

Aerodynamics in the education of prospective architects

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ABSTRACT: The inclusion of issues of aerodynamics in the education of architecture students is discussed in this article. The field of aerodynamics provides knowledge of the nature of wind phenomena around building developments. It is especially important to know how to influence the occurrence of such phenomena by means of shaping buildings through architectural and urban design. The method applied for working with Master's degree students in the Faculty of Architecture at Gdańsk University of Technology (FA-GUT), Gdańsk, Poland, included experimental studies in a wind tunnel. The technique allows prospective architects not only to become acquainted with a specific issue that ranges beyond their competencies, but also to attain a broader perspective on the interdisciplinary nature of building residential estates and on city design.

INTRODUCTION

The implementation of sustainable development in architecture and urban planning entails taking more criteria into account in the design process. These criteria concern a number of disciplines that do not normally fall within the scope of architects' knowledge. Therefore, a need arises to modify architectural design methods and to rely on interdisciplinary co-operation [1]. The meso- and microclimate in urban spaces is related to a variety of disciplines, including architecture and wind engineering; the latter discipline makes it possible to study and regulate aerodynamic phenomena occurring around buildings.

Discussed in this article is an approach to educating architecture students that incorporates aerodynamics into the design process for buildings and building complexes. Interdisciplinary co-operation shaped during education is likely to influence the transformation of the existing design process, not only in terms of aerodynamics, but also in other areas vital to architecture and urban planning. The method for working with students presented here assumes active participation of wind engineering specialists and the use of experiments in the wind tunnel.

Classes were held between 2009 and 2017, in the form of a seminar for students of the Faculty of Architecture at Warsaw University of Technology (FA-WUT), Warszawa, Poland, second degree studies (Master's degree), according to an original programme developed by the author. The interdisciplinary co-operation with the Faculty of Power and Aeronautical Engineering at Warsaw University of Technology (FPAE-WUT) was the key element of the course. Thanks to this co-operation, architecture students who participated in the scheme were given access to research equipment and support by specialists. This allowed students to conduct experiments in the Aerodynamic Division laboratory, which had a crucial impact on their understanding of the issues beyond architecture.

WIND PHENOMENA AROUND BUILDINGS: PRESENT STATE OF RESEARCH

Wind engineering is the discipline in which the airflow around buildings is analysed. It is based on aerodynamics, which is derived from the theory of fluid mechanics. Aerodynamics, initially applied mainly for aircraft, automotive or sports industries, has expanded gradually into new fields, including architecture and urban planning. Wind engineering is a field that has become established over the past few decades [2]. With regard to buildings, wind engineering can be divided into areas related to these issues: structural, building ventilation and the environment surrounding a building.

The issues discussed in this work concern the environment surrounding a building. Research in this field has been intensively developed since the second half of the 20th Century [3]. An illustrative comparison of the issues was provided by the authors of the book, *City and Wind* [4], who specified the milestones of research on wind phenomena around buildings; the impact such phenomena have on people and climate quality; and the research methods applied to simulate these phenomena. In 1975, Gandemer isolated and described the 12 aerodynamic effects created around free-standing buildings and around buildings that form simple layouts. This research generally is considered the first breakthrough in terms of studying the implications of wind phenomena on architecture. The research gave rise to formulation of design guidelines for architects and urban planners.

Gandemer applied experimental tunnel research, which was being developed at the turn of the 1980s and 1990s by subsequent researchers, such as Hussain and Lee, Brown and DeKay and, especially, Oke. It offered a chance to recognise more precisely the nature of wind phenomena that occur in a three-dimensional system [5]. These research results were recognised as a vital element of the pro-ecological approach to the design process developed in the 1990s by researchers, such as Daniels. This researcher described the findings in an influential book entitled *The Technology of Ecological Building* [6].

A great deal of the research was focused on the urban climate, occurring in the so-called street canyons, i.e. in the spaces between two parallel lines of building, which are typical of street layouts in cities. At the same time, research on numerical methods for simulating wind phenomena was being developed. Among the first regarding the ventilation of space between buildings was a study by Walker, Shao and Woolliscroft, conducted in 1993 [7]. The numerical research method has been explored until the present day as it provides a great amount of relevant data. The numerical method is faster and cheaper than tunnel research, but fails to reflect reality as accurately as does tunnel research. At present, in relation to complicated, complex geometric layouts, such as urban development layouts, the combination of tunnel research and numerical methods is considered the most appropriate approach [8][9].

