

A Case Study of Teaching Method and Students' Learning Experience in Integrating Urban Design and Performance Simulations for Climate Conscious Design in Estonia

Francesco De Luca

Tallinn University of Technology, Department of Civil Engineering and Architecture, Academy of
Architecture and Urban Studies

E-mail: francesco.deluca@taltech.ee

Copyright © 2020 by De Luca

Abstract

Indoor comfort, energy efficiency and outdoor comfort are critical factors for the design of sustainable, climate conscious and livable urban environments. Simulations tools are available to be used by architects and urban designers to improve the environmental performance of buildings and districts from the early stages of the design process. Building requirements, standards and metrics can be used efficiently to assess the simulation results and parametric design methodologies allow for finding optimal design solutions. The schools of architecture struggle to teach the students how to perform correctly simulations and how to integrated them in the design process. The reason lies in the separation of the courses in which simulations are taught, usually building technology courses, and architectural and urban design studio courses. This research presents method and outcomes of an urban design course taught by the author during which the students learned how to integrate architectural and urban design principles with simulations and analysis of results against standards and metrics through parametric design. The course succeeded as well in increasing the awareness of the students about sustainable and climate conscious design.

Key words:

parametric design, climate conscious, architectural and urban design, livable urban environments

1. Introduction

Nowadays, about 55 % of the world population, lives in cities. Projections show that it will be 68 % by 2050¹. Cities account for almost 70% of the global energy consumption, and the built environment is responsible for more than 50 % of the total carbon dioxide (CO₂) emission². Climate scientists state that the temperatures in European cities during the warm season will increase of more than 2 °C before 2100³.

The urban density and fabric has a significant influence on the solar radiation received by building interiors, affecting occupants' thermal and visual comfort⁴. The buildings' form, orientation and surroundings determine the quantity of solar energy received by building facades⁵. Direct solar radiation is among the main responsible factors of building energy efficiency^{6,7}. Studies proved the importance to consider the building groups layout, heights, mutual distances and orientations, and the surrounding built environment in order to achieve low energy buildings at north latitudes⁸. Research about urban design solutions proved that it is possible to save up to 50 % of energy consumption using environmental simulations and performance analysis⁹.

Buildings' reciprocal distance, height and orientation have a strong influence on daylight, which is one of the main factors that guarantees healthiness and comfort of occupants, and increases the architectural quality of building interiors^{10,11}. Daylight and access to sunlight have a positive

¹ United Nations Department of Economic and Social Affairs, World Urbanization Prospects: The 2018 Revision. United Nations, New York, USA, 2018.

² International Energy Agency, World Energy Outlook 2016. IEA, Paris, France, 2016.

³ Intergovernmental Panel on Climate Change (IPCC), Annex I: Atlas of Global and Regional Climate Projections Supplementary Material RCP8.5. In Climate Change 2013: The Physical Science Basis. Working Group I, Bern, Switzerland, 2013.

⁴ Chatzipoulka, C., Compagnon, R. and Nikolopoulou, M. 2016, Urban geometry and solar availability on façades and ground of real urban forms: using London as a case study, *Solar Energy*, 138, pp. 53–66.

⁵ Kanters, J. and Horvat, M. 2012, Solar energy as a design parameter in urban planning. *Energy Procedia*, 30, pp. 1143–1152.

⁶ De Luca, F., Voll, H. and Thalfeldt, M. 2016, Horizontal or vertical? Windows' layout selection for shading devices optimization. *Management of Environmental Quality: An International Journal*, 27(6), pp. 623–633;

⁷ Voll, H., De Luca, F. and Pavlovas, V. 2016, Analysis of the insolation criteria for nearly-zero energy buildings in Estonia. *Science and Technology for the Built Environment*, 22(7), pp. 939–950.

⁸ Voll, H., Thalfeldt, M., De Luca, F., Kurnitski, J. and Olesk, T., 2016, Urban planning principles of nearly zero-energy residential buildings in Estonia. *Management of Environmental Quality: An International Journal*, 27(6), pp. 634–648.

⁹ Kanters, J., Wall, M. and Dubois, M.C. 2014, Typical values for active solar energy in urban planning. *Energy Procedia*, 48, pp. 1607–1616.

¹⁰ Reinhart, C.F., Dogan, T., Jakubiec, A.J., Rakha, T. and Sang, A. 2013, UMI - An Urban Simulation Environment for Building Energy Use, Daylighting and Walkability. In *Proceedings of 13th International Building Performance Simulation Association Conference (BS 2013)*, Chambéry, France, 26–28 August 2013, pp. 476–483.

influence on the physiological and psychological wellbeing of occupants, helping to entrain correctly the circadian rhythm¹². Studies show that an adequate quantity of daylight in working environments increases workers' productivity¹³. In the last decades, the increasing relevance of daylight as a design criterion for comfort, healthiness and resource efficiency, is proved by the new and continuously updated metrics and regulations^{14,15}. Computer tools are available to support the design process¹⁶. Validated software can be used by designers to correctly take into account daylight and solar access of buildings during the early stages of the design process^{17,18}.

The design of commercial building clusters in urban areas strongly influences the daylight available in the premises and the pedestrian thermal comfort¹⁹. Recent studies prove that the pattern of new residential buildings in the city of Tallinn is an important factor for the design of dwellings fulfilling the Estonian solar access regulation, and of livable outdoor public areas²⁰. The form of buildings and the articulation and dimensions of open spaces such as plazas and green areas, alter the local microclimate that has a direct influence on pedestrian thermal comfort and energy

¹¹ Reinhart, C.F, *Daylighting Handbook I. Fundamentals and Designing with the Sun*. Building Technology Press, Cambridge (MA), USA, 2014.

¹² Lockley, S.W. 2009, *Circadian Rhythms: Influence of Light in Humans*. In L. R. Squire (ed.), *Encyclopedia of Neuroscience*, pp. 971-988. Elsevier, Amsterdam, Netherlands.

¹³ Andersen, M., Mardaljevic, J. and Lockley, S.W. 2012, A framework for predicting the non-visual effects of daylight - Part I: Photobiology-based model. *Lighting Research & Technology*, 44(1), pp. 37–53.

¹⁴ Reinhart, C.F, Mardaljevic, J. and Rogers, Z. 2006, Dynamic Daylight Performance Metrics for Sustainable Building Design. *Leukos*, 3(1), pp. 7–31.

¹⁵ Darula, S., Christoffersen, J. and Malikova, M. 2015, Sunlight and insolation of building interiors. *Energy Procedia*, 78, pp. 1245–1250.

¹⁶ De Luca, F. and Nardini, M., *Dietro le quinte: tecniche d'avanguardia nella progettazione contemporanea*. Testo & Immagine, Torino, Italy, 2003.

