Global Journal of Engineering Education

Interdisciplinary education in the architectural design of engineering structures

Ľubica Ilkovičová†, Ján Ilkovič† & Maria B. de Oliveira‡

Slovak University of Technology in Bratislava, Bratislava, Slovakia†
Federal University of Rio de Janeiro, Rio de Janeiro, Brazil‡

ABSTRACT: Structural engineering of buildings demonstrates a challenging combination of architectural form and structure. This phenomenon of simultaneity must be reflected in architectural education. The aim of this article is to present the teaching method in the course Engineering Structures Design Studio in the Faculty of Architecture and Design at Slovak University of Technology (STU) in Bratislava, Slovakia, under specific conditions. These conditions included: on-line teaching and a challenging assignment in the form of a case study. At the same time, the education of future architects encompassed interdisciplinarity facilitated by on-line co-operation with a foreign teacher - specialist. The study presented here was focused on the evaluation of the selected methods, and a non-hierarchical approach employed throughout the learning process and its outcomes in the Engineering Structures Design Studio course. The case studies included in the article serve as examples of two structurally and architecturally different designs for a promenade bridge over the Danube River in Bratislava, Slovakia.

Keywords: Design studio, engineering structure, non-hierarchical approach, coordination, collaboration

INTRODUCTION

Design studio (DS) courses are a core and prestigious subject in architecture schools. These schools are compared and ranked on the basis of their results in the subjects through various criteria. The DS is a course that on the one hand attracts students, but also one that inspires respect. This respect arises from the complex scope and content of the assignments, but above all, it is due to the need to apply the knowledge and skills acquired in previous or current study.

Architecture oscillates between science and art, and therefore interdisciplinarity logically enters the curriculum. It can be assumed that more typologically and technically demanding assignments require a higher degree of interdisciplinarity. If the assigned topic is in the field of engineering structures, interdisciplinarity in this design is essential. Interdisciplinarity that goes beyond engineering education helps to achieve significant learning outcomes [1]. Interdisciplinary teaching of architects on a global and local scale is essential, as it helps in the complexity and understanding of the creative process [2]. According to Kim:

> *Most engineering educational institutions are in an ongoing process of transformation from the traditional paradigm to a new, interdisciplinary, contextualised, student-centred paradigm* [3].

Group-based teaching linked to interdisciplinarity and the creative process are extremely challenging, especially in the pandemic-induced on-line environment over the two past years. In these challenging conditions, it was proposed to apply non-hierarchical learning. According to Herrera and Fuller, the collaborative model in remote education and in non-hierarchical groups relies on two supporting pillars, i.e. group interaction and knowledge building [4]. The non-hierarchical learning approach posits that each student or a small group of students, works on their own task and then reports back to the class [5].

This approach encourages the exercise of creativity and gradually eliminates the stress of more challenging assignments. In architecture education, creativity is self-evident and indispensable in DS courses. Teaching methods must take into account the fact that, in general, architecture students tend to be not only creative but also sensory learners, including visual. An ongoing question is what method is advantageous to apply to a given topic in the studio that would be optimal for both students and teachers, and that would form the appropriate conditions for good creative results. In this context, the research seeks to answer the following questions:

1. What is the degree of mutual participation of technical and artistic disciplines in the design of an engineering work?
2. Does the student perceive the simultaneous supporting of subjects in the design process?
3. What is the contribution of non-hierarchical learning within the DS?

MATERIAL AND METHODS

In the teaching of the DS, the method of teamwork and the form of non-hierarchical learning were applied. A quality architectural work can only be created if it is preceded by a dialogue between the architect and the investor, the owner, and of course, the professions involved in the design and implementation of the work. By analogy, dialogue is essential in architectural education which is conducted by the teacher with the student. Peer-to-peer dialogue over a problem is the basis for non-hierarchical learning. At the same time, it serves to relieve the negatives brought about by on-line learning induced by the pandemic. Non-hierarchical learning gives students the space for their own self-development, as they can choose their assignment without any biases or influence of others (availability of time versus difficulty of the assignment versus individual student's possibilities and abilities).

