MARIA HELENOWSKA-PESCHKE*

THE IMPACT OF BUILDING PERFORMANCE ANALYSIS ON INTUITION DEVELOPMENT AND DECISION MAKING RATIONALITY

WPŁYW ANALIZ WYDAJNOŚCI BUDYNKU NA KSZTAŁTOWANIE INTUICJI I RACJONALNOŚCI WYBORÓW PROJEKTOWYCH

A b s t r a c t

Contemporary architectural technique is characterized by the ability to efficiently collect and process huge amounts of geometric and non-geometric information. Virtual substitutes for buildings and structures allow various aspects of real life activity to be analysed at various stages of the design process. The possibility of increased prognostic quantitative data acquisition, such as cost of energy consumption, shifts architectural practice towards rationalizing design decisions and multi-criteria objectivization. This article presents a view in the discussion on the importance of digital tools for building energy modelling and daylight simulation in the initial conceptual design phase for shaping architectural intuition and empowering design decisions. Issues related to the methodology of digital design, along with the possibilities and limitations of currently available tools tailored to the needs of architects will be discussed.

Keywords: performance / energy modelling of the building, digital design, design methodology

S t r e s z c z e n i e

Współczesny warsztat architektoniczny cechuje możliwość efektywnego gromadzenia i przetwarzania ogromnych ilości informacji geometrycznych i niegeometrycznych. Wirtualne substytuty budynków/budowli pozwalają na analizę różnych aspektów zachowania się rzeczywistych obiektów na różnych etapach procesu projektowego. Możliwość pozyskiwania prognostycznych danych ilościowych, takich jak na przykład wielkość zużycia energii, przesuwa mocniej architektoniczną praktykę ku racjonalizacji decyzji projektowych i wielokryterialnej obiektywizacji. Artykuł jest głosem w dyskusji na temat znaczenia cyfrowych narzędzi do modelowania energetycznego budynku i symulowania światła dziennego we wstępnej koncepcyjnej fazie projektowania dla kształtowania architektonicznej intuicji i umocowania decyzji projektowych. Poruszone zostaną kwestie związane z metodologią projektowania cyfrowego oraz możliwości i ograniczenia aktualnie dostępnych narzędzi dopasowanych do potrzeb architektów.

Słowa kluczowe: analizy wydajności/energetyczne budynku, projektowanie cyfrowe, metodologia projektowania

* D.Sc. Ph.D. Arch. Maria Helenowska-Peschke, Department of Visual Arts, Faculty of Architecture, Gdańsk University of Technology, mhelen@pg.edu.pl.

1. Introduction

Energy modelling and other performance simulation tools do not replace expertise and experience, but offer support, providing concrete feedback that enables architects to sharpen their intuitive judgments both within the project and from project to project[1].

Architectural design as a complex intellectual activity is the object of scientific investigation from many different perspectives. It covers issues related to the creative conception of the architectural idea, organization and technological equipment of the design process, and also the importance of architectural artefacts for societies. It is known that architects and designers differ in terms of both creative and cognitive abilities, as well as style and methods of work. This article presents a view in the discussion of merging an intuitive and rational approach to creating architecture in the context of digital tools usage for building energy modelling and daylight simulation. The theory of information processing was chosen as the starting point for reflection, showing design as an activity similar to knowledge-based problem solving. A human solves problems by searching a problem space, i.e. the mental representation of the problem he creates, which contains possible holistic and partial solutions. Knowledge is of great importance in defining the problem space, as it consists of task statement, previous experience in solving similar tasks and knowledge of general schemes for solving many different problems. Firstly, cogitation and decision making take place in the absence of full knowledge and undefined project tasks (ill-structured task). Later, as the amount of information increases, new knowledge is revealed, which allows for gradual narrowing of the problem space[2].

In the era of computer-aided design, huge input in building new knowledge about the problem/project task is provided by feedback through computer simulations of architectural object functioning. Design practice shows that detailed (lower level) decisions affect the revision of previously made (higher level) arrangements owing to the appearance of information generated in subsequent phases of the design process. The combination of a creative, intuitive design idea conception with reliable simulation results leads to rational decisions, reduces the probability of errors and increases the confidence to better meet contemporary architectural challenges regarding environmental protection and the quality of the built environment.

