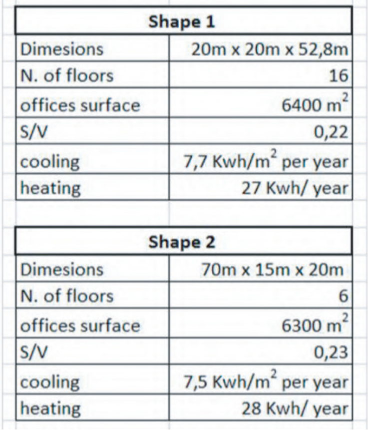
The developed typical site includes an urban context: neighboring buildings and streets. The density and the shape of the nearby buildings, the presence of green surfaces is based on the characteristics of the district Charlottenburg in Berlin. The shadow that neighboring buildings make on the analyzed site and buildings as well as the microclimatic influences of the micro-urban context are calculated in the simulations.

The first step was the generation of the building shape and orientation towards the cardinal points. Based on the above-defined requirements, Grasshopper generated different building shapes (composed of one or at most two buildings). Among these, six shapes that were compatible with an architectural form of a building were taken into account. The two shapes that had a surface-to-volume-ratio compatible with German climate zone [19], a U-value between 0.28 W/m^{2}K (standard for the reference building according to the German standard EnEv 2016) and 0.15 W/m^{2}K (required for Passivhaus standard) and with the lowest energy demand for heating and cooling were selected. Energy demand for heating and cooling were calculated with EnergyPlus for the period of one “typical year” and visualized in Grasshopper (as graphic interface) through the plug-in Honeybee. At this stage, the calculated results are very similar for the two selected shapes (Figure 2). In this phase, energy demand for heating and for cooling was calculated without windows because the definition of window size and position is the topic at the building scale. The values obtained at the micro-urban scale don´t consider direct solar thermal gains and are therefore not comparable to those of a real building, but they make sense when compared to each other in order to choose the best building-shape variant.

In order to define the best position of the building on site, the level of outdoor comfort was taken into account as a decision-making parameter. The two selected building shapes were

FIGURE 2. Some building shapes generated from Grasshopper and data of the two chosen shapes.