Working in a group multiplies this effect, since working in a group becomes more natural and motivational in the design/learning process. Collective work values interaction reflecting on solutions that demonstrate cultural differences between people. This type of work can enhance listening skills necessary for responses with multiple perspectives. Collaboration is reached through: a collaborative attitude, the compatibility of results and trust. Interaction must be carried out to achieve: coordination, the exchange of information and the sustaining of a continuous learning process by the various actors [6], Figure 1.

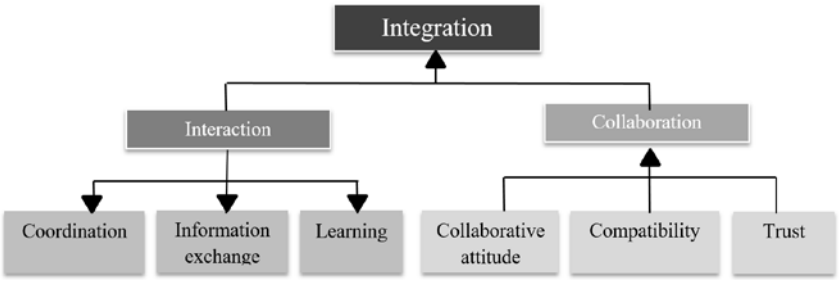

Figure 1: Integration components.

The teacher's role is primarily *coordinative*, moving from a mediator of knowledge to the position of *expert mediator* with typical non-hierarchical leadership [7]. It should be added that the distribution of repetitive tasks in the group can provide more time for the study and analysis of problems for decision-making in the project.

Students were also encouraged to creatively use the grounded theory (GT) method - gathering information and applying knowledge from related subjects (see Figure 3), comparing and verifying new solutions and evaluating results. The GT develops the interdisciplinarity approach [8]. Task specificity and the level of design detail determine which disciplines are prioritised in the project.

Research Area

An opportunity to validate the teaching methodology was the task for students of designing a pedestrian bridge. The aim was to design a bridge over the Danube River and to accentuate Bratislava as a city on the Danube. The challenge was to design a bridge that would also be a public promenade space providing panoramic views of the city from a point above the river. From an urban planning point of view, the task was to connect cultural focal points on the left and the right bank of the Danube (the Slovak National Theatre on one bank, and the planned Congress Centre on the other), which would form a citywide centre connected by a promenade bridge, Figure 2.

Figure 2. Case studies location - a pedestrian bridge over the Danube River.

In addition to the given transverse perimeter of the river - 400 metres, the task also had limitations that resulted from: the observance of the navigation parameters of the Danube River (navigational gauge 160 metres), access to the bridge from the existing pedestrian promenade along the river, respect to the statue of General Milan Rastislav Štefánik (Slovak politician and scientist) in the axis of the square in front of the Slovak National Theatre, and others.

RESEARCH

The research focused on the methodology of teaching the architectural design of an engineering structure, wherein the interdisciplinarity is directed towards the dominance of the building-construction disciplines and the interconnection of technical and artistic disciplines. The coordination of disciplines occurs at the level of validation and evaluation of designs from different perspectives.

The research focused on the timing of developing interdisciplinarity. More specifically, the question was: at which steps of architectural design it is important to develop interdisciplinarity. During the studies, students have the opportunity to acquire theoretical knowledge from various fields that can be synthesised in the field of studio work. The design of an engineering work is particularly demanding because of the combination of artistic and technical parameters and because of the combination of logic, aesthetics and functionality in the design. The education process is limited by time, by the resources to experiment and by the individuality of the teacher and the student - their abilities and also their theoretical and practical knowledge.

The research had a parallel focus on non-hierarchical learning within the DS. The non-hierarchical approach eliminates fears of failure and poor results. It is focused on increasing the students' new and unique activities. Students often fail to connect the ideas, theories and methods learned in different courses. The methods presented in the Engineering Structures Design Studio help students to overcome barriers, encourage originality and creativity of the individual. The authors of this article incline to the opinion of Van den Beemt et al:

> *Combining the positive learning benefits of non-hierarchal, small-group and peer-to-peer learning with innovative and novel teaching aids quickly and effectively enhanced the student's learning experience* [9].