2. Architecture follows energy

The concern of modern societies for the natural environment and resources is the reason why the value of architecture, aside many non-quantified and difficult to objectify factors, is increasingly attributed to measurable environmental parameters, such as energy consumption. Performance-based design is a well-known concept that has now gained strong support in the form of computer tools. Modelling building performance[3] – including energy efficien-

[1] *An Architect's Guide to Integrating Energy Modelling in the Design Process*, Wyd. AIA, 2012, p. 32.

[2] A. Newell, H. A. Simon, *Human problem solving*, Prentice Hall, Englewood Cliffs, New Jersey 1972, p. 10.

[3] Building performance modelling provides information on energy efficiency, daylight penetration, glare control, thermal comfort, natural ventilation, etc.

cy[4] – has become one of the key aspects of architectural design in the 21st century. In many developed countries, standards and certification systems for green buildings (e.g. LEED, BREEAM, DGNB and others) are implemented, which allow for the identification and implementation of practical and measurable solutions in the field of environmentally friendly building design, construction, operating and maintenance[5]. The methods used to measure the efficiency of buildings are becoming increasingly elaborate[6]. Energy consumption, carbon dioxide emissions, thermal comfort, availability of daylight and operating costs, etc., may be considered as performance indicators.

New requirements and goals change the architectural design workflow. In the case of minor problematic project tasks or those that do not aspire to green standards, it is generally sufficient if architects follow general rules of thumb or make decisions based on experience related to previously used solutions, materials and construction systems.

In the case of more complex conditions (e.g. unusual location, investor setting ambitious environmental goals, there is a need of broad view exposition from the north side or to create specific lighting conditions for exhibits in a museum), it is necessary to consider various, mutually coupled parameters of the building energy efficiency and determine the general daylight energy implications and solar profits. Such ambitious design tasks require architects, engineers and installers to apply computer technology. *Performance-based design is redefined as the ability to directly manipulate the geometric properties of a digital model on the basis of performative analyses in order to optimize performance*[7].

In current, everyday practice, the building energy modelling is usually (if at all) entrusted to specialists after the team of architects has refined a stable, sustained configuration. On the one hand, this is a tradition of professional practice in which architects design buildings as formal constructions, and then installation engineers and energy modelling experts design solutions at the MEP systems level (mechanical, engineering, plumbing). Energy simulations serve to demonstrate the buildings' characteristics compliance with local building codes and ordinances, voluntary green building programs and/or customer requirements. Secondly, advanced simulations require complete data on all building components and systems that affect energy performance, which are determined in the later stages of the design process. As a consequence of delaying the simulation of energy efficiency (sunlight remains its important component), it is no longer possible to optimize solutions by early exploration of various design scenarios (when it matters the most).

Considering the aim to build energy optimization, the desired project workflow carries update and numerous analyses of energy models during the development of the design idea, providing necessary information when architects face a key decision. Energy analysis should be understood as *the process of analyzing a building's energy performance by calculating how well the integration of that building's form, systems, and envelope perform under the*