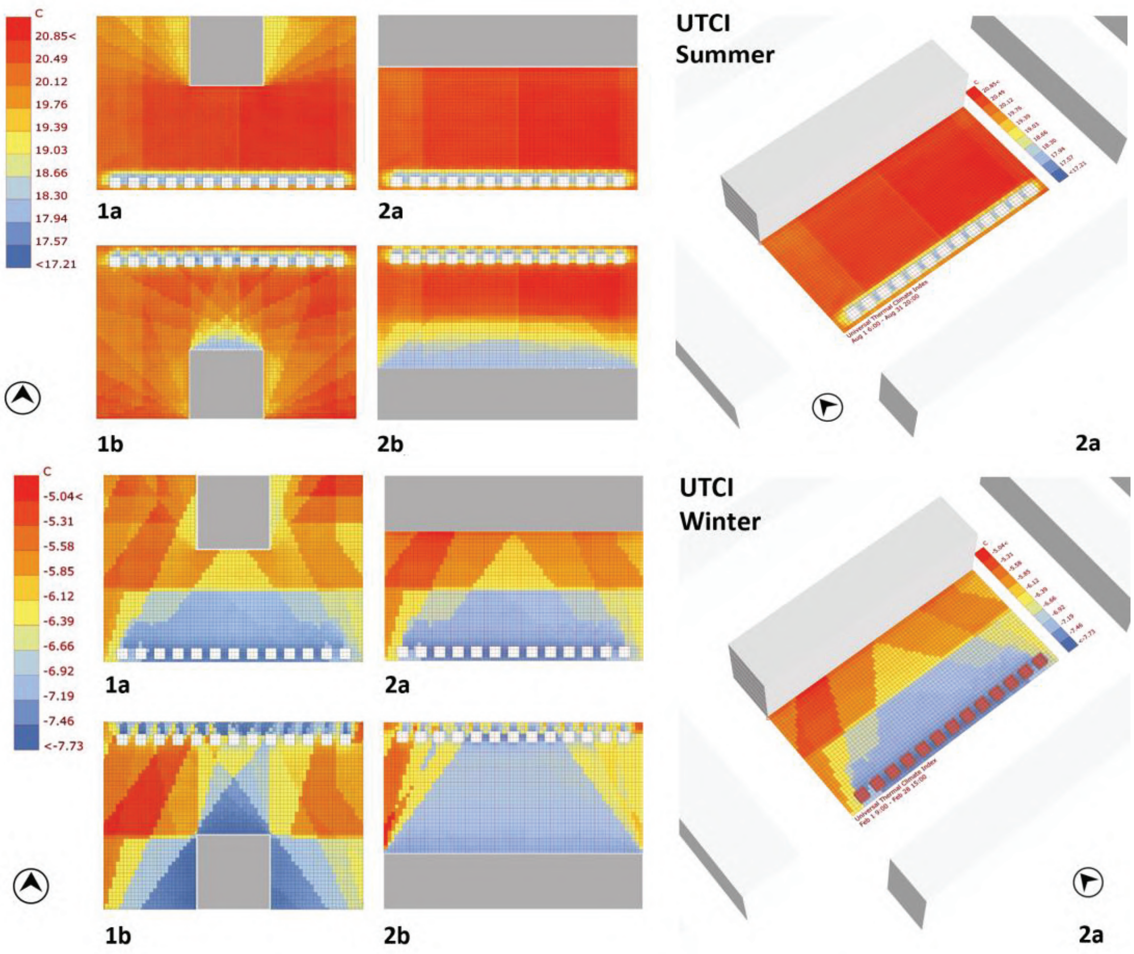




Shape 1	
Dimesions	20m x 20m x 52,8m
N. of floors	16
offices surface	6400 m^2
S/V	0,22
cooling	7,7 Kwh/m^2 per year
heating	27 Kwh/ year

Shape 2	
Dimesions	70m x 15m x 20m
N. of floors	6
offices surface	6300 m^2
S/V	0,23
cooling	7,5 Kwh/m^2 per year
heating	28 Kwh/ year

FIGURE 3. Visualisation (top view and 3D) of the UTCI-values in the four variants in summer and winter.



placed in two different positions on the site and both have been simulated to verify the outdoor comfort level.

The level of the outdoor comfort was valued, based on the UTCI that quantifies the "thermal stress defined by the combined influence of air temperature, radiation, humidity and wind on an equivalent temperature scale" [20] [21]. UTCI-values were calculated with Open Studio for two days of the year for each variant and imported through the plug-in Honeybee into grasshopper: One day in summertime (21st June—summer solstice) and one in wintertime (21st December—winter solstice), as these are the days with the lowest and the highest level of sun radiation. Climate data were generated with the Ecotect weather tool and simulations were run for a period from 6 a.m. to 4 p.m.

Results of these simulations, summarized in Figure 3, show that variant 2a achieves the best level of outdoor comfort in summer and in winter. For this reason, and since it was demonstrated that the two shapes have a similar energy demand, the building shape and the position on the site of variant 2a was chosen as output at the micro-urban scale and simultaneously as input for further consideration at the building scale.

4.2 Building scale

The objective at the building scale is the definition of window-to-wall ratio in the four facades of the building in order to minimize the energy demand for heating and cooling and, at the same time, to achieve a good level of natural lighting in the inside spaces with the consequent reduction of energy demand for lighting.

To speed up the Grasshopper form-finding process and to avoid solutions that do not make sense from an architectural/constructive point of view, literature-based ranges for the windows size were defined. As reference, the researches of the Department of ClimaDesign of the Technische Universität München [19] are used. For the North-oriented façade, the range was 20%-40% of windows, while the East- and West-oriented façade was 40%-60%, and the South-oriented façade was 50%-70%.

