Structural systems in the mind of an architect - cognition through a non-linear teaching model

Romuald Tarczewski

Wrocław University of Science and Technology
Wrocław, Poland

ABSTRACT: The possibility of materialising an architectural form depends on the correct adoption of the structural system, which is its carrier. This requires a deep integration of the *artistic* and *engineering* aspects of thinking in the creative process. After the definitive separation of the professions of architect and engineer in the 19th Century, when the amount of detailed knowledge exceeded the possibility of its absorption by one person, a gradual loss of crucial structural knowledge has begun in the mind of an architect, which now must be replaced with a structural intuition. In this article, the author presents an initial analysis of the results of the implementation of a *structural systems* teaching approach based on a non-linear model with elements of *learning by doing*. The main purpose of the analysis is to check the assumption of the high effectiveness of the adopted model and its advantage over traditional models. The study was conducted among students of the Faculty of Architecture at Wrocław University of Science and Technology (FA-WUST), Poland upon the completion of the course.

INTRODUCTION

Teaching structural systems in faculties of architecture has always been a challenge requiring a balance between the depth of knowledge imparted and the possibilities of its perception. The situation has become significantly complicated in the last twenty years, when changes in the aesthetic paradigm of contemporary architecture have forced the use of complex structural systems that are difficult to analyse. Undoubtedly, this situation is further amplified by the appearance of new tools in computer-aided design that have enabled the creation of forms so complex in terms of geometricity that their material implementation requires structural knowledge at the highest level. This also causes the occurrence of new, non-obvious threats, which so far could have been easily prevented by observing the developed design principles.

The scope of knowledge needed to navigate in such a complex matter is so large that traditional models of teaching structural systems to students of architecture, developed back in the 1950s (although their roots are much older) no longer meet expectations. These models involve first passing basic knowledge in the field of building mechanics, and then discussing design methods (although a more accurate term would be *calculation methods*) for different structures in the material division. Sometimes the cycle ends with a general review of solutions in relation to architectural problems. This model, although well-established and maintaining the logical order of knowledge transfer, is not eagerly accepted by students. The author of this article began teaching construction subjects in the Faculty of Architecture at Wrocław University of Science and Technology (FA-WUST), Poland, with many years of prior work experience in the construction industry and design offices. The observation of the constantly increasing discrepancy between the practiced model of teaching, the expectations of students and the real needs of the industry was an impulse to start working on changing this model.

Observation of the development of education models in the last hundred years reveals two different approaches to learning: linear and non-linear. The first is usually a highly rigid and controlled approach, focused on the transfer of the *canonical* knowledge, while the second is much more flexible and focuses on education by moderating the interests of the student who is provided with the necessary resources. Non-linear models are *natural* models that appear in spontaneous education processes, such as a child's speech learning. In the linear model, however, strict boundaries are set for what can be learned at a given moment. The linear learning model is defined for the purpose of this study as formal learning and the non-linear learning model as learning through doing.

Non-linear models have become increasingly popular in recent years, as their high efficiency and the lasting nature of learning outcomes are evident. However, linear models are still dominant and much more often used in practice, although they can lead to some passivity of students who cannot make choices in the education process or control their results satisfactorily. Although to some extent, the linear learning model can be successfully used, especially for particularly complex issues, non-linear models should be used as widely as possible in other cases. The fact that this is not the case and non-linear models are found relatively rarely results mainly from mental obstacles and not from the difficulties in their implementation.

BASICS OF NON-LINEAR TEACHING MODELS

The famous and commonly known is saying attributed to Confucius, but most likely created by Xunzi (c. 310 - c. 235 BC) *…Not hearing is not as good as hearing, hearing is not as good as seeing, seeing is not as good as knowing, knowing is not as good as acting; true learning continues until it is put into action* (usually presented in abbreviated form: *…I hear and I forget. I see and I remember. I do and I understand*), presents the hierarchy of perception of various forms of knowledge transfer in the education process. This hierarchy has been confirmed by modern research.