¹⁷ De Luca, F. and Voll, H. 2017, Solar Collection Multi-isosurface Method - Computational Design Advanced Method for the Prediction of Direct Solar Access in Urban Environments. In *Computer-Aided Architectural Design: Future Trajectories*, Communications in Computer and Information Science (CCIS), 724, Springer Nature, 170-187;

¹⁸ De Luca, F. and Dogan, T. 2019, A Novel Solar Envelope Method Based on Solar Ordinances for Urban Planning. *Building Simulation: An International Journal*, 12(5), 817-834.

¹⁹ De Luca, F. 2019, Environmental Performance-Driven Urban Design: Parametric Design Method for the Integration of Daylight and Urban Comfort Analysis in Cold Climates. In *Computer-Aided Architectural Design: "Hello, Culture"*, Communications in Computer and Information Science (CCIS), 1028, Springer Nature, pp. 15-31, 2019.

²⁰ De Luca, F. 2019, Sun and Wind. Integrated Environmental Performance Analysis for Building and Pedestrian Comfort. In *Proceedings of the Symposium on Simulation for Architecture and Urban Design (SimAUD 2019)*, Atlanta (GE), USA, 7-9 April 2019, pp. 3-10.

consumption of buildings²¹. Discomfort in urban outdoor areas, especially during the warm season, is a growing concern due to the heat stagnation, not flowing warm air, and lack of shading and vegetation²². The lack of a climate conscious design of urban districts has an immediate effect on the livability of outdoor spaces and resource efficiency of buildings, and a long lasting and cumulative effect that favor climate change²³.

Architects and urban designers are increasingly required to develop climate conscious and efficient urban design solutions to improve indoor and outdoor comfort, to decrease resource depletion and to help reducing climate change²⁴. The use of environmental simulations and performance-driven design methods help designers to develop climate-based solutions since the early stages of the design process, when the choices have more impact on the project outcome and on realized buildings and urban environments.

2. Background

In recent years, the use of computer simulations to evaluate the performance of buildings in relation to environmental and climatic factors is increasingly taught in architecture schools. Nevertheless, the skills of architecture graduates in using simulations to improve the sustainable aspects of their design do not match with the growing efforts in teaching and learning, though studies show that, with the appropriate methods the students can obtain significantly better results²⁵. At the same time, studies show that the majority of architects and urban designers lack the necessary skills to perform correctly environmental and energy simulations, and the capacity to evaluate correctly the results, either if they conducted the simulations or if those have been performed by external consultants. In this way, the design task does not fully exploit the potential of simulations²⁶.

Two issues arise in the teaching of environmental and building simulations for comfort and resource efficiency. The first is related to the project phase. Nowadays, the vast majority of the courses in

²¹ Lobaccaro, G., Acero, J.A., Martinez, G.S., Padro, A., Laburu, T. and Fernandez, G. 2019, Effects of orientations, aspect ratios, pavement materials and vegetation elements on thermal stress inside typical urban canyons. *International Journal of Environmental Research and Public Health*, 16(19), art. n. 3574.

²² Santamouris, M. 2014, Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Solar Energy*, 103, pp. 682–703.

²³ Oke, T.R., Mills, G., Christen, A. and Voogt, J.A., *Urban Climates*. Cambridge University Press, Cambridge, UK, 2017.

²⁴ E. Naboni and L. Havinga, *Regenerative Design in Digital Practice: A Handbook for the Built Environment*. Eurac Research, Bolzano, Italy, 2019.

²⁵ Reinhart, C.F., Geisinger, J., Dogan, T. and Saratsis, E. 2015, Lessons learnt from a simulation-based approach to teaching building science to designers. In *Proceedings of 14th International Building Performance Simulation Association Conference (BS 2015)*, Hyderabad, India, 7-9 December 2015, pp. 1126-1133.

²⁶ Reinhart, C.F., Dogan, T., Ibarra, D. and Samuelson, H. 2012, Learning by playing – teaching energy simulation as a game. *Journal of Building Performance Simulation*, 5(6), pp. 359-368.

which performance analysis are taught, are building technology classes not connected with the design studios²⁷. Simulations are performed on finished projects instead than on schematic massing developed during the early stages of the design process, when it can have the most significant impact on the design result²⁸. Studies show that students' learning capacity improves when they apply simulations to simple architectural computer model and tasks²⁹. Recent research shows a successful students' learning experience when building performance are related to architectural form studies³⁰. The second issue is related to the project scale and domain. The vast majority of the courses in which simulations are taught, focus on the building scale and indoor domain to analyse occupant thermal and visual comfort (daylight), and energy efficiency. Very little attention is given in the architecture schools to teaching climatic simulations for the outdoor domain that influences both the outdoor and indoor performance³¹ (Lobaccaro and Frontini, 2014). More importantly, students are not taught to link the two domains, the indoor and the outdoor, to obtain comfortable urban environments and livable pedestrian areas, and healthy, comfortable and resource efficient buildings³².

This paper introduces methods and outcomes of the course Planning Project I Energy Efficient Urban Quarter (High density mixed use efficient and comfortable new urban district in Tallinn), held by the author and by Arch. Ivan Gavrilov, at Tallinn University of Technology (TalTech), Academy of Architecture and Urban Studies, for students of the 4th year during Fall 2019. Developing the schematic design of a new mixed-use district in Tallinn, the students investigated the performance of buildings and pedestrian areas in relation to climatic factors and site conditions, and assessed different urban design solutions in consideration of Estonian indoor regulations and outdoor thermal metrics. The expected students' learning outcomes were: 1) to realize parametric models at the urban scale; 2) to perform correctly environmental and building simulations in the

²⁷ Charles, P.P. and Thomas, C.R. 2009, Building performance simulation in undergraduate multidisciplinary education: learning from an architecture and engineering collaboration. In Proceedings of the 11th International Building Performance Simulation Association Conference (BS 2009), Glasgow, UK, 27-30 July 2009, pp. 212-219.

²⁸ Samuelson, H.W., Lantz, A., and Reinhart, C.F. 2012, Non-technical barriers to energy model sharing and reuse. *Building and Environment*, 54, pp. 71-76.

²⁹ Ibarra, D.I. and Reinhart, C.F. 2009, Daylight Factor simulations – How close do simulation beginners 'really' get? In Proceedings of the 11th International Building Performance Simulation Association Conference (BS 2009), Glasgow, UK, 27-30 July 2009, pp. 196-203.

³⁰ De Luca, F. 2019, Learning Performance-driven Design. Students Approach Integrating Urban Form Studies and Building Performance Analysis. In Proceedings of the 16th International Building Performance Simulation Association Conference (BS 2019), Rome, Italy, 2-4 September 2019, pp. 1609-1616.

³¹ Lobaccaro, G. and Frontini, F. 2014, Solar Energy in Urban Environment: How Urban Densification Affects Existing Buildings. *Energy Procedia*, 48, pp. 1559-1569.