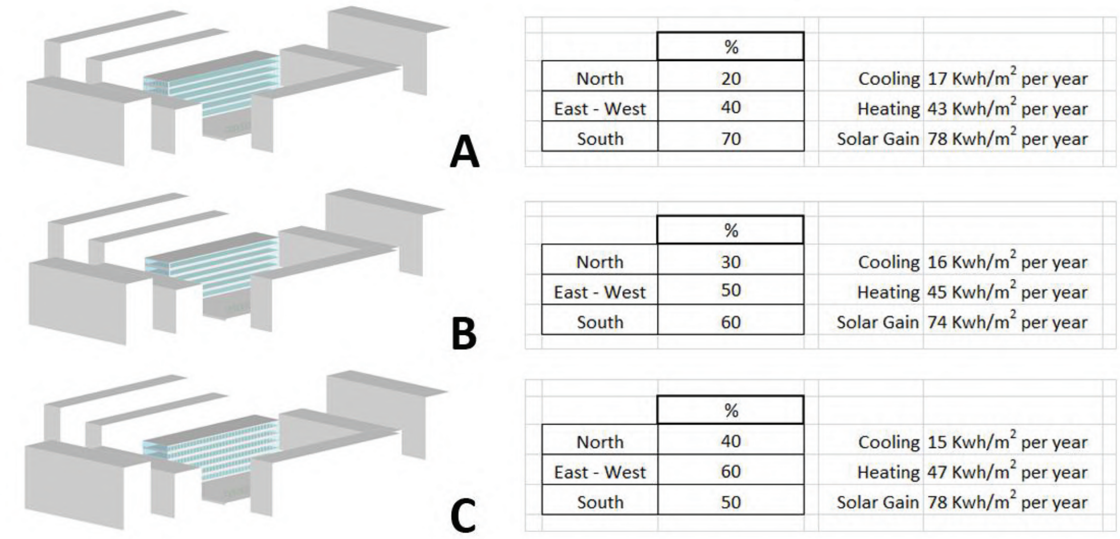
Also, at the building scale, the energy efficiency was calculated with EnergyPlus for the period of one "typical year" and visualized in Grasshopper (as the graphic interface) through the plug-in Honeybee.

Figure 4 shows 3D-views, energy demand for cooling and heating and the solar gains of the three best performing of the many calculated variants. The best solution is the one with the smallest north-oriented windows, the biggest south-oriented windows and a 50% of windows in the east and west-oriented facades. The obtained values of the energy demand are naturally higher than those calculated in the first phase of the design process (micro-urban scale, where the building was calculated without windows), but are also greater than those of a highly energy efficient building because the calculated materials used for external walls and windows didn´t have particularly high performances. In fact, the materials of the building skin and their characteristics will be defined in the next step at the skin scale and the values considered at the building scale have the only purpose of defining window-to-wall ratio in the four facades. The variant with the best performance is A, so this was taken as output at the building scale and as input at the skin scale.

4.3 Skin scale

The objective at the skin scale is to define geometry and materials of one or more energy efficient and climate-adaptive façade systems applicable in the building developed at the previous scales.

FIGURE 4. Examples of the graphic and numerical results obtained at the building scale.



	%		
North	20	Cooling	17 Kwh/m^2 per year
East - West	40	Heating	43 Kwh/m^2 per year
South	70	Solar Gain	78 Kwh/m^2 per year

	%		
North	30	Cooling	16 Kwh/m^2 per year
East - West	50	Heating	45 Kwh/m^2 per year
South	60	Solar Gain	74 Kwh/m^2 per year

	%		
North	40	Cooling	15 Kwh/m^2 per year
East - West	60	Heating	47 Kwh/m^2 per year
South	50	Solar Gain	78 Kwh/m^2 per year

To achieve this goal, a typical office room (with a floor surface of 4.5 m x 5 m and a height of 3 m) was defined/identified and used as a test room. This room is characterized by adiabatic walls, ceiling and floor and only one test wall that was modelled with different façade systems. Materials and performance of the test façades were defined in the software Therm and Window (both developed at the University of California, Berkeley) and exported as an IFD-file into Grasshopper (Figure 5). Also, in this case, each façade system was calculated in EnergyPlus in terms of energy efficiency for the period of one "typical year" and transferred to Grasshopper (as the graphic interface) through the plug-in Honeybee.