The education process was defined for the first time as the participation of the individual in the activities of the society by an American philosopher and theoretician of education, John Dewey, at the turn of the 19th and 20th Centuries [1][2]. In his approach, with a dynamically transforming society, the goal of education cannot be to transfer a limited amount of knowledge, but rather to develop the ability to evolve together with the society. Therefore, appropriate skills are needed to move in a changing environment in which the requirements for each individual are defined by the evolution of other individuals among which one operates, that is, by the needs of a changing world. Dewey formulated five stages of thinking leading to the solution of the problem: a feeling of difficulty, determination of difficulties (formulation of the problem), search for solutions (formulating hypotheses), logical verification of hypotheses, and empirical verification of the hypothesis, have become the basis for formulating a method based on a practical approach - students' interaction with the environment [1][2].

Another important step in strengthening the role of practical experience in learning was the model proposed by Edgar Dale. In his textbook on Audio-Visual Methods in Teaching, published in 1949 (later revised in 1954 and 1969) [3], Dale introduced a model of classification of educational media and methods from the most abstract to the most concrete. This model shows the results of his research on the effectiveness of learning and memory, and is called the learning pyramid or the cone of experience. This model presents a different level of remembering information conveyed in the learning process, depending on the type of educational media after approximately two weeks. In the cone of experience, the smallest amount of permanently remembered information refers to the most abstract methods, and the largest – to the most concrete. Although Dale did not provide percentages related to the retention of information transferred through various media and methods, the shape of the chart clearly defines this relationship. The Dale model was later modified many times by various researchers, but its basic shape remained unchanged [4][5][6]. The supplementation most often included the estimation of the amount of retained information.