RESEARCH ISSUES AND TASKS UNDERTAKEN BY STUDENTS

The seminar described in this article was centred on a research task that would be understandable to students and relevant to current issues in contemporary architecture. It was important for students to know from the beginning that they were to undertake experimental research to solve a specific problem. A task was to be conducted during the semester and modified in subsequent years. The task concerned city climate quality. To a large extent, it is affected by the geometric layout of the buildings, which causes alterations in wind flow through urban areas. According to research literature, wind directions in built-up areas are altered by about 10° to 20° on average, whereas wind velocities tend to be reduced by 20 percent to 30 percent on average, but winds of low velocity tend to increase [10]. Diverse wind phenomena are likely to occur in a relatively small area.

During the seminar, students were familiarised with the impact building shape exerts on the nature of the airflow around it, in particular on the possibility of properly ventilating urban spaces. The proper intensity of air exchange is one of the crucial factors that counteract the phenomenon of urban heat islands and the retention of smog in urban areas. Suppression of air exchange in cities, which results from excessively intensive development, intensifies these phenomena and leads to a decrease in the quality of the urban mesoclimate. This conclusion is confirmed by general knowledge, but is hardly included in legal regulations referring to the design process. The research question for the students was how intensively urban spaces may be developed to avoid worsening the existent climate problems in cities and how to account for this in urban and architectural design.

Research tasks conducted by students differed in subsequent years; each year a different building development layout was examined. Results are described elsewhere by the author of this article [11][12]. However, all the research tasks were subjected to a uniform principle governing the research. By means of tunnel experiments, it was necessary to:

- identify wind phenomena around specific layouts of building developments;
- specify problem areas related to the disruption of natural ventilation occurring in urban spaces;
- offer a geometrical modification (one or two) to be introduced into the layout of buildings;
- evaluate the effect of the modification.

The starting point for selecting layouts of building developments exposed to excessive restriction in natural ventilation was based on research by Daniels [5]. In this research, with winds perpendicular to the street axis, unobstructed ventilation in that street occurs when the h/w parameter (where h is the height of the buildings and w the distance between them) has a value less than 0.37. When the parameter value is increased beyond that, ventilation becomes gradually limited. If the parameter h/w value reaches 0.74, the air exchange ceases completely. Similar data were also found by the author of this article [11].

As for areas most at risk from the phenomenon described above, courtyards of urban developments, limited by buildings on four sides, tend to be the most vulnerable. In case of such developments, when building development proportions assume the values defined by Daniels as unfavourable for ventilation, the phenomenon of air stagnation occurs. It is also possible to identify stagnation zones in modern residential estate developments, as well as projects implemented to fill the existing downtown building developments in large Polish cities. Buildings with geometry posing a risk of insufficient ventilation can be easily noticed. This situation arises from regulations in force in Poland, especially regarding the minimum distances between buildings deemed acceptable in the case of downtown buildings.

METHODOLOGY

Co-operation between students was of a scientific experiment nature. The experiment involved the application of research tools in the field of aerodynamics. To conduct the classes, it was necessary to develop a model for connecting interdisciplinary issues and that would allow for active participation of students in experiments. It was obligatory to specify partial tasks, their scope and sequence. In the model (see Figure 1) two *paths* are specified in the model: architectural and urban (on the left) and aerodynamic (on the right). Moreover, common areas in the *paths* are defined.