The evaluated parameters are not only the energy demand for heating, cooling and lighting, but also the level of indoor comfort, quantified as PMV. This index predicts the mean response of a larger group of people according to the ASHRAE [22] thermal sensation scale where +3 means hot, 0 neutral (comfort condition) and –3 means cold.

At first, the South-oriented façade was taken into account. Based on the results of the simulation at the building scale, this façade should have a window-to-wall ratio of 70%. The 30% of opaque external walls were considered to have a U-value of 0.24 W/m^{2}K (compatible with the current minimum requirements according to the German standard EnEv 2016). For the 70% of windows, highly energy efficient and / or innovative components and materials that are able to change their performance (corresponding to changing external weather conditions) were tested. Components and systems able to change their geometry (kinetic elements) are not taken into account in this phase of the work, but the developed computational workflow is able to carry out this type of analysis.

Regarding the geometry of the building skin, a normal "flat surface" and a "diamond geometry surface"—inspired by an advanced building skin system that was developed by the German industry Schüco [23]—were tested (Figure 6). The two proposed solutions are only two extreme solutions among the many others analyzed.

The "flat surface" skin was simulated with different types of glass: double low-emissive glasses, double low-emissive glasses with argon, double glasses with integrated solar shading, triple low-emissive glasses with translucent insulation or translucent PCM.

FIGURE 5. Digital workflow and software interoperability.