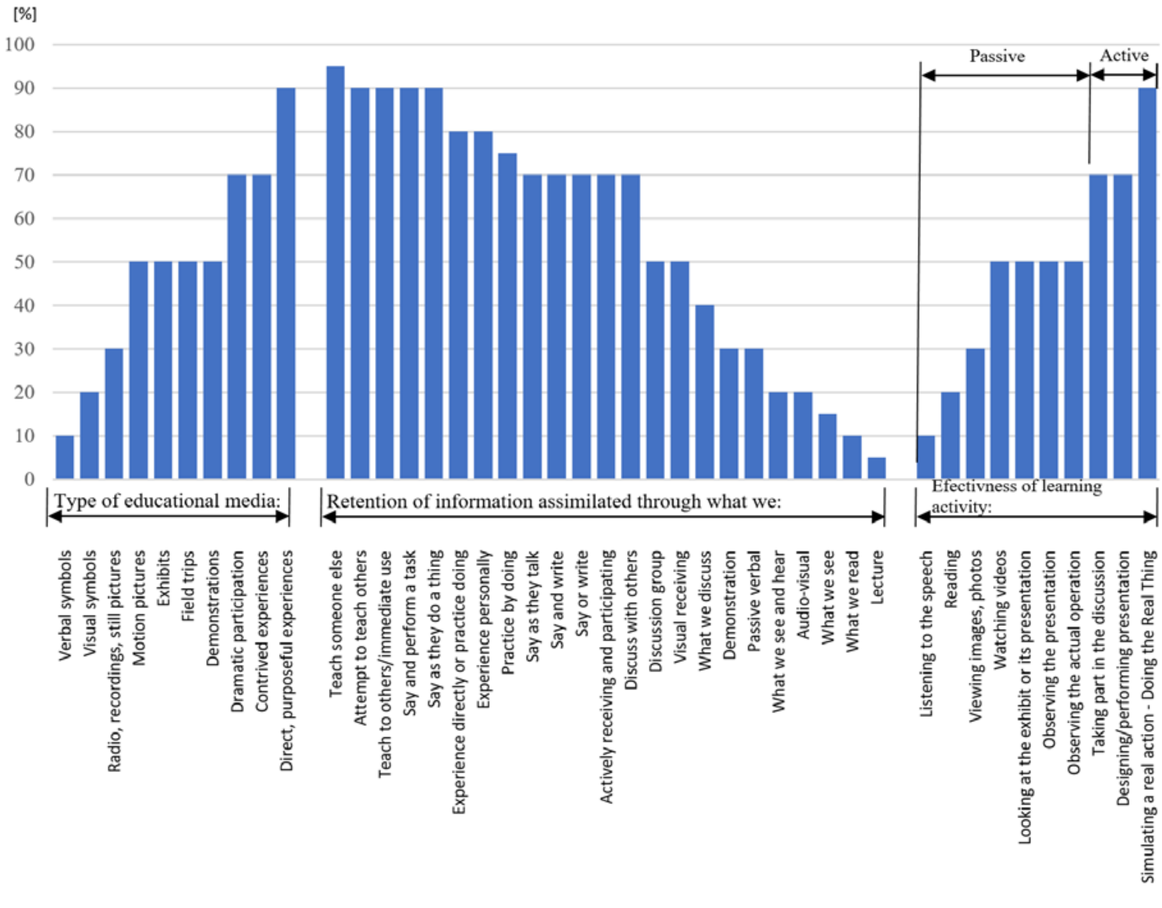

Figure 1: Dale's cone of experience and effectiveness of learning activity. Drawing: author, based on original versions [4-6].

The cone of experience (learning pyramid) in a quantified version is shown in Figure 1. To facilitate the comparison of several aspects of this model, it is presented not as usual in the horizontal layer arrangement (classical pyramid) but as a bar chart. The left part of the diagram shows the basic Dale's concept - classification of educational media and methods. The middle part of the chart presents the retention of information assimilated through various media and activities, while the right part presents the effectiveness of various learning activities. The visible similarity of the shape of these charts clearly shows that the most effective is active learning in which students are involved in various types of interactions and practical activities related to the topic. Simply put, it can be summarised by saying that people remember 20% of what they hear and 90% of what they do.

Conclusions regarding the perception of various forms of teaching, resulting from the learning pyramid, combined with the Dewey concept, have become the basis of the problem-based learning (PBL) method, developed in the late 1960s at McMaster University in Hamilton, Canada. Since its first development many different varieties have emerged [7], but generally itis a method of transferring knowledge, gaining skills and competence through independent work of students for a certain period of time, and finding answers or solutions to an engaging and comprehensive problem, i.e. project implementation. Students must be active, not passive, in the PBL teaching process. They must engage all knowledge and emotions, which leads directly to the reference of acquired knowledge and skills to the real world. The detailed teaching procedures of the PBL method have been developed by various institutions involved in education and they differ significantly in terms of the type of tasks, methods of assessment and organisation of group work. However, they are always development and refinement of the five points formulated by Dewey. It should be noted that this method refers to increasing the involvement of participants in the education process and raising the level of perception during this process. The ability to evolve and adapt to a changing society may take shape among students, but it is not the explicit goal of this method.

In parallel to the PBL method, the experiential learning (EXL) method has been developing since the 1970s. One of its main theoreticians was David Kolb [8]. The method, although, like PBL, refers to the work of John Dewey, and even to Aristotle's Nicomachean Ethics (*For the things we have to learn before we can do them, we learn by doing them* - Book 2), only partly overlaps with it. The essential element of the EXL method, inspired by the organisational change model developed earlier by Kurt Lewin, a German-American psychologist, and already popular at the time of its creation, is the so-called Kolb model - the equivalent of the praxeological cycle.

The Kolb model is a repetitive cycle of four steps:

- knowledge is acquired through practice and experience (concrete experience);
- some specific experience leads to intelligent observation (reflective observation);
- this reflection creates abstract generalising rules that are used not so much to describe a particular event, but all similar to it (abstract conceptualisation);
- the resulting knowledge is then verified by active experiments - i.e. checking a new idea in practice, which leads to new experiences and the cycle begins anew (active experiments) [8].