When preparing students for the DS process is important that they apply transferable competencies, i.e. that they use *everything they have learned before* in their study in favour of the quality of the proposed work. Preparation takes place in courses on four content levels (the definition of the levels depends on the DS topic):

1. typological - dominant in the design of buildings, they are based on the relational logic of spaces;
2. art-theoretical, composition - applicable in the design of buildings and engineering works;
3. technical-structural - dominant in engineering structures and atypical buildings;
4. history of architecture, city (place) and environment - focusing on the starting points of the design in terms of history (of the architectural work and the site).

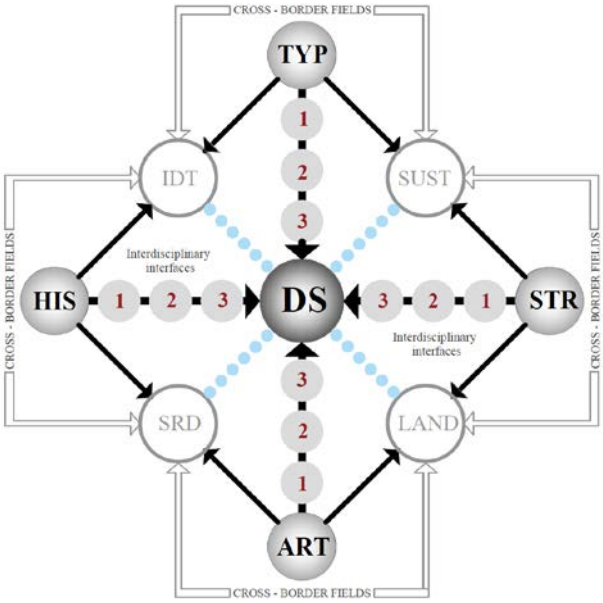

Figure 3: Relationship of the subjects with the DS. Subjects: TYP - typological; STR - structural-technical; ART - art-theoretical; HIS - history of architecture. Fields: SRD - surroundings; IDT - identity; SUST - sustainability; LAND - landscape.

Figure 3 expresses the relationship of the subjects (1, 2, 3…) taught with the Design Studio and the interdisciplinary interfaces. It also presents the impact on the different *cross-border* fields that complete the DS context.

The research was supported by a two-year survey of 76 students who answered the following three questions about non-hierarchical learning and interdisciplinarity:

1. Does the peer-to-peer dialogue methodology take away the stress and anxiety of a challenging assignment?
2. Did your knowledge of typology and technical subjects from your previous studies with a focus on civil engineering help you in the DS?
3. At which methodological step of the DS of engineering structures do you prefer to consult with a specialist (e.g. structural engineer)?

A five-point Likert scale was used to evaluate this survey. The survey results are shown in Figure 4 and Figure 5.

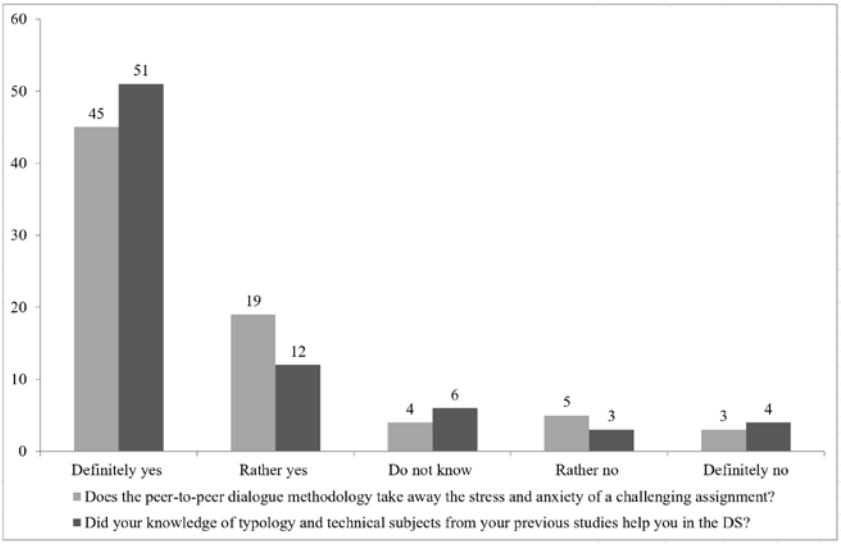

Figure 4: Survey responses to question 1 and question 2.