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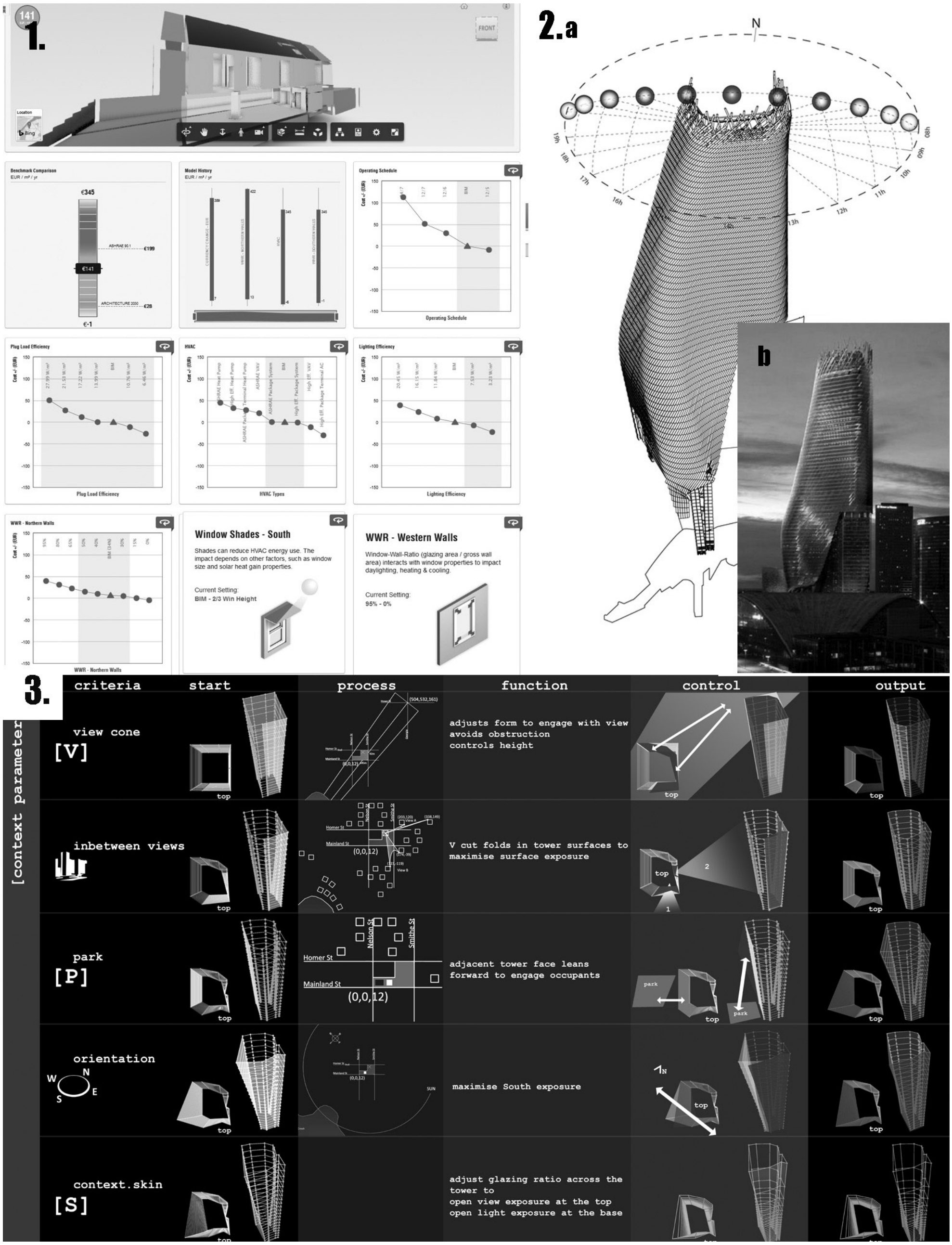
4 Energy modelling of a building provides information on the expected energy consumption of the building and possible savings and compliance of the forecasts with codes and standards.

5 https://plgbc.org.pl/certyfikacja-wielokryterialna/leed/

6 Broadly speaking, building performance is a design philosophy based on the assumption that homes should be safe, functional, healthy, comfortable, durable and energy efficient etc.

7 A. Prokopska, *Metodyka projektowania architektonicznego,* Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów 2016, p. 5.



Ill. 1. Insight 360 – panel layout with diagrams for energy efficiency simulation

Ill. 2. “Tower Formation”, parametric forming using environmental criteria, research project, Madkour Y., Neumann O., 2009

Ill. 3. Phare Tower in Paris, design by Morphosis, a) the influence of the sun path on the building shape, b) view *surrounding environmental conditions*[8]. Due to their competences, are the most appropriate team members to assume a leadership role in the process[9].

Platforms (tool collections) for building energy modelling and daylight analysis have been developed for over a decade. The wide range includes both commercial and opening programs (based on industry-leading simulation engines DOE 2.2, EnergyPlus and Radiance) created for different end users. Current strategies of developers of analytical software include the development of interfaces dedicated directly to architects, adapted to their working methods and needs (e.g. OpenStudio, DesignBuilder Architectural, Green Building Studio).

3. Energy analysis and development of a design idea

the process of architectural design starts with a creative initial phase covering basic design decisions and is usually crucial for aesthetic and functional values of the designed artefact. Many publications in the field of design methodology prove little awareness by architects regarding the impact of early design decisions on energy efficiency and use of daylight[10]. *Although the designer's experience could be sufficient in the decision-making process in early design stages, BPS tool simulation could be a valuable support in terms of reconsidering preconceived ideas, leading to the innovation and evolution of the designer's knowledge during the same project*[11]. Early virtual energy models treat the building as a system composed of various subsystems (geometry, elevation, HVAC system), whose interaction significantly affects the energy efficiency of the building. They provide designers with important and sometimes surprising data[12] on the operational and energetic effects of early design decisions. The proper use of daylight requires the associated forms and devices to be perceived as an integral part of the architectural design from the conceptual stage (as soon as the form of the building and the elementary layout are known).