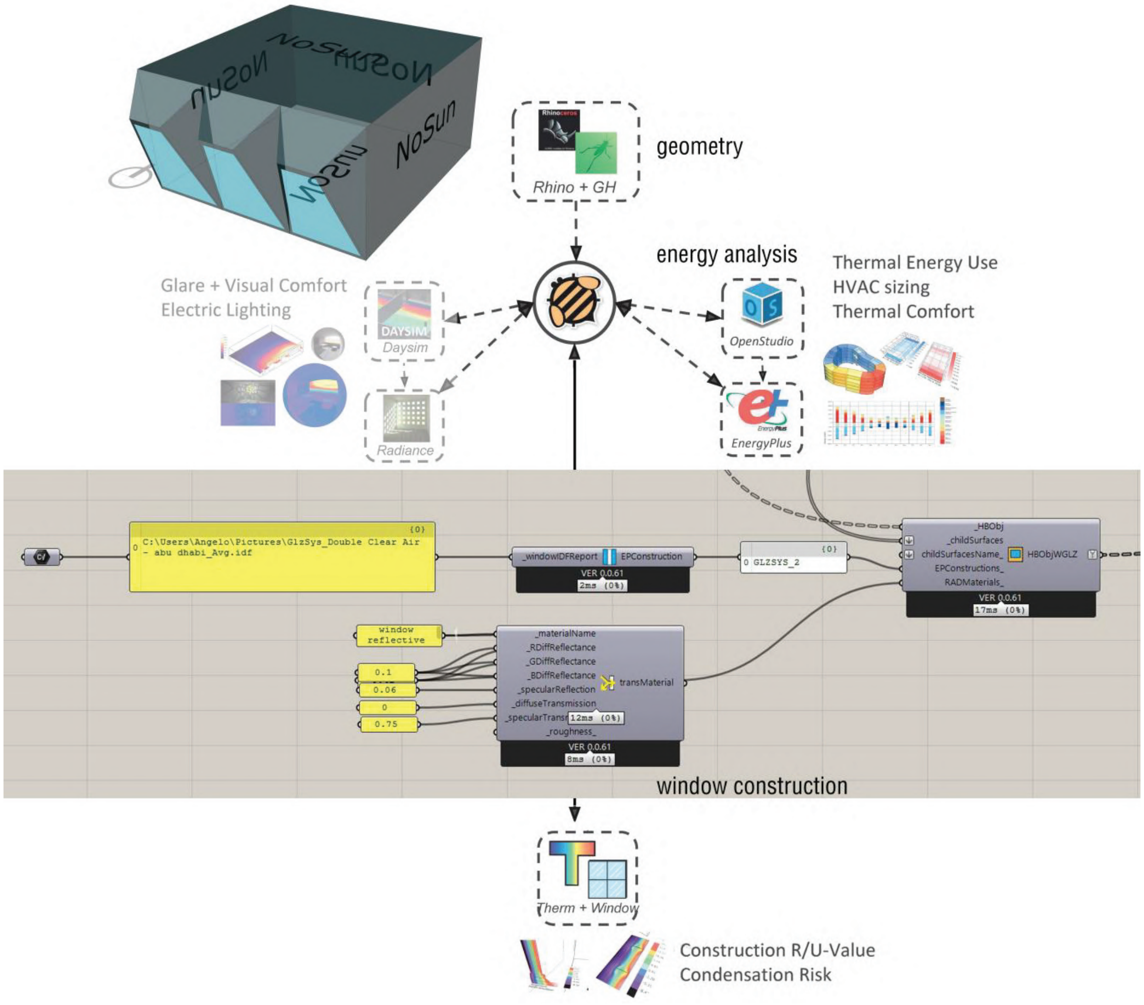


FIGURE 6. Test-office with “flat surface” skin and “diamond geometry” skin.