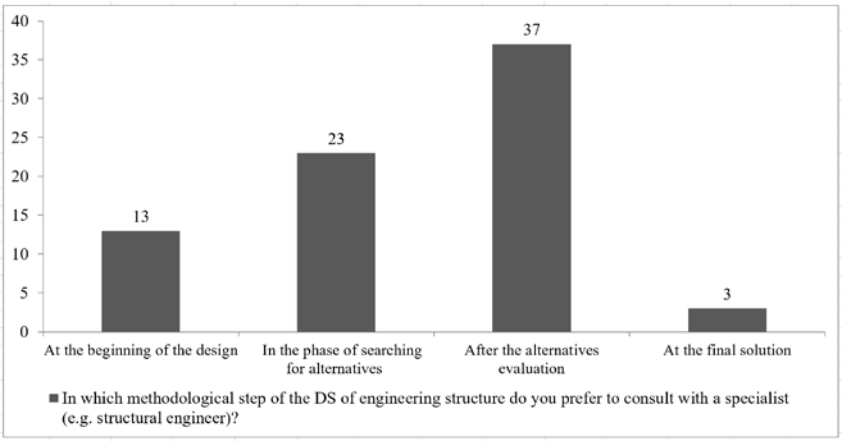

Figure 5: Survey responses to question 3.

RESULTS AND DISCUSSION

The results of the research are presented by evaluating the survey and by comparing the learning outcomes - comparing case studies. Critical reading, discussion and analysis should be emphasised in developing students' skills [10]. The research results confirmed that non-hierarchical learning and the GT method promote these skills. The conducted survey of students confirmed the positives of non-hierarchical learning, especially in relieving stress and motivating students to work on challenging assignments. Similar reasoning can be also found in an article by Rahman at al:

> *One possible explanation of the success of cooperative learning is that cooperative learning is effective learning, and often occurs through the interaction of individuals with their environment* [11].

The students positively perceived the possibility of mutual exchanges of knowledge. Especially during on-line teaching, this form encouraged them to co-operate; the remote environment creates an opportunity for pleasant interactions. Interdisciplinary research relies on shared knowledge [12].

When coordination was applied, the opinions of the students in the survey varied. Coordination of disciplines is preferred at the stage of looking for alternatives or after the alternatives have been evaluated. The different attitudes of the students are determined by the design difficulty of the assignment and the level of interweaving of aesthetic and technical parameters within the assignment, as well as the individual student's abilities. The diversity of opinions can be attributed to the personal experiences of the students. An article by Badawi and Abdulah could serve as a comparison:

The students expressed satisfaction with the interdisciplinarity design education. They claimed that the collaboration raised the awareness of each other's knowledge and the understanding of the integrated design process. They reported negative feedback regarding the course schedule and course administration [13].

Another study has confirmed that it is not correct for an architectural design to emphasise only the external aesthetics of a building, while largely ignoring the use of the space that surrounds it and disregarding factors based on an interdisciplinary approach [14].

Case Studies

The results of the case studies are proof of the correct application of the methodology and interdisciplinarity. Students chose approaches with a high degree of creativity. Two basic approaches can be seen in their results:

- contextual expressive;
- oriented to the shaping of the structure.

In terms of structural design, both approaches can work with an original structure shape or focus on a traditional, proven or repeated design solution.

Contextual Approach (1st Example)

It can be characterised as narrative. It is dominated by small stories and inspirations set in the historical and spatial context of the work on the Danube:

- historical figure: the inspiration is General Štefánik, his scientific activity as an astronomer in the transformation of the shape of the telescope - the retraction of circles;
- connecting the banks of the river: the inspiration is the throwing of pebbles onto the surface of the water, creating the effect of circles;
- connection of activities on the banks of the river: the context of the Slovak National Theatre (which has segments of a circle in its plan) and the New Centre.

The common element of the stories is the circle. One of the students solved a difficult structural and architectural problem with a great deal of originality, see Figure 6. The lightness of the design is also inspired by Wright's principle of *tenuity* [15].