The tools for building performance analysis also have an educational value because they allow the user to better understand and capture the relationship between the body with the façade and the interior and therefore develop and inform intuition[13] . It is in the public interest that architects enrich their own design workshop with digital tools for performance/energy and daylight analysis.

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8 B. Cross i in., *Whole Building Energy Analysis: A Comparative Study of Different Simulation Tools and Applications in Architectural Design*, 2014 ACEEE Summer Study on Energy Efficiency in Buildings, 2014, p. 2.

9 *An Architect's Guide to Integrating Energy Modelling in the Design Process*, Wyd. AIA, 2012, p. 27.

10 M. Ianni, Sanches de Leon M., *Applying Energy Performance-Based Design in Early Design Stages. A methodological framework for integrating multiple BPS tools*, eCAADe 31, Computation and Performance, v1., 2013, p. 39.; *Lee A.* i in., *Developing a workflow for daylight simulation in early design stages to address the Green Star ratings***,** Proceedings *CAADRIA 2016, p. 363–372; Lima M.X. i in., The use of simulation to evaluate design options on conceptual mass study phase. SIGraDI 2012, p. 458–461; A. Prokopska, Metodyka projektowania architektonicznego,* Oficyna Wydawnicza Politechniki Rzeszowskiej, 2016.

11 M. Ianni, Sanches de Leon M., *op.cit.*, p. 39.

12 For example, in some cases, a smaller window area may be disadvantageous for achieving a balance of solar gain and heat loss through the north façade.

13 J. Frazer, *Lecture on Computational Design*, 2014. access on line 20.05.2018 https://www.youtube.com/watch?v=xd4TiPnwGwE&feature=youtu.be.

3.1. Integration with BIM

Fortunately for professionals (and customers), tools for analyzing building energy efficiency are now integrated with BIM modelling, which helps to achieve a smooth flow of information/work between modelling and simulation, reducing the time needed to improve the design. The latest version of Revit, (BIM software popular on the Polish market), offers a service in cloud[14] named Insight 360 (based on the Green Building Studio platform), which integrates many available procedures (building energy analysis, daylight and artificial light analysis, solar radiation and photovoltaic energy potential) providing a holistic approach to determining the performance of a building[15.] From the architect's point of view, it is important that the architectural model (constituting the record of the current reality of the project) is used to automatically create an analytical energy model that is being uploaded to Insight 360. In addition to geometry, the early energy model contains data relevant for the level of simulation, such as: weather data from the nearest meteorological station, target percentage glazing, building type, operating schedule, HVAC system, room/spatial data, material thermal properties. For parameters that may not be known at an early stage of the project, the program adopts default values representative of minimum or typical requirements and general construction standards. The final report contains information on forecast energy costs and a series of interactive diagrams enabling changes in parameters of several key parameters (namely: building orientation, operating schedule, plug load and lightning efficiency, HVAC type, wall and roof construction, window to wall ratio, glass properties, solar efficiency, light darkening system, window shades, air infiltration, daylighting & occupancy controls, infiltration, PV panel efficiency and *surface coverage),* without modification of the architectural model (Ill. 1). Insight360 compares the effectiveness of the solution and possible modifications with the reference levels given in ASHRAE 90.1 standards[16]. Modification of settings (e.g. increasing window area, building rotation in relation to the world pages) automatically updates the report, which ensures real time interaction with the parameters. Owing to the possibility of quick exploration of various scenarios, the architect gains the feeling (shape intuition) of how different related parameters affect the energy efficiency of the designed object, identifies the range of options within the design constraints (resulting from e.g. location, budget, etc.) and can compare the relative efficiency of these options. Insight 360 also enables basic simulations of daylight efficiency for different comparison periods – winter and summer solstice and spring and autumn equinox. Solar analysis of surface models allows the most favorable location of photovoltaic panels to be determined in order to maximize solar gain. In addition to reports based on tables and standard charts, the results of the analysis are mapped on the surfaces of the building or displayed directly in the building spaces. As the project develops, it is possible to create a more accurate energy model by replacing default values and assumptions by data resulting from previous design decisions.