Kolb defined the EXL method as *learning through reflection on doing*. It can also be described as a permanent learning model. This method fits well with Dewey's postulate of learning through social participation. The successive steps in the Kolb cycle correspond to the stages of the social interaction of the learner.

Among the non-linear teaching models should be mentioned emergent design based on the sequential and cyclic process of perception and cognition [9], and constructionism whose central strategy is to engage students to draw conclusions from the experiments carried out and to knowledge construction by students rather than its transmission by a teacher [10][11]. However, a discussion of these models is beyond the scope of this article.

PRACTICAL APPLICATION OF THE NON-LINEAR TEACHING MODEL

The non-linear teaching models described above were applied at the FA-WUST for classes in structural systems, especially in terms of shaping the structural intuition of architecture students. These courses focus on selected types of structures that are difficult to discuss in a computational approach, while traditional structures are discussed in other courses. The curriculum is based on problem solving, and not on hierarchical, sequential information transmission. The approach adopted in the PBL method including elements of constructionism and a strong focus on group work has been developed [12][13]. An important part of the course is the development and making of small- and large-scale models, searching for a form using graphic static methods and illustrating complex issues with numerical simulations. This allows to understand what *degrees of freedom* the designer has at the beginning of the creative process, and how, as design decisions are made, their number is reduced.

Small-scale structural models are most often made in groups of two students, illustrating the solution of a given design problem with a specific type of structure. The assumption underling topics development for students is that the structural system for a given problem should be so complex that its correct solution by methods other than physical modelling would be very difficult. The membrane structures based on minimal surfaces, catenary systems - 2D and 3D, lattice structures, deployable structures, shell structures, etc, are modelled. Models are made of various materials, often those whose proper purpose is complete (e.g. elements of electrical installations). The only limitation is the creativity of the students. Figure 2 shows some examples of small-scale models made during the classes.

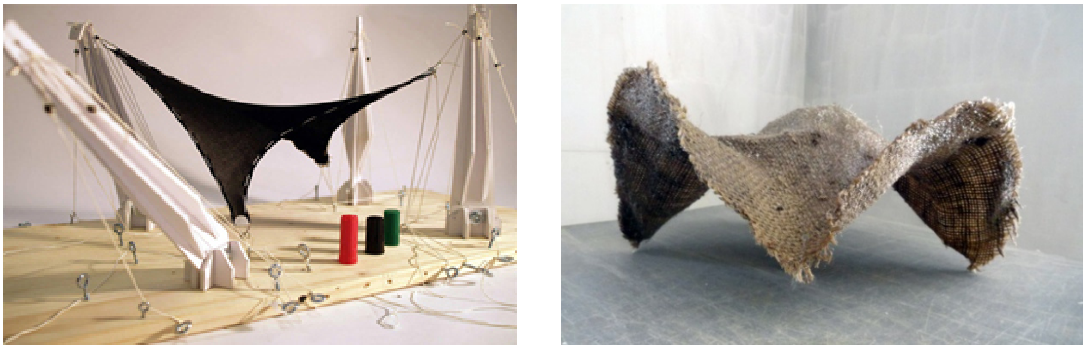

Figure 2: Sample small-scale models made by students during the classes: membrane structure (left) and shell structure (right). Photographs: author.