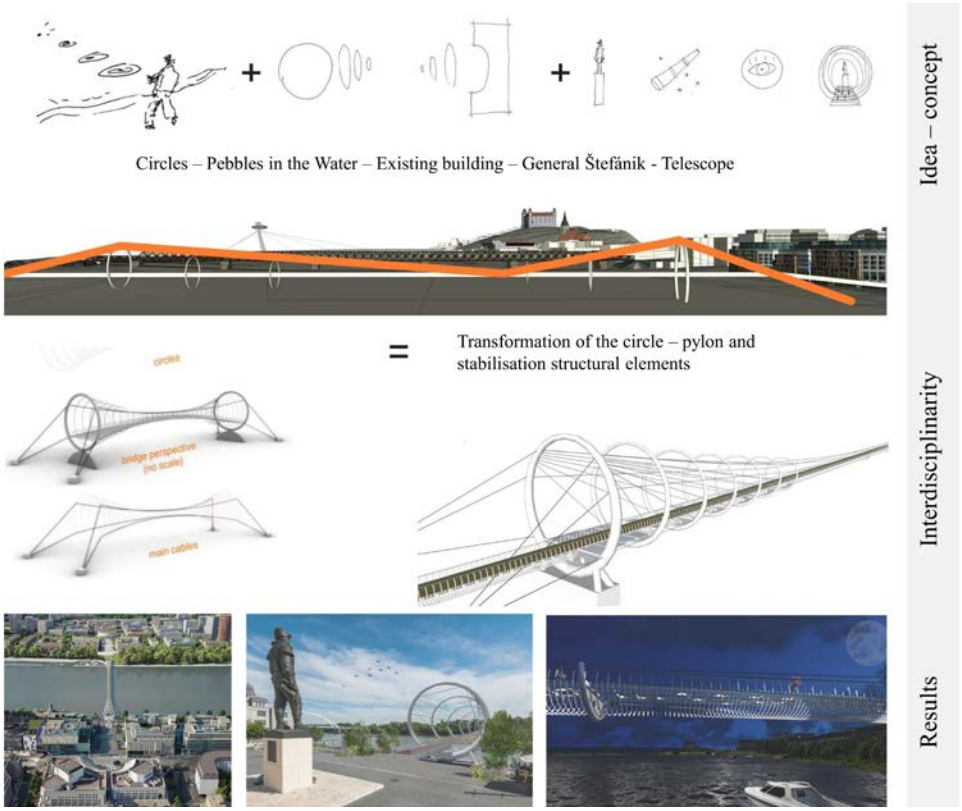

Figure 6: Presentation of the 1st case study - student Hermína Mikešová from the DS conducted by the authors.

Approach Oriented to the Shaping of the Structure (2nd Example)

The students' respect for the design solution was evident in the effort to be detail-oriented in the structure of the footbridge. The peer-to-peer dialogue helped overcome the fear of the difficult design of the structure and the overall result, shown in Figure 7. The design is dominated by a shaping of the structure inspired by the works of architect Mirko Baum. The form is

also determined by the bridges built on the Danube, in an effort not to repeat the already standing bridges and to form the new design as a communication *backbone*. The overall undulating shape makes the city skyline stand out. Two levels of view can be highlighted - the shape of the footbridge from the level of the pedestrian is simple, allowing the historical panorama to stand out. During a river cruise, the beauty of the *soffit* of the structure, on the principle of a trussed beam, is opened up.