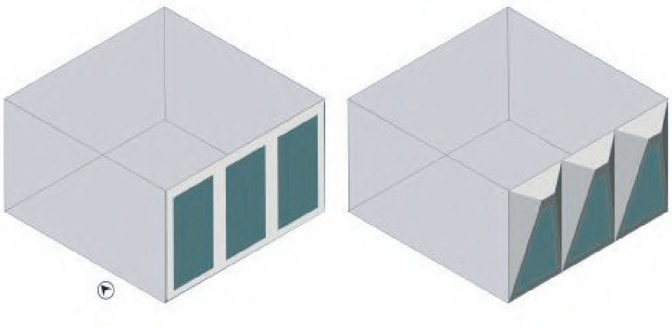
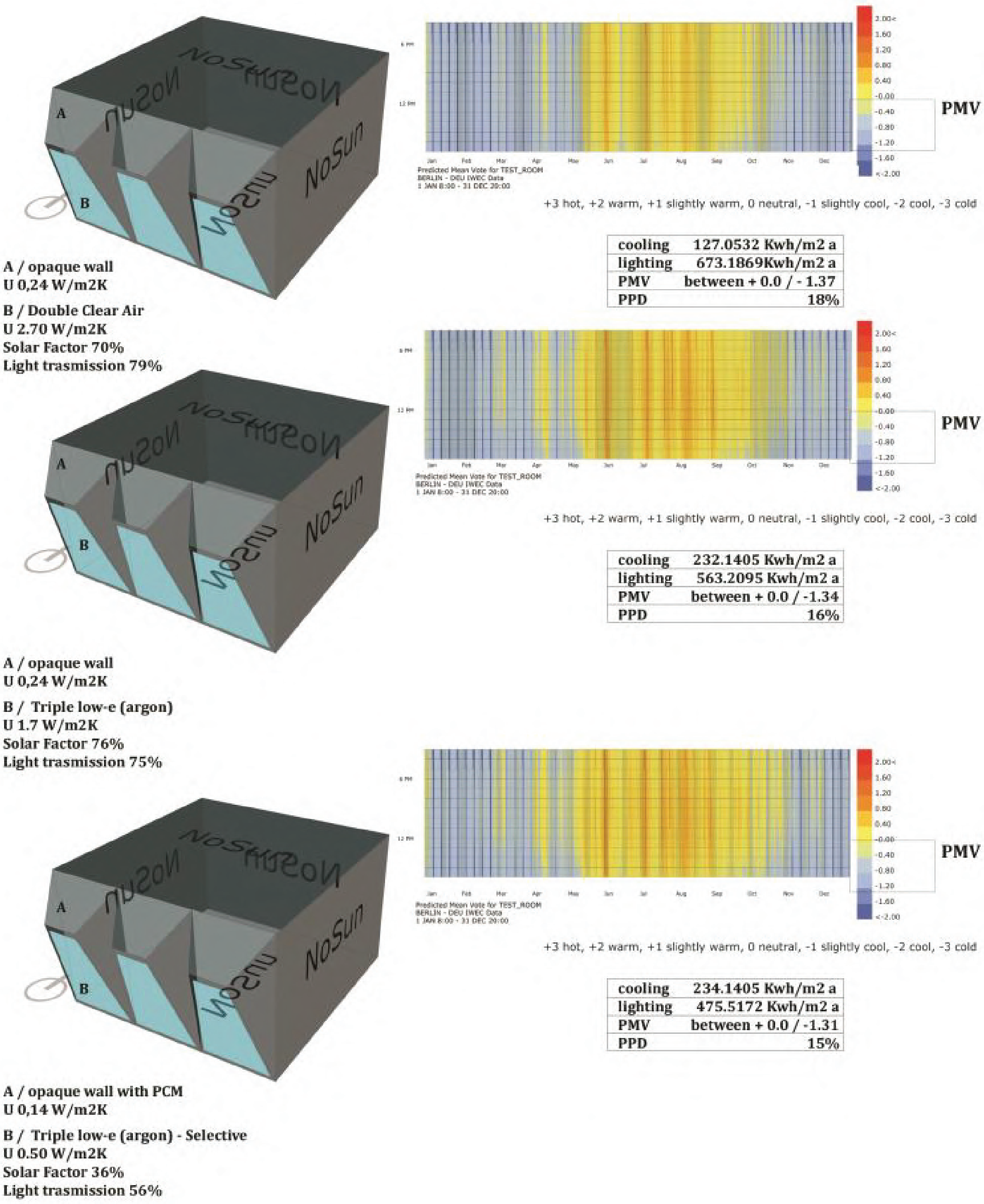


FIGURE 7. Example of simulation results in the "diamond geometry" skin.



cooling	127.0532 Kwh/m2 a
lighting	673.1869Kwh/m2 a
PMV	between + 0.0 / - 1.37
PPD	18%

cooling	232.1405 Kwh/m2 a
lighting	563.2095 Kwh/m2 a
PMV	between + 0.0 / -1.34
PPD	16%

cooling	234.1405 Kwh/m2 a
lighting	475.5172 Kwh/m2 a
PMV	between + 0.0 / -1.31
PPD	15%

For the "diamond geometry" skin, combinations of different materials and components were developed. The building skin was divided into two parts (part A is opaque and part B is transparent or translucent) and for each of these parts several possible materials have been defined. Materials that have been used in part A of the building skin are: opaque façade systems with different U-values (0.24 W/m^{2}K and 0.14 W/m^{2}K) and PCM. Windows that have been used in part B of the building skin are: double clear air (U-value 2.70 W/m^{2}K), triple low-e with argon (U-value 1.70 W/m^{2}K) and triple low-e with argon selective (U-value 0.14 W/m^{2}K). In Figure 7 some results of the simulation are summarized.

The different combinations of the above listed materials in the three parts of the façade allows the development of several different solutions of adaptive building skins, of which 8 were simulated from an energy point of view for a period of one year. The obtained results demonstrated that at least two of the developed systems achieve high-energy performance and provide a good level of comfort inside both in summer and winter time. Since in a real project, the choice of the actual building skin is motivated not only by the performance level but also by economic and aesthetic aspects, at the skin scale no single building skin was defined as a final solution.