³² Naboni, E., Natanian, J., Brizzi, G., Florio, P., Chokhachian, A., Galanos, T. and Rastogi, P. 2019, A digital workflow to quantify regenerative urban design in the context of a changing climate. *Renewable and Sustainable Energy Reviews*, 113, art. n. 109255.

early design stage; 3) to use building regulations and metrics to evaluate different design solutions; 4) to link the indoor and outdoor domains of performance analysis; 5) to integrate indoor and outdoor performance analysis and optimization with architectural and urban design principles to define optimal design solutions.

3. Methods and materials

3.1. Method

The course Planning Project I Energy Efficient Urban Quarter was subdivided in four main activities: 1) Architectural Concept; 2) Parametric Design; 3) Performance Simulations and Analysis; and 4) Urban Design. The four activities have been carried out consequentially and in parallel (Figure 1). After having developed the architectural concept about the new urban quarter, the students, divided in ten groups, realized parametrically a number of possible alternatives of the design idea and performed indoor and outdoor simulations to analyze the performance of different design solutions. The simulations have been performed until a number of optimal design solutions fulfilled the initial performance requirements. Among the fulfilling solutions, the student groups selected one on the basis of its performance and correlation with the initial architectural concept. Finally, the selected solution has been used to design the general site plan and the open public area. Detailed description of the activities is presented in the following sections.

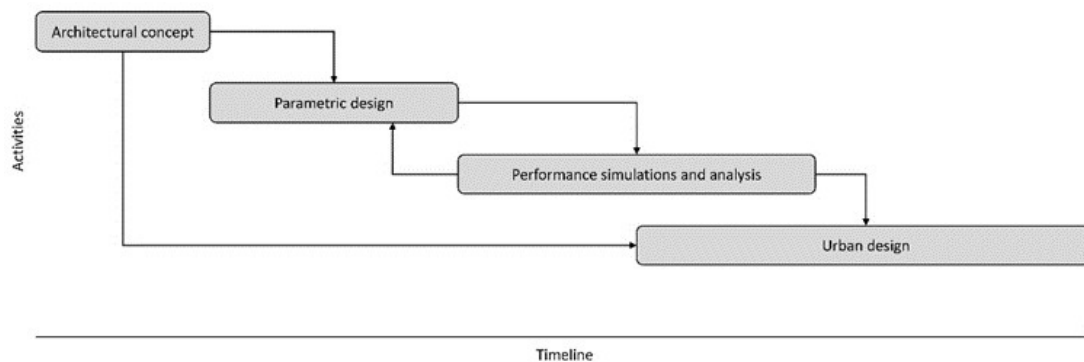


Figure 1. Flowchart of the main activities of the course.

3.2. Architectural Concept

The design area selected for the course is located in Tallinn (Lat. 59.43° N, Lon. 24.75° E), in the Sikupilli district, part of the Lasnamäe quarter, close to the airport. The area is characterized by business and logistic activities, warehouses and large parking lots. Most of the existing buildings located in the area have poor quality and conditions. For the course, all the buildings on the design area could have been demolished. Two type of building had to be used for the new quarter: residential and office. At the beginning of the course the students formed ten groups: Curve;

Hourglass; Unexpected journey; Great Majaka; Levels; Lasnamäe fringe; Skew; Sikupilli quarter; The heart of Sikupilli; Sikupilli block.

The first step of the design process is the Architectural Concept. The student groups developed the design idea using their knowledge of urban planning acquired in previous studio courses and after attending lectures of the course. It was required that the project idea had a strong relation with the site and with a more extended neighborhood area. The architectural concepts investigated can be classified in four categories: Vectors; Morphology; Circulation; and Zoning (Figure 2). The concept Vectors informed the design through expansion/attraction points and trajectory lines that created fields and directions shaping the building plots. The morphology of the urban fabric, in the vicinity of the design area or using typological references, was used to define the quarter density and layout. The pedestrian and car circulation determined the layout of the design area, connecting it with the surrounding path and street networks, and with specific locations in the neighborhood as the small artificial lake and the shopping area. The Zoning concept was used to rationalize the design area subdividing it in sub-areas used for similar or different functions, built or pedestrian areas, in relation with surrounding building densities. The lecturers stressed the importance of the architectural concept as the guideline for the design process, from the development of the idea, to the parametric variations generation.

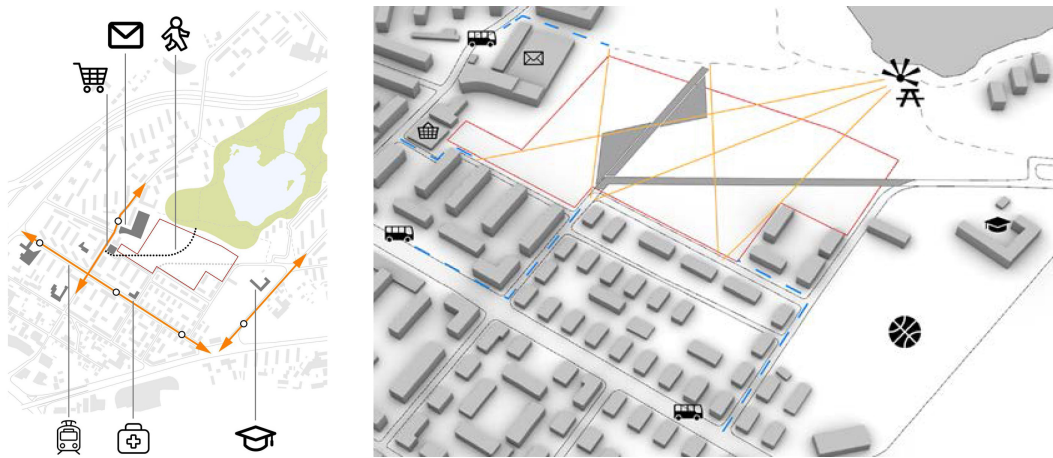


Figure 2. Diagrams showing the architectural concepts Circulation used by the students' group Hourglass (left), and Vectors used by the students' group Great Majaka (right).

3.3. Parametric Design

During the second activity of the course, parametric design methodologies were used through the software Rhinoceros and Grasshopper^{33,34}. After a crash course on parametric design, taught by the author, the students realized a parametric model incorporating the main concepts of the project idea. The model was included in the general 3D model of the neighborhood, provided by the author. The scope was that to generate a number of alternatives of the project idea to be used for performance simulations and analysis. Parametric design is a valid design method to create relations between critical factors and aspects of the architectural and urban project, to obtain efficient design solutions integrated in the environment, linking qualitative and quantitative design aspects. The possibility to test for performance different design alternatives, based on key architectural concepts, favors the bottom-up design thinking by the architecture students, that allows them to find optimal design solutions using objective data and simulation results.