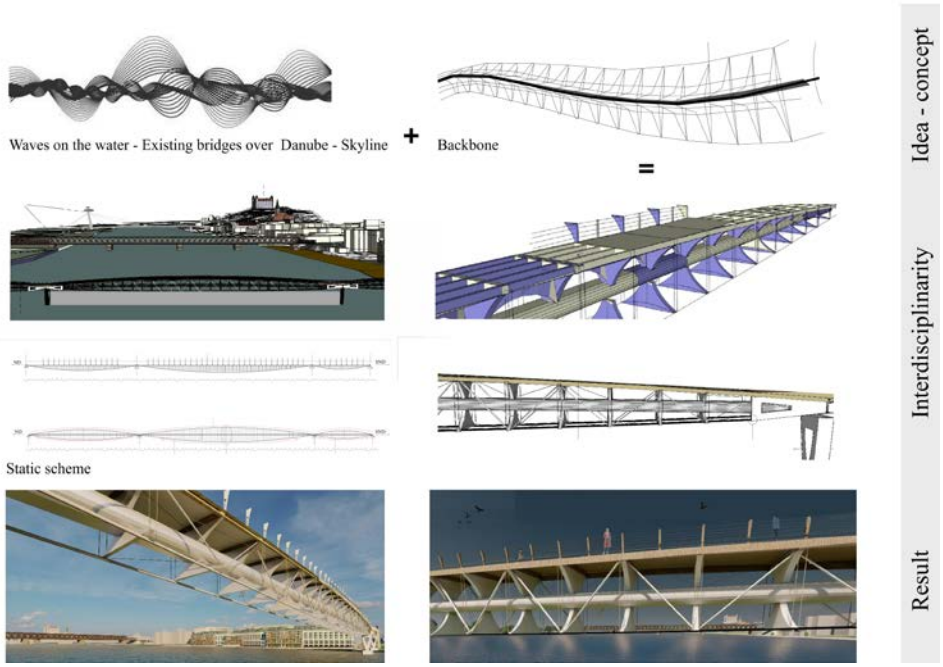

Figure 7: Presentation of the 2nd case study - student Simona Podolcová from the DS conducted by the authors.

The way in which the interaction takes place throughout the designing process depends on the degree of importance of the structure for the design under development, which can be a typical design, a design with very little structural content (e.g. a usual and simple residence) or a design with extreme structural contents, such as the bridges project referred to by Franco [16]. Following the same reasoning, interaction processes occur in different ways over a design of a very simple bridge, a traditional bridge or over a more inventive bridge design, Figure 8.

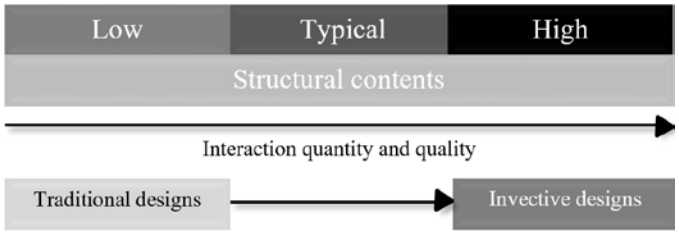

Figure 8: Interaction processes in designing.

The different approaches to designing bridges demonstrate the simultaneity between form and structure. A comparison of different case studies approaches is presented in Table 1. The positive results from the DS can be attributed to non-hierarchical learning and the application of interdisciplinary elements in the teaching methodology.

Table 1: Comparison of the case studies with emphasis on interaction processes in designing.

1. Example - contextual approach			2. Example - structural approach	
1	Art-oriented, narrative		1	Technique-oriented
2	Poetry/air/liberty		2	Prose/almost earth/rational detailing
3	More inventive structure, the form cannot be defined *a priori*		3	More conventional structure, shape can be defined *a priori*
4	Structure as the form and expression bearer		4	Tectonic form of structure
5	The suspension bridge, lightweight structures, minimal material volume, form explains the path of forces		5	The beam bridge, the longitudinal curves minimise the volume of the structure subjected to bending, coincide with the drawings of the main tension
6	The pedestrian bridge will mark the landscape, sculptural form (despite the function)		6	The longitudinal curves have continuity with the design of the legacy constructions
7	Predominant material - steel		7	Predominant material - steel
8	The authors value art, the solution is challenge for construction and structure		8	The authors value the technique, the classic solution is easier for construction and structure

Complexity in education and interdisciplinarity are complementary. People's work and thinking becomes interdisciplinary [17][18]. Interdisciplinarity in teaching, in engineering and architectural education, and the collaboration of different disciplines, is essential [19]. To some degree, a different concept is conveyed by transdisciplinarity and transcending disciplines. As argued by Santos y Ganges et al:

> *In our Educational Innovation Plan, living on the border is the basic effort of transdisciplinarity* [20].

It could be said that from the point of view of architecture it is a different shade of interdisciplinarity.

CONCLUSIONS

Despite the relatively large number of publications on the topic of design studio, the authors argue that the perspective on the issue presented in this article is different and novel. This perspective is determined by the application of a non-hierarchical approach in the Engineering Structures Design Studio course and the development of the concept of interdisciplinarity in the methodology of the course.