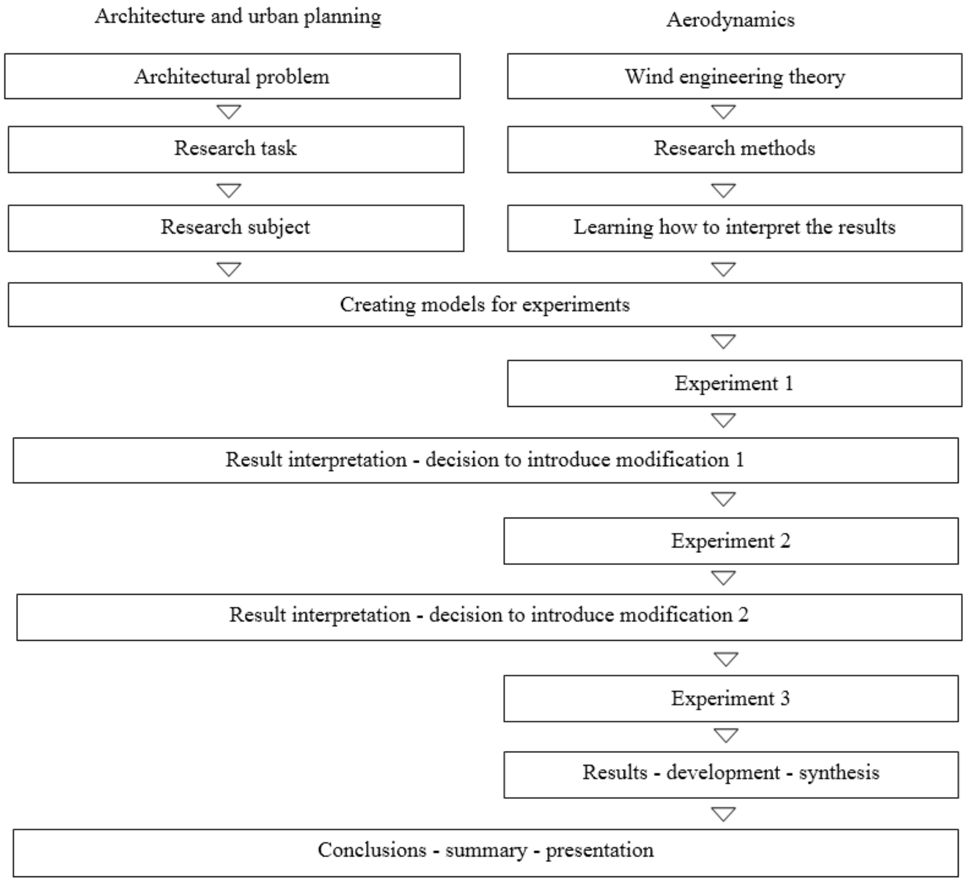

Figure 1: Model of combining architectural and aerodynamic issues for the needs of the research task (by the Author).

The research concerned the impact of building development geometry on the ventilation of urban spaces. This was juxtaposed to, and presented against, a broader background of the concept of the compact city and the connection between climate quality in cities and their spatial arrangement. The research was directed towards the search for specific building layouts characterised by geometric proportions, as indicated in the research literature on aerodynamics, as unfavourable for the proper ventilation of urban spaces. Students used maps of Warsaw, available via Google Maps, to identify contemporary building developments that were likely to pose a risk of ventilation problems.

Finding such proved easy, especially for districts subject to intensive densification in the past few years. Of the many analysed examples, three were selected for more detailed analyses. Students were divided into three research teams, each of which was given one example to analyse. The research task and partial tasks were common to all three research teams, though the research subject for each differed.

Concurrently, the students were being acquainted with the basics of fluid mechanics, which is the field of physics wind engineering originates in, as well as with experimental research techniques. The focus was put on visualisation techniques that reflect the qualitative picture of phenomena (such as water tunnel research, smoke and oil visualisations, sand erosion technique, thermal vision techniques). These methods proved the most appropriate for architects, for whom images provide the most understandable communication tool.

Students during the course were familiarised more precisely with the oil visualisation technique, which was selected for the research. This technique produces an image, the characteristics of which were discussed in detail. As well, methods for recording such an image and rules for its interpretation were defined. This material was mostly new to students of architecture and underwent changes during subsequent editions of the seminar. There appeared a difficulty in selecting the scope of knowledge and the way to transfer it to match the students' ability to grasp the issue.

Having concluded the two paths of work, the architectural-urban and aerodynamic paths merged. The first step was to work on maquettes of layouts of building development. The experimental research was divided into three steps taken sequentially by all three research teams:

- phenomena analysis and initial problem identification;
- modification 1 of geometrical layout - proofreading;
- modification 2 of geometrical layout - proofreading.

The tunnel work schedule was precise and scrupulously observed, so as to complete the test results in the required sequences. Students conducted research as active participants, assisted and supervised by laboratory employees. Along with working on the three stages described above, it was necessary to make decisions regarding modifications to the shape of building developments. This was the step where the strongest connection took place between the two *paths*. A specialist in aerodynamics proved helpful by predicting the type of modification to the geometry of the building development that could minimise the largest zones of air stagnation.

Architects decided which of the available modifications seemed the most beneficial from an architectural and urban-planning point of view, i.e. a modification that will have no negative effects on the functional system and that will not disturb the composition. The modifications were introduced to the existing geometry, so as to disturb the spatial concept to the least extent possible and that would reduce the building volume by the least amount. These modifications typically comprised the introduction of gate openings or introducing *intersections* of buildings. There were discussions of the dimensions and the location of the proposed intersections.