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[14] The principle of cloud computing works by transferring the entire burden of providing IT services (data, software or computing power) to the server and enabling constant access via client computers source: https://pl.wikipedia.org/wiki/Chmura_obliczeniowa.

[15] https://medium.com/autodesk-university/discover-insight-360-for-building-energy-modelling-272e13a7bb0.

[16] An international standard that specifies minimum energy requirements – efficient building projects, with the exception of low-intensive housing.

The last act in the process of performance analysis belongs to the experts on energy modelling, whose task is to forecast the real costs of building operating and to determine the compliance characteristics with the applicable requirements and/or expectations of the client. At this stage of design development, major changes in the basic assumptions are very labour-intensive and time-consuming, even when the project is developed in BIM technology.

3.2. Digital tool personalization

Around the world, innovative architects who are looking for the idea and optimization of design solutions are more and more willing to use digital parametric-algorithmic design. The distinguishing feature of this methodology is the creation of digital tools personalized for the specific task on the script level (internal language of the application)[17]. The script (algorithm containing variables / parameters) is a record of the procedure generating output geometry according to the logic defined by the designer (corresponding to the solution space). Changing the values of the parameters describing the geometry enables generation and testing of the entire class of alternatives (family of forms). The number of parameters, their role and location in the algorithm determine the range of possible variances that follow the same generative logic. Under the influence of new knowledge, requirements and design constraints emerging in the course of designing, the tool is modified and the geometry levels are extended (the script has a modular structure)[18]. *Essentially, this exploration has its own dynamics, involving intuition and spontaneity, and without which there is no design*[19]. In the context of building performance, the advantage of parametric-algorithmic models is also the capability to acquire different geometry descriptions for various analytical tools[20]. Improvement of design solutions can be done using the built-in optimization algorithms with embedded internal feedback loops (Ill. 3).

The combination of development of computational techniques, progress of knowledge about biological evolution and optimization theory results in the development of design methods based on the use of evolutionary algorithms for generating and optimizing designs. The concept consists in building the criteria controlling the process of evolving the form (from generation to generation) directly into the generative script by means of feedback[21]. This enables multi-criteria optimization as evolutionary algorithms are capable of creating a range of optimized compromise solutions between the extremes of each target.

The combination of integration of simulation and evaluation processes with digital form generation is a step towards future computer systems for performance-based design. *In such*

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17 The following visual editors of scripts are generally used by designers here: Generative Components, Grasshopper (Rhinoceross plugin) and Dynamo.

18 M. Helenowska-Peschke, *Parametryczno algorytmiczne projektowanie architktury*, Wydawnictwo PG, 2014, p. 85.

19 R. Aish, *From Intuition to Precision*, AA Files 52 The Architectural Associacion, London, 2005, p. 10.

20 For example, the DIVA and Honeybee extensions combine Grasshopper with the EnergyPlus, Radiance, Daysim and OpenStudio engines for energy analysis, thermal comfort, daylight and lighting simulation.

21 The geometry is generated and transformed according to the assessment criteria (eg structural efficiency, solar load, acoustic and aerodynamic conditions).

circumstances digital design diverges from a design paradigm in which the formal manipulative skills and preferences of the human designer externally control the process to one in which the design is informed by internal evaluative and simulation processes[22].

Exploration of the space of solutions using generative methods favours the discovery of new innovative solutions allowing the balance between aesthetics and project effectiveness to be maintained (according to the criteria set by the architect but without the possibility of direct process control.

4. Barriers and limitations

In recent years, software for energy simulations and daylight analysis has been the subject of practical verification and comparative analysis for the reliability of results, interface functionality and speed of operation. The research revealed divergences with the energy efficiency of real buildings, results obtained with physical models as well as between different applications. In cases of more complex building components and passive systems, calculations are prone to errors and unreliable[23]. Therefore, the ability to interpret the information correctly is important (it is only an approximation of reality). Construction, operation and maintenance, seasonal weather changes and operational schedules affect the actual performance of the building in a way that will inevitably move away from the modelled conditions. The results of the calculations make it possible to compare different variants together, determine the amount of savings as a percentage, but it is not allowed to provide a guarantee to the client as to the amount of costs based on them. The same applies to the credibility of tools for daylight and lighting analysis[24]. According to comparative studies, although competition is increasing among the software for lighting analysis, the margin of error of results is still high.