The answers to the posed research questions confirm the necessity for a constant exercise of creativity by both parties involved in the teaching/learning process. On the teacher's side, it means transforming appropriate methods that lead the other side - the students - to active study; to an interdisciplinary approach; to a simultaneous understanding of the problem; to verifying their own result.

The difficulty of the Engineering Structures Design Studio course is enhanced by: the time coordination of teaching procedures in the on-line environment, coordination of the disciplines with a crossing of the boundary between aesthetic and technical parameters, and appropriate presentation of the output. The contribution of peer-to-peer pedagogical coaching has a positive psychological effect, motivating students to work and to engage in their studies, while eliminating the anxiety of failing a challenging subject.

REFERENCES

1. Marcinkowski, R.A., Steep roof design: a combination of history and geometry as part of an interdisciplinary education for architects. *World Trans. on Engng. and Technol. Educ.*,16, **1**, 23-28 (2018).
2. Schneider-Skalska, G., Interdisciplinary education of architects both globally and locally. *World Trans. on Engng and Technol. Educ*., 16, **4**, 356-361 (2018).
3. Kim, M-S., A conceptual framework to develop a project management system with multidisciplinary consilience in the capstone design course. *Global J. of Engng. Educ*., 17, **2**, 53-60 (2015).
4. Herrera, O.A., and Fuller, D.A., Collaborative model for remote experimentation laboratories used by non-hierarchical distributed groups of engineering students. *Australasian J. of Educ. Technol*., 27, **3**, 428-445 (2011).
5. Bury, J. and Masuzawa, Y., Non-hierarchical learning: sharing knowledge, power and outcomes. *J. of Pedagogy Develop*., 7, **1**, 32-51 (2018).
6. Oliveira, M.B., Sistematização da gestão do desenvolvimento de edificações. *Proc. IV Congresso Nacional de Construção*, Universidade de Coimbra, Portugal, 10p. (2012) (in Portuguese).
7. Outcalt, C.L., Faris, S.K. and McMahon, K.N., *Developing Non-hierarchical Leadership on Campus: Case Studies and Best Practices in Higher Education*. London: Greenwood Press, 144 -152 (2000).
8. Ilkovičová, Ľ. and Ilkovič, J., Industry 4.0 in architecture education. *World Trans. on Engng. and Technol. Educ*., 19, **3**, 331-336 (2021).
9. Van den Beemt, A., MacLeod, M., Van der Veen, J., Van de Ven, A., Van Baalen, S., Klaassen, R. and Boon, M., Interdisciplinary engineering education: a review of vision, teaching, and support. *J. of Engng. Educ.*, 109, **1**, 508-555 (2020).
10. Bobrova, Y., Marjanovic-Halburd, L. and McLennan, P., Developing critical reading, thinking and discussion skills among students at a masters level using virtual learning environment. *Proc. EDULEARN 16*, Barcelona, Spain, 11-20 (2016).
11. Rahman, A., Ahmar, A.S. and Rusli, The influence of cooperative learning models on learning outcomes based on students' learning styles. *World Trans. on Engng. and Technol. Educ.*, 14, **3**, 425-430 (2016).
12. The Difference Between Multidisciplinary, Interdisciplinary, and Convergence Research (2020), 17 August 2022, https://research.ncsu.edu/rdo/the-difference-between-multidisciplinary-interdisciplinary-and-convergence-research/
13. Badawi, A.M. and Abdullah, M.R., Interdisciplinary design education: development of an elective course in architecture and engineering departments. *J. of Engng. and Applied Science*, 68, **1**, 1-13 (2021).
14. Frescura, F., *Visual Cognition and the Struggle for the Soul of Architecture*. In: Samuel, M., Dhunpath, R. and Nyna Amin, N. (Eds), Disrupting higher education curriculum: undoing cognitive damage. Rotterdam: Sense Publishers, 59-80 (2016).
15. Cleary, R., Lessons in tenuity: Frank Lloyd Wright's bridges. *Proc. Second Inter. Congress on Construct. Hist.*, Cambridge, England, 741-758 (2006).
16. Franco, M., Arquitetura e estrutura: experiências e perspectivas. *IDEA, IE-SP*, São Paulo, Brazil, (1995) (in Portuguese).