5. RESULTS, CONCLUSION AND FUTURE APPLICATION IN DIFFERENT CLIMATE CONDITIONS

The application of AB&S in the design of an office building in Berlin at the three different scales of the design process has demonstrated that the developed computational workflow is practicable and efficient regarding both the computing time and complexity of the proposed computational workflow. The transition from one scale to the next has happened without any problems; the experimentation was successful at all three scales and the performance-based, form-finding procedure ran speedily, also thanks to the initial definition of the range of acceptable results.

All the predefined objectives have been achieved, in particular the one of developing an easy-to-use instrument that can support e.g. small architectural studios—with often limited financial resources and manpower—in designing energy efficient buildings characterized by climate adaptive skins but is at the same time able to optimize the performance at other scales of the project.

Indeed, AB&S will soon be tested with sites of different sizes and characteristics, with different building typologies, more complex materials and systems for building skin, and, in particular, with different climate data to evaluate its application in different climate zones globally.

Further development of the research will involve the use of genetic algorithms for optimizing the performance at the three different scales of the design process. The introduction of more sophisticated algorithms implies the shift from a literature-based approach to a computer-based workflow that relies on computational power and artificial intelligence in combining different shapes and performance criteria. The genetic optimization process will produce many more variations and the analyses of the results will be used to extract general rules that could be used as recommendations to architects and designers.

REFERENCES

[1] G. Hausladen, M. de Saldanha, P. Liedl, *"ClimateSkin: concepts for building skins that can do more with less energy,"* Birkhauser Verlag, Munich, 2006.

[2] R.C.G.M. Loonen, M. Trčka, D. Cóstola, J.L.M. Hensen, "Climate adaptive building shells: State-of-the-art and future challenges," *Renewable and Sustainable Energy Reviews*. No. 25, 2013, pp. 483–493.

[3] R. Fortmeyer, C.D. Linn, *"Kinetic Architecture: Designs for Active Envelopes,"* Images Publishing, Victoria, 2013.

[4] R. Cocci Grifoni, R. D'onofrio, M. Sargolini, M. Pierantozzi, "A Parametric Optimization Approach to Mitigating the Urban Heat Island Effect: A Case Study in Ancona, Italy," *Sustainability* 8(9), 2016.

[5] M. Rossi, V.M. Rocco, R. Grascelli R, A.A.A. Magny, A. G. Leuzzi A G, *"Design choices and comfort outdoors in sustainable neighborhoods,"* in: W. Lang Sustainable architecture for a renewable future, Proceedings PLEA 2013 Conference, Munich, Fraunhofer IRB Verlag, Munich, 2013.

[6] R. Pinotti, S. Avesani, A. Belleri, G. De Michele, P. Ingenhoven, “Load-Responsive Cellular Envelopes with Additive Manufacturing,” *Journal of Façade Design & Engineering*, Vol 5, No. 1, 2017, pp. 37–49.

[7] W. Heusler, *“Latest developments in building skins: a new holistic approach”* in O. Englhardt, Proceedings of Advanced Building Skins, Graz, 2015, pp. 1–20.

[8] S.G.L. Persiani, A. Battisti, T. Wolf “Autoreactive architectural facades—discussing unpowered kinetic building skins and the method of evolutionary optimization” in *Proceedings of Advanced Building Skins* 2016, Wilen, 2016.

[9] R. Naboni, A. Kunic, L. Breseghello, I. Paoletti, “Optimized Parametric Model of a Modular Multifunctional Climate Adapive Façade for shopping Center Retrofitting,” *Journal of Façade Design & Engineering*, Vol 5, No. 1, 2017, pp. 23–36.

[10] R. Deutsch, “*Data-driven design and construction: 25 strategies for capturing, analyzing and applying building data*,” Wiley, Hoboken, 2015.

[11] K. Negendahl, “Building performance simulation in the early design stage: An introduction to integrated dynamic models,” Automation in Construction, No. 54, 2015, pp. 39–53.