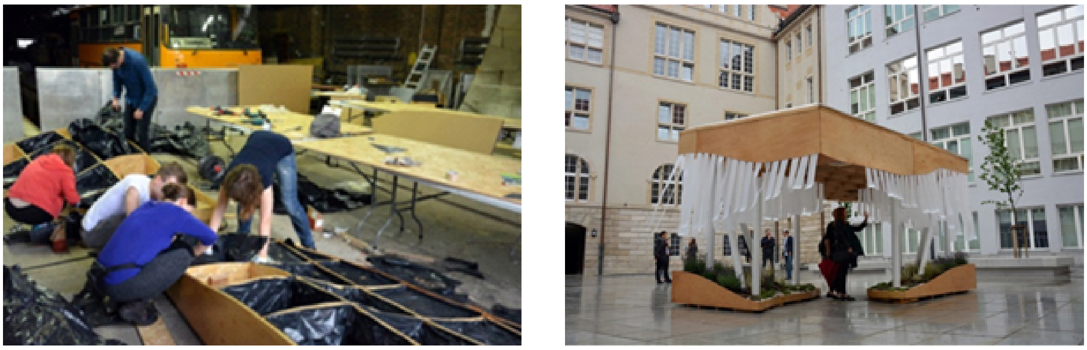

Figure 3: Making a large-scale model: works on the structure in the workshop (left) and the finished object (right). Photographs courtesy of J. Łątka (WUST).

Making large-scale models includes comprehensive development of a pavilion-scale facility in a simulated full investment process. Starting from the initial leading idea, students develop alternative solutions for the form of the object, which is then elaborated in detail together with the construction system, down to the detailed design level. Then the object is realised. Students also prepare bills of materials, cost calculations and promote the object. Figure 3 shows the construction process and public presentation of a large-scale model made within the 2018 course.

SURVEY OF PERCEPTION OF THE NON-LINEAR TEACHING MODEL

The model of teaching structural issues to architecture students described above was introduced at the FA-WUST in 2007. Initially, changes were made to the arrangement of topics and the method of conducting classes, and in 2009, small-scale physical modelling was introduced. Large-scale physical modelling was introduced experimentally also in 2009, with the construction of a membrane pavilion with dimensions in the projection of 15×10 m. For financial reasons; however, the construction of large-scale models was suspended for several years and resumed in 2018. Since then, it is now being continued every year.

The essential changes in the teaching model of structural systems, consisting in the introduction of a non-linear model, also in the formula of problem-based learning and the use of a wide range of physical modelling, required an ongoing analysis of the perception of these changes. For this purpose, a written survey was carried out among students each time after the end of the course until 2020. The survey was informal and not compulsory, but the vast majority of students participated in it. The time range of the analysis carried out covers the years 2008-2019. In the years 2020-2021, due to the limitations related to the COVID-19 pandemic, the survey was not conducted.

Of the many types of survey questions used in practice, *closed-ended questions* were selected. Within this type, a subgroup of *closed-ended questions –> questions that describe and evaluate –> evaluative continua* was selected [14]. It is the numerical scale with eleven response options (0-10), where 0 is the lowest, completely negative rating, and 10 is the highest, positive, unqualified rating. To eliminate measurement errors, the surveys were anonymous and voluntary. At the time the surveys were conducted, the students had already received the course grades and were in no way dependent on the person conducting the course. No other ethical concerns were detected. Interviewers carefully avoided suggesting or leading respondents to specific answers and tried to eliminate additional sources of bias associated with the respondents. All the principles of good practice were applied when conducting surveys [14]. Due to the completely anonymous nature of the survey, grades in answers cannot be associated with specific groups of students.

The questions began with evaluation of the non-linear methodology of learning. The first question (Q1) was about the students' general assessment of the teaching model. The second one (Q2) - about their perceived effectiveness of developing structural intuition. The third question (Q3) concerned the need for further development and improvement of the model. Figure 4 to Figure 6 present in sequence the results of the analysis of mean value *m*, standard deviation *s* and coefficient of variation *v*, for the responses to the relevant questions.

The data analysis presented in Figure 4 to Figure 6 shows that the assessment of all three analysed aspects was relatively high (> 60%) since the first year. In the following years, the positive value of the assessment increased, fluctuating in the range of 75-80%. Considering that structural courses are not generally favoured by architecture students and that the non-linear model requires increased commitment on their part, these grades are very good. This fully confirms the assumption of the effectiveness of changes introduced into the teaching model.