In Polish conditions, the relatively low popularity of BIM technology in the architectural and construction industry is still an obstacle to the wide use of building performance simulation tools. Data from the AutoDesk 2015 report, "BIM – The Polish perspective", revealed that only about 25% of respondents declare the use of BIM methodology in their projects[25]. Therefore, the consequences of decisions regarding the energy efficiency of buildings, in particular distant in time and space, are too seldom taken into account when making design decisions. Moreover, there are no legal regulations in force, private developers expect quick profits and the society is not in a position to make demands. Nevertheless, in the light of the the need to minimize the negative impact of architecture on the environment, it seems reasonable to postulate the extension of architectural education with knowledge and skills

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[22] R. Oxman, *Performance-based Design: Current Practices and Research Issues*, International Journal of Architectural Computing 1 (06), 2008, p. 3.

[23] B. Cross i in., *Whole Building Energy Analysis: A Comparative Study of Different Simulation Tools and Applications in Architectural Design*, *op.cit.*, pp. 1–11; M. Gomaa: J. Wassim, *Evaluating Daylighting Analysis of Complex Parametric Facades*, eCAADe 34, Evaluations, v 2, 2016, pp. 147–156.

[24] The building's energy models can only help predict the effects of daylight design. They do not provide the designer with the information necessary to design a well-lit space.

[25] BIM awareness is higher among architects (65.4%) than structural engineers and installation designers (50.3%).

in this area. Together with the need to influence current practice, this seems to be a challenge in itself[26]. It is important for architects to know what information they can get from the analytical energy model and light simulation, which will be helpful in making important decisions, and they can correctly interpret the results. Finally, it should be emphasized that, despite the undoubted advantages of quantitative measurements, intangible benefits, such as the emotional and aesthetic needs of users, are difficult to link with the economic value in direct quantification.

5. Final remarks and conclusions

Computer technologies influence what architects create, but also how they create. The next generations of 3D modelling tools and performance simulation analyses are increasingly suited to the needs of architects. Decisions to improve energy efficiency and reduce CO_2 emissions due to complex interactions between different building components and subsystems are difficult to resolve intuitively. Both initial and more detailed energy models and lighting analyses provide quantitative data sufficiently accurate to reduce the uncertainty of decisions, and verify pre-determined solutions in terms of their energy efficiency. That is why, in the environmentally aware architectural practices, they are becoming an element of the design process present at all stages of the idea development. According to W. Gasparski, *Being able to design is able to make decisions supported by the strength of the argument, not the argument of strength* [27] This does not diminish the role of intuition, instinct and humanistic tradition in creating an architectural idea.

Design is different to 'craft'; to directly 'making' or 'doing'. It necessarily has to be predictive in order to anticipate what the consequence of the 'making' or 'doing' will be. Therefore we inevitably have to counter balance our intuition with a well developed sense of premeditation[28].

The aesthetic consequences of performance driven design have long been present in architectural discourse and invariably draw the attention of theoreticians. The importance of effective daylight in the design of energy-efficient buildings is reflected in the aesthetic changes of modern architecture[29]. As a consequence of formal freedom, resulting from digital modelling and manufacturing building components, innovative buildings are created, often with curvilinear geometry, which is the result of computer optimization. (Ill. 2a, b) Instead of focusing on applying the latest technology in the form of external mechanical systems (e.g. solar heating or cooling systems, etc.), avantgarde designers are looking for an answer on how adequately shaped architectural form can meet the requirements of energy efficiency by itself. Contemporary elevations are distinguished by advanced systems of solar blinds and double constructions. *Architecture evolves towards artistic rationalism, adapted to today's*

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[26] Reinhart i in., *Learning by playing: teaching energy simulation as a game*, Harvard University GSD, 2012.

[27] Knowledge on organization and management and its cognitive consolidation. W. Gasparski http://kklinc.blox.pl/resource/SeminariumReferatProfGasparskiego.doc.

[28] R. Aish, *From Intuition to Precision*, AA Files 52 The Architectural Associacion, London, 2005, p. 10.

[29] M. Rogińska-Niesłuchowska, *The architecture of daylight in the discourse about the aesthetics of sustainebility*. 17th International Multidisciplinary Scientific Geoconference SGEM, 2017, pp. 1031–1038.

material, technical and technological possibilities[30]. Many great contemporary architects successfully respond to the challenges related to environmental protection and the timeless human need to experience beauty.

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