[12] B. Raji, M. Tenpierik, A. Van den Dobbelsteen, “Early-Stage Design Considerations for the Energy-Efficiency of High-Rise Office Buildings,” *Sustainability*, 2017, Vol. 9 No. 4, pp. 2–28.

[13] K. Konis, A. Gamas, K. Kensek, “Passive performance and building form: An optimization framework for early-stage design support,” *Solar Energy*, No. 125, 2016, pp. 161–179.

[14] E. Elbeltagi, H. Wefki, S. Abdrabou, M. Dawood, A. Ramzy, “Visualized strategy for predicting buildings energy consumption during early design stage using parametric analysis,” *Journal of Building Engineering*, No. 13, 2017, pp. 127–136.

[15] Y.S. Huang, W.S. Chang, S.G. Shih, “Building Massing Optimization in the Conceptual Design Phase,” *Computer-Aided Design and Applications*, No. 12(3), 2015, pp. 344–354.

[16] D. Rutten, *Grasshopper*, version 0.9.0072 (McNeel, 2014), http://www.grasshopper3d.com/

[17] A. Tedeschi, *“AAD_Algorithms-Aided Design, Parametric Strategies Using Grasshopper®,”* Edizioni Le Penseur, Brienza, 2014.

[18] M. S. Roudsari, M. Pak, *“Ladybug: a parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design”* in E. Wurtz, Proceedings of the 13th International IBPSA Conference Held in Lyon, Chambery, France, 2013.

[19] G. Hausladen, P. Liedl, M de Saldanha, *Building to Suit the Climate: A Handbook*, Bitkhäuser, Basel 2012.

[20] K. Błażejczyk, G. Jendritzky, P. Bröde, D. Fiala, G. Havenith, Y. Epstein, A. Psikuta, B. Kampmann, “An Introduction to the Universal Thermal Climate Index (UTCI),” *Geographia Polonica*, Vol. 86, Iss. 1, pp. 5–10, 2012.

[21] P. Bröde, E.L. Krüger, F. Rossi, D. Fiala, “Predicting urban outdoor thermal comfort by the Universal Thermal Climate Index UTCI—a case study in Southern Brazil,” *International Journal of Biometeorology*, Vol. 56, No. 3, pp. 471–480, 2012.

[22] Standard 55-2010: Thermal Environmental Conditions for Human Occupancy (most recent version: 2017)

[23] A. Fuchs, S. Peter, O. Hans, J. Möhring, “Schüco parametric system uniqueness in series” in O. Englhardt, *Proceedings of Advanced Building Skins*, Graz, 2015, pp. 31–36.

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Ai Commissari dell’Abilitazione Scientifica Nazionale,

Con la presente si certifica che il sottoscritto, Angelo Figliola nato a Giulianova il 01/06/1986 e residente a Tortoreto (TE), Largo del Vecchio Focolare 1, Tortoreto (TE), ha svolto il ruolo di co-primo, Writing – Original Draft Preparation, nell’ambito della pubblicazione sottoposta a valutazione, Rossi-Schwarzenbeck M., Figliola A. (2019). Adaptive building and skin: An innovative computational workflow to design energy efficient buildings in different climate zones. JOURNAL OF GREEN BUILDING, vol. 14, p. 1-15, ISSN: 1552-6100, doi: 10.3992/1943-4618.14.4.1. L’autore ha curato la parte metodologica relativa al processo computazionale e ha condotto la ricerca applicata (caso studio) oltre che elaborato le conclusioni dell’articolo.

Il primo autore, Prof. Monica Rossi, ha svolto il ruolo di Supervisor curando la parte teorica relativa alla progettazione tecnologica-ambientale, condividendo l’impostazione metodologica del contributo, garantendo la revisione dello stesso prima di essere sottoposto a peer review e analizzando i risultati della sperimentazione condotta.

Luogo e data Firma degli autori

Tortoreto, 19/06/2020

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