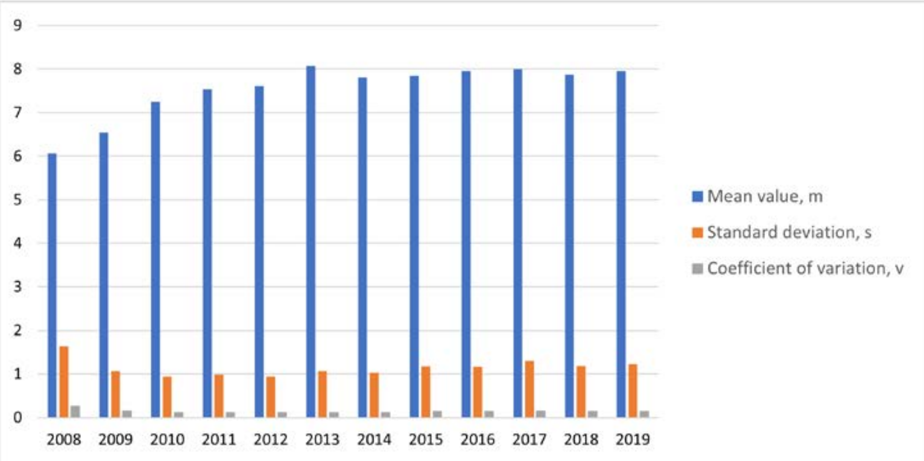

Figure 4: Analysis of results of students' rating - question Q1.

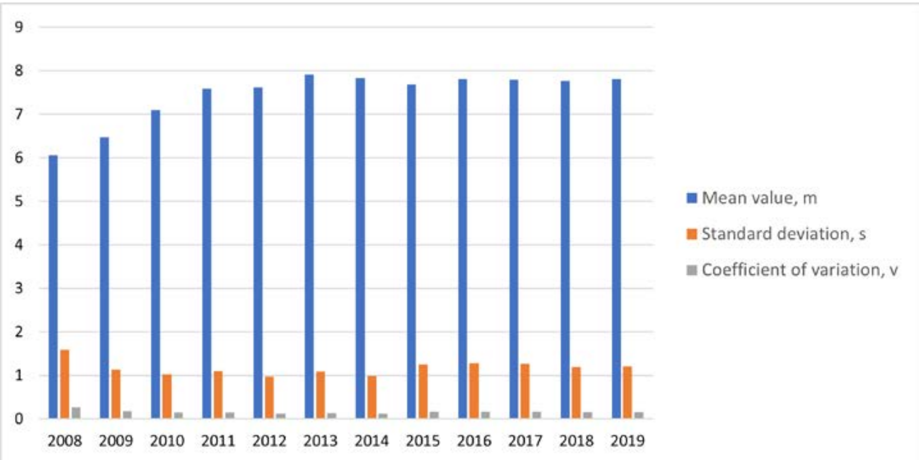

Figure 5: Analysis of results of students' rating - question Q2.

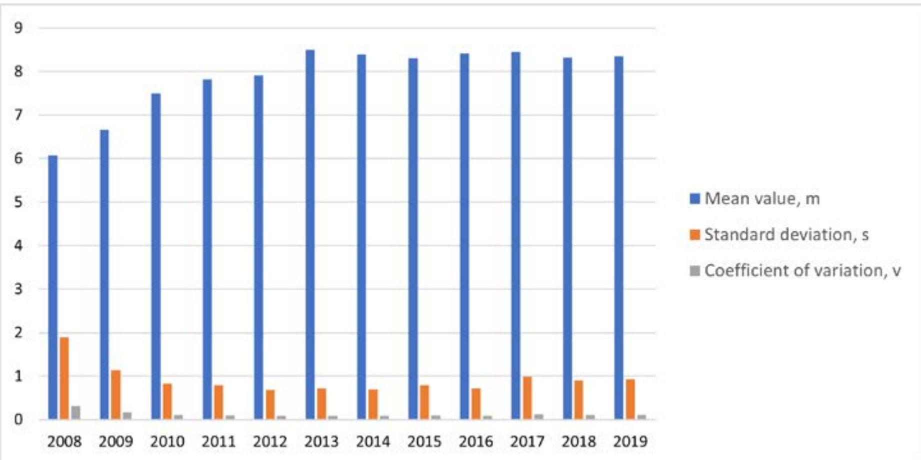

Figure 6: Analysis of results of students' rating - question Q3.