During the Parametric Design activity, the students had to take into account the first project requirement. Being the scope that to design a high density quarter, the selected project should have a Floor-to-Area-Ratio (FAR) of 2 (ratio between the total built floor area and the design area). This requirement was decided by the lecturers for the course, though the FAR for the area as required by the municipality is lower. Additionally, the required FAR was to be obtained using a maximum height of seven floors for the residential buildings, and fourteen floors for the office buildings. An example of parametric design workflow realized by the student groups is presented in Figure 3.

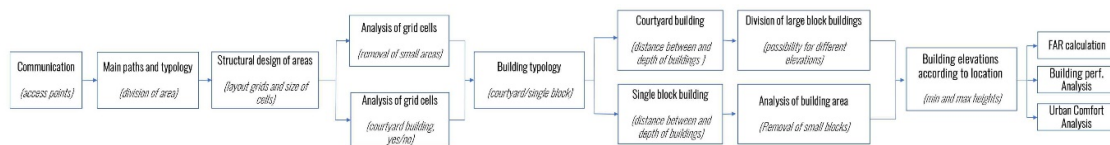


Figure 3. Diagram of the parametric design workflow realized by the students' group Hourglass.

The main steps of the parametric design workflow used by all the groups are:

- Generation of the buildings' footprint pattern.
- Adaptation of the pattern to the new quarter layout based on the design idea.
- Variation of the generated pattern and building typologies.
- Buildings' massing through height extrusion in relation to the building function.
- Calculation of FAR.

³³ McNeel, R., Rhinoceros. Robert McNeel & Associates, Seattle, USA, 2019. Available at: <https://www.rhino3d.com/>

³⁴ Rutten, D., Grasshopper. Robert McNeel & Associates, Seattle, USA, 2020. Available at: <https://www.grasshopper3d.com/>

Through the parametric model, the student groups realized a number of variations of the new urban quarter layout, different for density, buildings' distance height and orientation, quantities of the different building typologies and functions (residential or office), and location and layout of the pedestrian areas (Figure 4). The variations were then used for performance simulations and analysis.

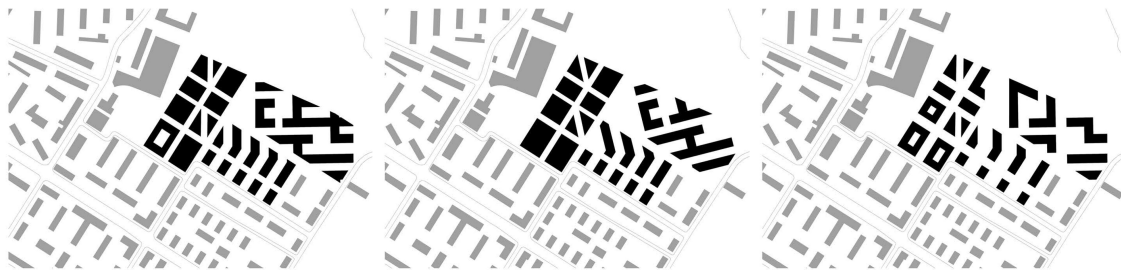


Figure 4. Some of the urban quarter layout variations generated through the parametric model by the students' group Skew.

3.4. Performance Simulations and Analysis

Indoor and outdoor simulations were taught by the author to the students of the course. These were integrated in the parametric design workflow through specific design components. For every pattern variation of the new urban quarter, indoor simulations were performed. These were daylight and energy simulations, and were conducted using the software Urban Modeling Interface (UMI)³⁵. The indoor simulations were used to assess and compare the performance of the design variations and for the selection of one solution. For the outdoor pedestrian thermal comfort was simulated on a small pedestrian area, selected inside the entire quarter, to get useful information about where to design different activities such as sitting, playing, relaxing and socializing. The assessments of the simulation results were conducted by the student groups using standards, building requirements and metrics.

Daylight performance was investigated using climate based daylight simulations, in relation to the metric Spatial Daylight Autonomy (sDA)³⁶. According to sDA, an interior space is well daylight if at least 55 % of its floor area receives the required illumination (300 lux) by daylight only for at least 50 % of the occupied time. Daylight is a function of building density, orientation, window size and

³⁵ Reinhart, C.F., Dogan, T., Jakubiec, A.J., Rakha, T. and Sang, A. 2013, UMI - An Urban Simulation Environment for Building Energy Use, Daylighting and Walkability. In Proceedings of 13th International Building Performance Simulation Association Conference (BS 2013), Chambéry, France, 26-28 August 2013, pp. 476-483.

³⁶ Illuminating Engineering Society, LM-83-12 - Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE). IES, New York, USA, 2013.

glass transparency (Visible Transmittance). The student groups simulated daylight availability on all the floors of all the new buildings. The requirement was that all the buildings had to be well daylight, i.e. the average sDA per building was $\geq 55\%$ (Figure 5). If not all the building were fulfilling the requirement, new parametric variations of the building pattern were generated. It was also possible to change the Window to Wall Ratio (WWR) to increase the daylight availability (in accordance with the energy analysis). At the end of the process, a number of project variations fulfilling the daylight requirement were generated (Figure 5). Daylight and energy simulations were carried on in parallel, due to the fact that they are conflicting performances (increasing window size increases daylight and decreases electric lighting energy, but also increases energy consumption when cooling energy is used). The scope was that to obtain buildings that could fulfill both the requirements.

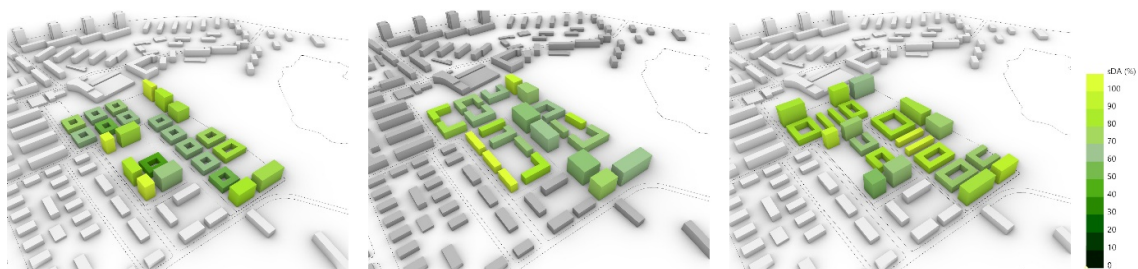


Figure 5. Daylight analysis for the buildings of the urban pattern variations 1, 5.2, and 8 of the group Sikupilli block. The buildings color-coded in relation to the colored legend above 55% fulfill the Spatial Daylight Autonomy (sDA) requirement.