The next stage consisted of developing the research results; processing them in a graphic way; the description of research results, followed by their synthesis and by drawing conclusions. A great deal of involvement was required at this stage of the aerodynamic specialists. Not only was a full understanding of the nature of the phenomena by students vital, but so was their ability to describe these in professional language, in as simple a way as possible. The class concluded with the presentation of results to the whole group.

RESEARCH TECHNIQUE

Experimental visualisation studies were conducted in the aerodynamic tunnel at average velocities. The oil visualisation method proved appropriate as it provided a clear picture, while allowing the active participation of the students. The method revealed phenomena at the pedestrian level, and thus was appropriate for the analysis.

A model of a building development layout was built of polystyrene foam at a 1: 400 scale and attached to a black, round glass base. The model was painted with a mixture of oil and white pigment. The base, with the model, were placed in the tunnel and subjected to wind simulation. In the course of the simulation, the oil distributed on the surface was blown off from areas of high airflow velocity, whereas it accumulated in areas where the airflow is much less. The higher the airflow rate, the less pigment tends to be left on the model surface. The resulting image provides information on time-averaged airflow velocities and air flow lines.

The visualisation was conducted for the two most common wind directions in Warsaw - northern and westerly. The wind velocity profile characteristic of built-up areas was taken into account. In the course of the experiment, pictures were taken every 30 seconds. Analysis of their sequence provided a better understanding of the airflow phenomena and their correct interpretation. Graphic symbols were applied to the final photograph in the sequence. A system of graphic symbols that clearly reflects the nature of the phenomena observed in the image was developed and improved in subsequent editions of the seminar, owing to which, research results obtained by individual teams were comparable.

EXAMPLES OF RESEARCH RESULTS

A sample research on air circulation around a selected complex of building development in downtown Warsaw is presented below. The buildings form a quadrangular development, with heights of between three and seven storeys (see Figure 2). Distances between buildings were from single to double their heights.

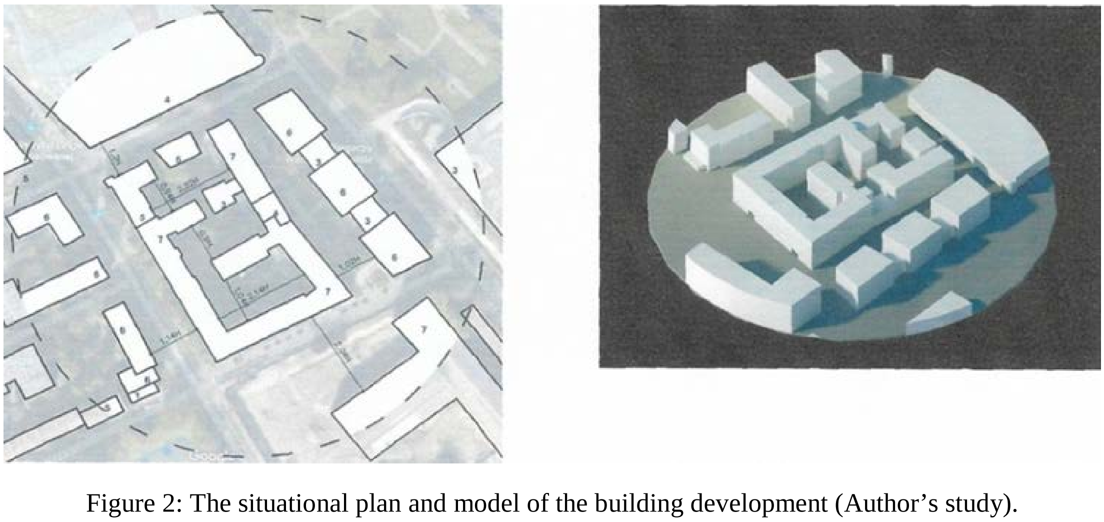

Figure 2: The situational plan and model of the building development (Author’s study).

The existing situation was examined. Afterwards, a geometrical modification was introduced to the layouts. The correction was intended to minimise the phenomenon of insufficient ventilation in internal courtyards. A graphic image illustrating the initial situation and that following the modifications for the western wind direction is presented in Figure 3.