CONCLUSIONS

The development of methods and techniques of architectural design caused the increasing complexity of the forms of objects and structural systems necessary for their materialisation. To enable students to develop the appropriate structural intuition necessary in their future work, it is necessary to introduce a new teaching methodology in this area.

In this article, the author presented the implementation of a non-linear teaching model based on the problem-based learning method. Interdisciplinarity and working with physical models on a different scale play a crucial role in the curriculum of the course. Over the years of this course delivery, participants have been regularly asked to provide their views in an anonymous survey. The analysis of the answers shows a very good perception of the course by the students, who notice the effectiveness of the applied learning model. At the same time, they indicate the need for its continuous improvement.

The directions of the anticipated further improvement of the adopted teaching model include the expansion of the material base for physical modelling, as well as the introduction of numerical simulations in a much wider range, treated as a replacement for physical modelling, allowing for independent implementation and verification of multiple variants of solutions.

REFERENCES

1. Dewey, J., *My Pedagogic Creed*. Withorn: Anodos Books (2018).
2. Dewey, J., *How We Think*. New York: Dover Publications (1997).
3. Dale, E., *Audio-Visual Methods in Teaching*. New York: Dryden Press (1946).
4. Januszewski, A. and Betrus, A., For the record: the misinterpretation of Edgar Dale's Cone of Experience. *Proc. Annual Conv. of the Assoc. for Educational Communications and Technology*, Dallas, USA (2002).
5. Subramony, D., Molenda, M., Betrus, A. and Thalheimer, W., The good, the bad, and the ugly: a bibliographic essay on the corrupted cone. *Educational Technol.*, 54, **6**, 22-31 (2014).
6. Ilkovič, J. and Ilkovičová, L., Creativity and play in modern teaching of structural design. *World Trans. on Engng. and Technol. Educ.*, 13, **3**, 286-290 (2015).
7. De Graaff, E. and Kolmos, A., Characteristics of problem-based learning. *Inter. J. of Engng. Educ.*, 19, **5**, 657-662 (2003).
8. Kolb, D.A., *Experiential Learning: Experience as the Source of Learning and Development*. Upper Saddle River: Pearson Education (2014).
9. Gero, J., Differences between Practice-Based and Practice-Led Research (2004), 31 December 2007, http://www.creativityandcognition.com/content/view/124/131/
10. Papert, S. and Harel, I., *Constructionism: Research Reports and Essays*, 1985-1990. Norwood: Ablex Publishing (1991).
11. Ilkovič, J., Ilkovičová, L. and Špaček, R., To think in architecture, to feel in structure: *Teaching Structural Design* in the Faculty of Architecture. *Global J. of Engng. Educ.*, 16, **2**, 59-65 (2014).
12. Tarczewski, R., Trocka-Leszczyńska, E., Wowrzeczka, B., Bober, W. and Stobiecki, P., Formation of minimal surface: case study I - education training. *Architectural design & construction education: experimentation towards integration (EAAE Trans. on Architectural Educ.),* Leuven: Leuven, Belgium, 247-252 (2009).
13. Trocka-Leszczyńska, E., Jabłońska, J. and Tarczewski, R., Architectural education at the Faculty of Architecture Wrocław University of Technology. *Architectural education towards 2030: an inquiry among European Architecture Schools (EAAE Trans. on Architectural Educ. 65)*, Santarcangelo di Romagna, Italy, 155-159 (2015).
14. Glasow, P.A., *Fundamentals of Survey Research Methodology*. McLean VA: MITRE (2005).