Energy simulations were performed to analyze the performance of all the buildings of every project variation realized by the student groups, in relation to the Estonian energy regulation³⁷. Thus, all the buildings of the new urban quarter had to be low energy buildings (Figure 6). According to the Estonian regulation, the maximum allowed energy consumption calculated as Primary Energy was 120 kWh/m²y for the residential buildings, and 130 kWh/m²y for the office buildings. The result of the simulations obtained in UMI was the operational energy for lighting, heating and equipment for residential and office buildings, and also for cooling for the office buildings. The students integrated in the parametric model the formula to convert operational energy into Primary Energy. To perform urban building energy modeling the Tallinn weather file was used. Additionally, building templates with data about construction and use were provided by the author. The parametric design variations in terms of size and ratio of buildings' footprint, heights and orientation of buildings and distance between buildings were investigated in order to reach the required performance (Figure 6). Additionally, student groups could adjust the WWR of

³⁷ Estonian Government, Minimum requirements for energy performance, Ordinance n. 68, 30.08.2012. EVS, Tallinn, Estonia, 2012. Available at: <https://www.riigiteataja.ee/en/eli/520102014001>

the different building facades in order to meet the energy requirements, in accordance with the daylight performance.

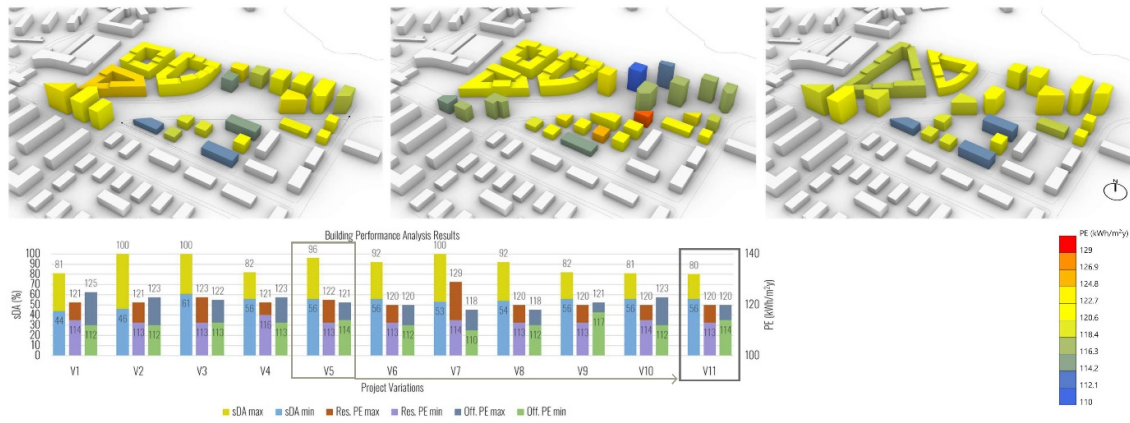


Figure 6. Energy analysis of the urban pattern variations 5, 7 and 9, and chart indicating the daylight and energy performances of all the variations of the group Hourglass. For each variation, the first bar indicates the min. and max. daylight performance (sDA - left axis), the other two bars indicate the min. and max. energy performance for residential and office buildings respectively (PE – right axis). The rectangle indicates the design solution selected (V11).

After having obtained a number of design solutions of the new urban quarter fulfilling both the daylight and the energy performance requirements, the student groups selected one on the basis of its architectural quality and legacy with the initial architectural concept and project ideas, also under the guidance of the lecturers. The selected variation was used for the project site plan detailing and for the design of the pedestrian area utilizing the information obtained through the outdoor comfort analysis.

Outdoor comfort was assessed using the Universal Thermal Climate Index (UTCI)³⁸, through the Grasshopper plugin Ladybug Tools³⁹. UTCI assesses the temperature perceived by a person taking into account the air temperature, solar radiation, Mean Radiant Temperature (MRT), wind and humidity, the metabolic rate and the clothing insulation. A person is in state of comfort if the perceived temperature lies between 9 and 26 °C UTCI. For the scope of the course the climatic data was derived from the Tallinn weather file. The built context was used in relation to the solar

³⁸ Bröde, P., Jendritzky, G., Fiala, D. and Havenith, G. 2010, The Universal Thermal Climate Index UTCI in 27 Operational Use. In Proceedings of Conference: Adapting to Change: New Thinking on Comfort, Windsor, UK, 9-11 28 April 2010.

³⁹ Sadeghipour Roudsari, M, and Pak, M., 2013, Ladybug: A Parametric Environmental Plugin for Grasshopper to Help 10 Designers Create an Environmentally-conscious Design. In Proceedings of 13th International Building Performance Simulation Association Conference (BS 2013), Chambéry, France, 26-28 August 2013, pp. 3128–3135.

radiation calculation. Outdoor comfort assessment was performed for two typical days during spring and summer, when people use the most the pedestrian areas. The results were outdoor comfort maps from which were derived information used for the design of the pedestrian area (Figure 7).

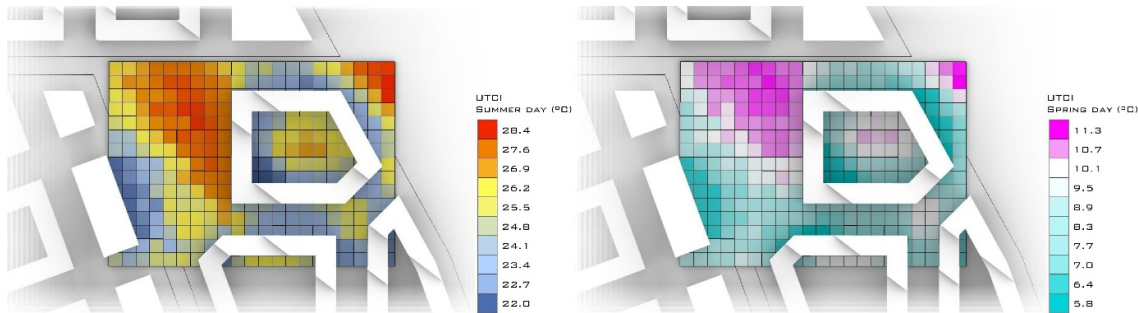


Figure 7. Outdoor comfort maps obtained through UTCI analysis by the students' group Levels.

3.5. Urban Design

The Urban Design activity was divided in two parts, conducted in parallel. In the first, the student groups developed the design of the selected layout of the quarter; in the second, they identified one area inside the new quarter characterized by particular urban qualities to be developed as public space. The latter activity started during the Performance Simulations and Analysis activity, with the selection of the public area to be used for outdoor comfort analysis. The required level of detail of the whole project was that of a general site plan. Thus, the selected schematic project variation was detailed using, paths and sidewalks, paved and green areas, and parking areas (Figure 8). A strong consistency of the site plan with the initial concept and ideas was required.



Figure 8. Aerial view of the general site plan of the design proposal of the students' group Lasnamäe fringe.

The outdoor comfort maps were used by the student groups as evidence for the design of the areas more suited for sitting, walking, playing and relaxing inside the public pedestrian space in relation to the two analysis period used, the typical spring and summer days. The result relative to the spring day indicated areas of favorable thermal conditions where to locate terraces, benches and playgrounds, that can be used from spring. The result relative to the summer day indicated where mitigation strategies were necessary to reduce the perceived temperature, such as pergolas, shades, greenery and trees. Thus, the design included paved areas and paths, cafes and restaurant terraces, benches and playground, green areas and small water basins (Figure 9).