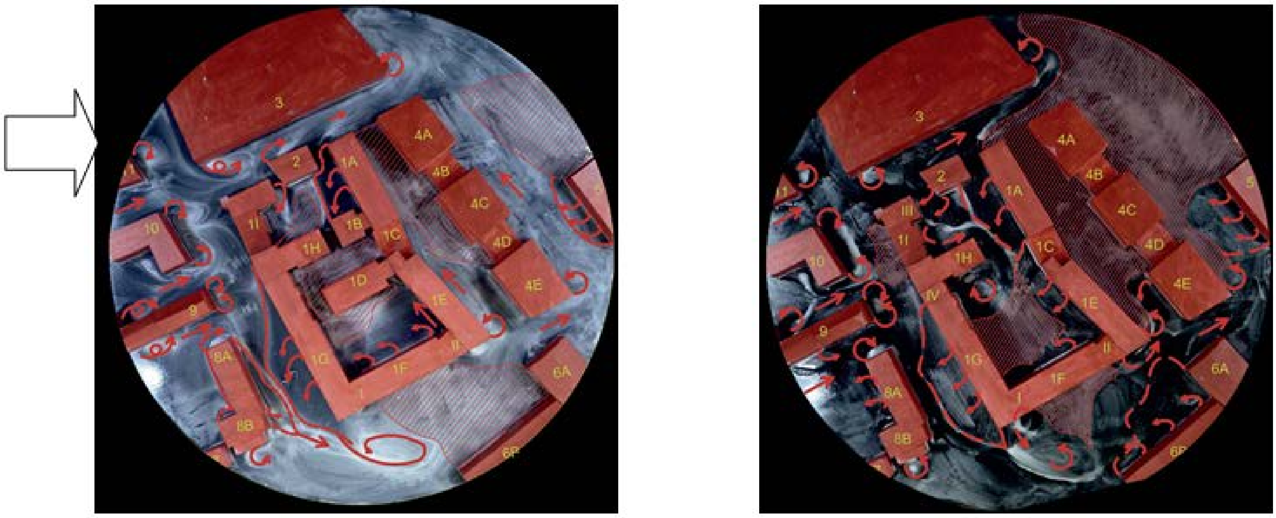

Figure 3: Image of the airflow around the building development. Oil visualisation for the western wind; on the left: the initial situation; on the right: the situation following modification in the building development shape (removal of two elements of building inside the courtyard). The image presents the result of simulation, with graphic symbols. The arrows indicate air movement directions and air swirls; air stagnation zones are hatched (Author's work).

Initial research shows air stagnation in almost the entire space of the courtyards inside the closed building development layout, marked as 1A to 1I in the picture (hatched areas in Figure 3 on the left). Removal of two elements of building within the quarter resulted in only slight intensification of the air movement. In the larger courtyard, the stagnation zone became apparent again (Figure 3 on the right), which indicates that the courtyard dimensions are insufficient. Tightly formed urban interiors around the building quarter additionally hinder the access of air to the inside of the quarter. The lack of noticeable improvement in ventilation with minor geometric modifications introduced to the building development in closed layouts was observable in a number of the cases examined. This result leads to the conclusion that in the absence of the recommended geometrical proportions, the possibilities are limited for improving ventilation in urban spaces.

CONCLUSIONS

The course described here provides an example of an interdisciplinary approach to architectural and urban design, as well as demonstrating the importance of research, while working towards environmental goals. Given the faint understanding of the issue among architects, it might be concluded that working with students in this area is particularly important. The students demonstrated a great deal of involvement and clearly appreciated the ability to conduct the experiment independently, as well as the chance to be in direct contact with specialists from another field.

Thanks to the seminar, the students were able to acquire knowledge in a different way than solely by means of books, and to see for themselves that decisions related to building development modelling, and therefore, the decisions made by architects in the design process, exert an impact on the physical phenomena that influence the human environment. In addition, tests of various building development layouts, repeated independently, emulated by the students, as well as observation of the work performed by other teams allowed students to develop an intuitive understanding of wind problems associated with specific building developments.

This seminar, although an elective, was immensely popular despite the fact it required more work and discipline than did other seminars. The research results were applied and developed in subsequent works, e.g. Master's theses prepared by students from the Faculty of Power and Aeronautical Engineering, and the Faculty of Architecture.

Representatives of both fields of science; namely, architecture and urban planning, as well as wind engineering, had to learn from each other, facilitating communication and exchange of experience. The architects brought their knowledge of the city space and architectural problems, i.e. models were not only a layout of blocks, but provided an actual approximation of the city structure. They also proved highly competent in graphic representation of phenomena and presentation of results. Specialists in the field of aerodynamics provided substantive support, but also learned during the process. They acquired knowledge on how to explain complex phenomena in a graphic way that makes it easier to be intuitively understood by a discipline other than their own. The experiments proved most useful in further works in the field of wind analysis of buildings commissioned by the Aerodynamic Division.

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