17. Polačko, J. and Dancák, P., *Interdisciplinarita ako kľúčový element vysokoškolského vzdelávania v digitálnej dobe.* In: Hrehová, D. (Ed), Vzdelávaním k perspektívnemu uplatneniu (kompetencie, internacionalizácia, interdisciplinarita a inovácia vysokoškolského vzdelávania) Košice: Technická Univerzita v Košiciach, 78- 87 (2020) (in Slovak).
18. Kuc, S. and Tadewicz, A., Interdisciplinary studies for PhD students in the Faculty of Architecture at Cracow University of Technology: part 1 - first year study. *Global J. of Engng. Educ.*, 20, **3**, 224-229 (2018).
19. Perez Gil, J., Santos y Ganges, L., Almonacid Canseco, R., Lalana Soto, J.L., Garcia Nistal, J. and Jimeno Guerra, V., Interdisciplinarity in architecture: towards a genuine cross-disciplinary education. *Proc. EDULEARN 16*, Barcelona, Spain, 6362-6367 (2016).
20. Santos y Ganges, L., Perez Gil, J. and Fernández-Maroto, M., Multidiscipline, interdiscipline and transdiscipline in the teaching of architecture. *Proc. EDULEARN 21,* Barcelona, Spain, 411-418 (2021).

ACKNOWLEDGMETS

The authors wish to gratefully acknowledge students Hermína Mikešová and Simona Podolcová whose works created in the DS conducted by the authors, are presented in this article.

This article was prepared under the financial support from the Cultural and Educational Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic through the grants numbered 029STU-4/2021 and 037STU-4/2021.

BIOGRAPHIES

Ľubica Ilkovičová graduated from the then Faculty of Architecture of Slovak University of Technology (STU), where she also completed her PhD studies in 1992. Since 1992, she has worked at the Faculty as a pedagogue. She has been appointed an associate professor since 2013 at the Institute of Construction in Architecture and Engineering Structures. She mainly deals with issues of production and engineering buildings, focusing on identity of architecture of industrial and agriculture production, and conversion of old industrial buildings. She also teaches these topics in theoretical courses, as well as in courses on architectonic design. Her scientific-research portfolio comprises four scientific monographies, more than 45 scientific publications. She has co-operated on more than ten scientific projects concentrating on architecture of production and structure in architecture. She has actively participated in many international scientific conferences.

Ján Ilkovič graduated from the then Faculty of Architecture (FA) of Slovak University of Technology (STU), in 1982, and in 1989 he completed his doctoral studies. He was appointed an associate professor in 1998. Besides other posts, he was in 2006-2019 the Head of the Institute of Construction in Architecture and Engineering Structures at the Faculty of Architecture of the STU (since 2006). From 2010 until 2018 he held the post of the Vice-Dean for Education at the Faculty of Architecture of the STU; he was a member of the Scientific Board and a member of several editorial boards of the FA-STU. He has been the principal investigator of ten scientific projects focused on structural design, architecture of industrial and engineering buildings, and conversion of old industrial buildings. He has introduced innovative teaching methods in courses focusing on structures in architecture. He has published five scientific monographs and dozens of scientific publications. He has actively participated in many international scientific conferences.

Maria Betânia de Oliveira is an associate professor in the Department of Structures at the Faculty of Architecture and Urbanism of the Federal University of Rio de Janeiro (UFRJ), in the city of Rio de Janeiro, Brazil. She studied civil engineering (1991) at the Federal University of Uberlândia. In 1995, she obtained a Master of Civil Engineering (structural engineering) from the Universidade de São Paulo (USP), and in 2001 a PhD in civil engineering (structural engineering) from USP. She has had over twenty years of experience teaching structures in civil engineering and architecture and urbanism courses. At UFRJ, she has been a professor since 2012. Her research interests centre around the analysis of tensile structures (balancing form and structure), structural design, project management and teaching of structures. She is the author of a book entitled Introdução à Modelagem dos Sistemas Estruturais (available in Portuguese) published in 2020 by Letra Capital from Rio de Janeiro, Brazil.