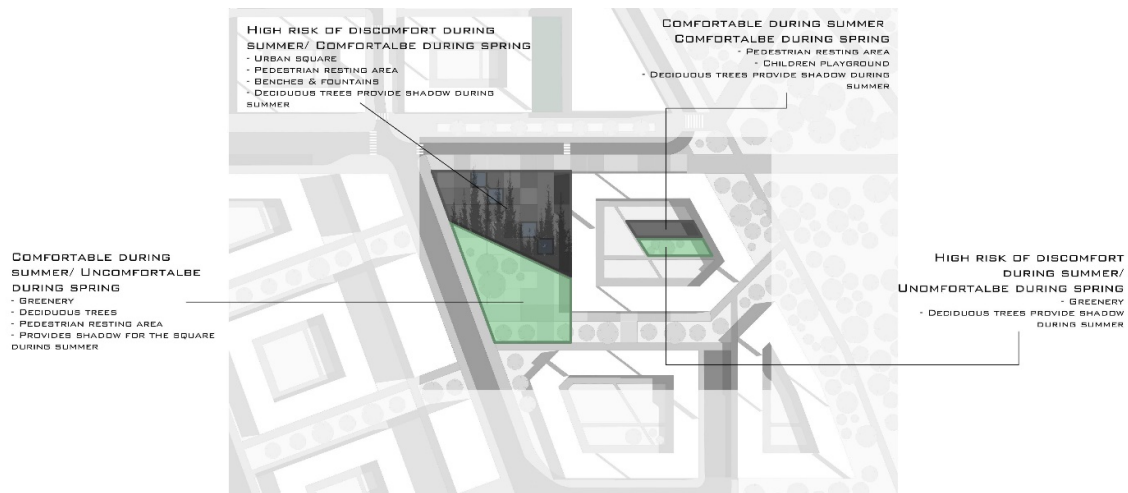


Figure 9. Location of the functions and features of the public pedestrian area developed by the students' group Levels.

4. Results

During the course, all the students participated actively in the different activities. The groups were formed by two or three students. The students shared the work with different roles during the different activities. All of them were required to participate in all the phases from concept to design, and to learn the parametric design methods, the basic theory of the simulated phenomena, and principles of simulations. The involvement of the students with different roles and team working proved to be an effective method to improve learning⁴⁰.

The results of the study present the students' learning capacity and approach during the different course activities, the difficulties encountered and how the process influenced the final project outcomes. The scope is that to evaluate the teaching method used by the author, analyzing its

⁴⁰ Westrup, U. and Planander, A. 2013, Role-play as a pedagogical method to prepare students for practice: The students' voice. *Högre utbildning*, 3(3), pp. 199-210.

strength and weak points, in order to improve the course in the coming years and to provide the reader with useful information for teaching similar courses. For the purpose, the author developed an assessment method to evaluate the learning outcomes of the groups on the basis of previous studies that investigated the teaching of simulations as a game and integrated qualitative evaluations of building forms with quantitative assessment of performance simulation procedures⁴¹. The evaluation is then conducted by the author using the chart presented in Table 1.

The key aspects are: for the activity Architectural Concept the relation of the idea with the site and the neighborhood, and the use of the concept as a guideline for the project; for the activity Parametric Design the correspondence of the pattern to the concept, the number of different variations generated and the differentiation of the buildings' massing; for the activity Performance Simulations and Analysis the appropriateness of the daylight and energy simulations, the use of the analysis results to select the project layout and the appropriateness of the outdoor comfort simulations; for the activity Urban Design the consistency of the site plan with the project idea, the quality of the detailed plan and the correct use of the evidence obtained from the outdoor comfort simulations for the design of the public area. The tackling of the different key aspects by the student groups has been rated by the author with scores from 1 to 3 corresponding to "sufficiently", "properly" and "remarkably" respectively.

Table 1. Evaluation chart of the activities' key aspects for the ten student groups participating in the course.

Groups	Arch. Concept		Parametric Design			Perf. Sim. and Analysis				Urban Design			
	Relation		Pattern			Daylight				Consistency			
	Guideline			Variation			Energy				Detailing		
				Massing			Analysis				Evidence		
							Comfort						
G1	2	1		1	2	2	2	1	1	2	2	1	1
G2	2	2		3	2	2	2	2	3	3	2	1	2
G3	1	1		1	1	1	2	2	1	2	1	1	2
G4	2	2		3	3	2	3	2	3	3	2	1	3
G5	2	3		3	2	3	2	2	2	2	3	2	3
G6	2	2		2	3	2	2	1	3	3	3	3	2
G7	2	2		2	1	2	2	1	1	2	2	1	2
G8	1	2		2	1	2	2	1	1	2	2	1	2
G9	2	1		2	1	1	2	1	1	2	1	1	2
G10	2	3		2	3	2	2	2	3	2	3	1	3

⁴¹ Reinhart, C.F., Dogan, T., Ibarra, D. and Samuelson, H. 2012, Learning by playing – teaching energy simulation as a game. Journal of Building Performance Simulation, 5(6), pp. 359-368.

The results show that, in most cases, projects with architectural concepts based on solid and significant relations with the site and the neighborhood were more successful in using these as guidelines for the realization of the parametric model and to properly conduct the different project phases. In this way the project idea remained unaltered during the design process, even through the performance analysis and selection step. Only in the cases of groups 1 and 9 a proper architectural concept relation was not able to support the project idea, because a large number of elements have been used to formalize the concept, though each one was properly related to the site.

In most of the cases, a solid architectural concept used as guidelines permitted to realize a well structured parametric model. This one, on one side allowed for the correct realization of the urban pattern models based on the project ideas, on the other side permitted the generation of a large number of project variations and buildings' massing. In few cases, i.e. for groups 8, and 9 an overly complex parametric model has led to a limited number of usable variations and buildings' massing.

The results relative to the Performance Simulations and Analysis activity show that all the groups were able to perform proper daylight simulations, whereas half of the groups encountered difficulties performing energy simulations. This result was expected due to the higher complexity of the energy simulations. However, it is worth noting that the capacity shown by the student groups to perform simulations is not directly related with the capacity shown in previous activities of the course, and with the capacity to conduct properly the analysis of the simulation results.

The analysis of the simulation results to select the project solution, was properly conducted by the groups that were able to generate a large number of project variations through the parametric model, except few cases, i.e. the groups 1 and 7. Further, the projects generated through a large number of parametric variations and massing, yielded better daylight and energy performances. Results show as well that all the student groups were able to perform outdoor comfort simulations in a proper or remarkable way. The reason is to be found in the direct integration of this type of simulation in the parametric design workflow, whereas daylight and energy simulations are performed by external software connected to the parametric model, thus more difficult to control.

The results relative to the Urban Design activity show that the final design proposal was more consistent with the initial idea for the projects characterized by a stronger relation of the architectural concept with the site. The exception is group 9, that was not able to develop a strong design proposal, though they presented an architectural concept properly related to the site, for reasons related to the students' work organization. The groups 5, 6, and 10 developed design proposals with a remarkable consistency, improving the score relative to the architectural concept. The reason is to be found in correctly realized parametric patterns and in an adequate number of project variations and massing options.

The results show as well that the student groups that showed capacity to correctly use the performance analysis results for the selection of the design proposal were the same groups able to develop projects consistent with the initial ideas. Two groups, i.e. group 2 and 4, presented design

proposals with a low consistency, though they used the analysis remarkably. The reason is to be found in the particular attitude toward technical solutions instead than urban design methods. The average quality of the site plan was low. The author argues that this is due to the big amount of work required previously by the parametric and performance design activities. At the same time, on average the student groups showed good capacity to transform the evidence obtained from the outdoor comfort simulations in livable and pleasant outdoor spaces. The reason is to be found in the clarity of the method design-analyze-adapt.

5. Conclusion

The study introduces and discusses methods and outcomes of the course Planning Project I Energy Efficient Urban Quarter, taught by the author at TalTech during Fall 2019. The students had the possibility to develop the design of a high density urban quarter for living and working in Tallinn, characterized by the indoor comfort and resource efficiency of buildings, and livability of outdoor spaces. Based on an architectural concept, the students successfully realized an urban scale parametric model to generate a number of project variations to be used for daylight and energy simulations. The performance results have been analyzed on the basis of building regulations and standards, allowing them to correctly select one design layout, also in accordance with the initial project ideas, and to develop further the design of a public area on the basis of outdoor comfort simulations results.

The lessons learned in the course will be useful to improve the quality of the future courses delivered by the author, and can be relevant also for other lecturers interested in integrating urban design and performance simulations. The suggestions and recommendations are:

- Design ideas based on significant relations with the site and simple architectural concepts allow to realize correctly parametric models and consequently consistent urban design proposals.
- Students must be urged to realize well structured parametric models that allow the generation of a large number of project variations that increase the availability of optimal design solutions.
- The different students' success to develop the architectural concept and to realize the parametric model than performing simulations and analyzing the results indicate the necessity to teach simulations integrated in urban design courses to improve the students' skills and knowledge.
- The application of simulation software integrated in the parametric design workflow, as the outdoor comfort simulation plug-in, as opposed to external software, as the daylight and energy tool used in the course, allows students to learn simulations more easily and effectively.
- Students learn successfully the use of simulations and performance analysis when the results are used directly to take design decisions using the method design-analyze-adapt.

The course method developed presents one main limitation. The design of the public area through outdoor comfort analysis has been developed after that the optimal configuration has been selected on the basis of the building performances. This process does not guarantee also the optimal outdoor comfort for the public area. The reason of this choice was that to limit the complexity of the process of selection by the students of the most performative design solution. In future courses it will be added simplified methods to add objectives related to the improvement of the outdoor comfort for the selection of the urban design solution. Further, additional analysis periods will be included in the simulations, such as winter and autumn, to design public area with increased comfort during the whole year.

The course succeeded in increasing the awareness in the students of the importance of considering climatic factors as crucial aspects in architectural design. They learned how to integrate urban design principles and performance-driven design methodologies through parametric design, for the realization of sustainable and climate conscious cities. They experimented the evidence-based method of design, that uses environmental data, building requirements and dweller preferences as input and produces objective project outcomes. In this way the students integrated a research with a design experience. The author stands for the necessity for the architecture students nowadays to be able to prove with objective arguments the quality of one design solution over another, adding value to their design.

References

- Andersen, M., Mardaljevic, J. and Lockley, S.W. 2012, A framework for predicting the non-visual effects of daylight - Part I: Photobiology-based model. *Lighting Research & Technology*, 44(1), pp. 37–53.
- Bröde, P., Jendritzky, G., Fiala, D. and Havenith, G. 2010, The Universal Thermal Climate Index UTCI in 27 Operational Use. In *Proceedings of Conference: Adapting to Change: New Thinking on Comfort*, Windsor, UK, 9-11 28 April 2010.
- Charles, P.P. and Thomas, C.R. 2009, Building performance simulation in undergraduate multidisciplinary education: learning from an architecture and engineering collaboration. In *Proceedings of the 11th International Building Performance Simulation Association Conference (BS 2009)*, Glasgow, UK, 27-30 July 2009, pp. 212-219.
- Chatzipoulka, C., Compagnon, R. and Nikolopoulou, M. 2016, Urban geometry and solar availability on façades and ground of real urban forms: using London as a case study, *Solar Energy*, 138, pp. 53–66.
- Darula, S., Christoffersen, J. and Malikova, M. 2015, Sunlight and insolation of building interiors. *Energy Procedia*, 78, pp. 1245–1250.
- De Luca, F. and Nardini, M., *Dietro le quinte: tecniche d'avanguardia nella progettazione contemporanea*. Testo & Immagine, Torino, Italy, 2003.

De Luca, F., Voll, H. and Thalfeldt, M. 2016, Horizontal or vertical? Windows' layout selection for shading devices optimization. *Management of Environmental Quality: An International Journal*, 27(6), pp. 623–633.

De Luca, F. and Voll, H. 2017, Solar Collection Multi-isosurface Method - Computational Design Advanced Method for the Prediction of Direct Solar Access in Urban Environments. In *Computer-Aided Architectural Design: Future Trajectories*, Communications in Computer and Information Science (CCIS), 724, Springer Nature, 170-187.

De Luca, F. and Dogan, T. 2019, A Novel Solar Envelope Method Based on Solar Ordinances for Urban Planning. *Building Simulation: An International Journal*, 12(5), 817-834.

aDe Luca, F. 2019, Environmental Performance-Driven Urban Design: Parametric Design Method for the Integration of Daylight and Urban Comfort Analysis in Cold Climates. In *Computer-Aided Architectural Design: "Hello, Culture"*, Communications in Computer and Information Science (CCIS), 1028, Springer Nature, pp. 15-31, 2019.

bDe Luca, F. 2019, Sun and Wind. Integrated Environmental Performance Analysis for Building and Pedestrian Comfort. In *Proceedings of the Symposium on Simulation for Architecture and Urban Design (SimAUD 2019)*, Atlanta (GE), USA, 7-9 April 2019, pp. 3-10.

cDe Luca, F. 2019, Learning Performance-driven Design. Students Approach Integrating Urban Form Studies and Building Performance Analysis. In *Proceedings of the 16th International Building Performance Simulation Association Conference (BS 2019)*, Rome, Italy, 2-4 September 2019, pp. 1609-1616.

Estonian Government, Minimum requirements for energy performance, Ordinance n. 68, 30.08.2012. EVS, Tallinn, Estonia, 2012. Available at: <https://www.riigiteataja.ee/en/eli/520102014001>

Ibarra, D.I. and Reinhart, C.F. 2009, Daylight Factor simulations – How close do simulation beginners 'really' get? In *Proceedings of the 11th International Building Performance Simulation Association Conference (BS 2009)*, Glasgow, UK, 27-30 July 2009, pp. 196-203.

Illuminating Engineering Society, LM-83-12 - Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE). IES, New York, USA, 2013.

Intergovernmental Panel on Climate Change (IPCC), Annex I: Atlas of Global and Regional Climate Projections Supplementary Material RCP8.5. In *Climate Change 2013: The Physical Science Basis*. Working Group I, Bern, Switzerland, 2013.

International Energy Agency, *World Energy Outlook 2016*. IEA, Paris, France, 2016.

Kanters, J. and Horvat, M. 2012, Solar energy as a design parameter in urban planning. *Energy Procedia*, 30, pp. 1143–1152.

Kanters, J., Wall, M. and Dubois, M.C. 2014, Typical values for active solar energy in urban planning. *Energy Procedia*, 48, pp. 1607-1616.

Lobaccaro, G. and Frontini, F. 2014, Solar Energy in Urban Environment: How Urban Densification Affects Existing Buildings. *Energy Procedia*, 48, pp. 1559–1569.

Lobaccaro, G., Acero, J.A., Martinez, G.S., Padro, A., Laburu, T. and Fernandez, G. 2019, Effects of orientations, aspect ratios, pavement materials and vegetation elements on thermal stress inside typical urban canyons. *International Journal of Environmental Research and Public Health*, 16(19), art. n. 3574.

Lockley, S.W. 2009, Circadian Rhythms: Influence of Light in Humans. In L. R. Squire (ed.), *Encyclopedia of Neuroscience*, pp. 971-988. Elsevier, Amsterdam, Netherlands

McNeel, R., Rhinoceros. Robert McNeel & Associates, Seattle, USA, 2019. Available at: <https://www.rhino3d.com/>

E. Naboni and L. Havinga, *Regenerative Design in Digital Practice: A Handbook for the Built Environment*. Eurac Research, Bolzano, Italy, 2019.

Naboni, E., Natanian, J. Brizzi, G., Florio, P., Chokhachian, A., Galanos, T. and Rastogi, P. 2019, A digital workflow to quantify regenerative urban design in the context of a changing climate. *Renewable and Sustainable Energy Reviews*, 113, art. n. 109255.

Oke, T.R., Mills, G., Christen, A. and Voogt, J.A., *Urban Climates*. Cambridge University Press, Cambridge, UK, 2017.

Reinhart, C.F, Mardaljevic, J. and Rogers, Z. 2006, Dynamic Daylight Performance Metrics for Sustainable Building Design. *Leukos*, 3(1), pp. 7–31.

Reinhart, C.F., Dogan, T., Ibarra, D. and Samuelson, H. 2012, Learning by playing – teaching energy simulation as a game. *Journal of Building Performance Simulation*, 5(6), pp. 359-368.

Reinhart, C.F., Dogan, T., Jakubiec, A.J., Rakha, T. and Sang, A. 2013, UMI - An Urban Simulation Environment for Building Energy Use, Daylighting and Walkability. In *Proceedings of 13th International Building Performance Simulation Association Conference (BS 2013)*, Chambéry, France, 26-28 August 2013, pp. 476-483.

Reinhart, C.F, *Daylighting Handbook I. Fundamentals and Designing with the Sun*. Building Technology Press, Cambridge (MA), USA, 2014.

Reinhart, C.F., Geisinger, J., Dogan, T. and Saratsis, E. 2015, Lessons learnt from a simulation-based approach to teaching building science to designers. In *Proceedings of 14th International Building Performance Simulation Association Conference (BS 2015)*, Hyderabad, India, 7-9 December 2015, pp. 1126-1133.

Rutten, D., Grasshopper. Robert McNeel & Associates, Seattle, USA, 2020. Available at: <https://www.grasshopper3d.com/>

Sadeghipour Roudsari, M, and Pak, M., 2013, Ladybug: A Parametric Environmental Plugin for Grasshopper to Help 10 Designers Create an Environmentally-conscious Design. In *Proceedings of*

13th International Building Performance Simulation Association Conference (BS 2013), Chambéry, France, 26-28 August 2013, pp. 3128–3135.

Samuelson, H.W., Lantz, A., and Reinhart, C.F. 2012, Non-technical barriers to energy model sharing and reuse. *Building and Environment*, 54, pp. 71-76.

Santamouris, M. 2014, Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Solar Energy*, 103, pp. 682–703.

United Nations Department of Economic and Social Affairs, *World Urbanization Prospects: The 2018 Revision*. United Nations, New York, USA, 2018.

Voll, H., De Luca, F. and Pavlovas, V. 2016, Analysis of the insolation criteria for nearly-zero energy buildings in Estonia. *Science and Technology for the Built Environment*, 22(7), pp. 939–950.

Voll, H., Thalfeldt, M., De Luca, F., Kurnitski, J. and Olesk, T., 2016, Urban planning principles of nearly zero-energy residential buildings in Estonia. *Management of Environmental Quality: An International Journal*, 27(6), pp. 634–648.

Westrup, U. and Planander, A. 2013, Role-play as a pedagogical method to prepare students for practice: The students' voice. *Högre utbildning*, 3(3), pp. 199-210.

Biography

Francesco De Luca (PhD, Architect) graduated with honors in Architecture and defended his PhD thesis in Architectural Design and Theories at the University of Rome "La Sapienza". Currently he is Research Scientist at Tallinn University of Technology (TalTech). His work merges architectural and urban design, performance analysis, computational and environmental design and is finalized to develop solutions, methods and tools to tackle the pressing issues of resource depletion, healthiness and climate change. He holds the National Scientific Qualification of the Ministry of University and Research of Italy as Associate Professor of Design and Architecture Technology. He has been Lecturer at Sapienza University of Rome (2001-2006) and Visiting Associate Professor at TalTech Tartu College (2010-2014). He lectured at Aalto University, Oslo School of Architecture, Cornell University, TU Delft and Université de Montréal. He is author of peer-reviewed publications for journals such as *Automation in Construction*, *Building and Environment* and *Building Simulation*, and for conferences such as SimAUD, CAAD Futures, eCAADe, ACADIA and IBPSA. He participated in several research programmes such as Central Baltic Cooperation in Energy Efficiency & Feasibility in Urban Planning (Interreg) and Centre of Excellence in Zero Energy and Resource Efficient Smart Buildings and Districts (EU Structural Fund). During the professional career as registered Architect he received awards to architectural design competitions and realized buildings that received sustainability and energy efficiency awards.