

# Architectonics as synthesis of architectural and engineering disciplines

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## Abstract

The article is dedicated to the solution of some tasks faced when teaching students of architectural departments and related to insufficient knowledge of technical science. The need for introducing a profound study of such technical disciplines as “Structural performance of materials”, “Construction mechanics” into the educational program of architecture students has been proved. Methodological principles for selecting and structuring the contents of the Architectonics discipline have been defined. A project for scientific and methodological support of the Architectonics discipline has been developed. We state that currently there is a wide range of graphical software products allowing students of architectural departments to model various interesting shapes. Along with that, we note that graphic software products do not allow for adequate check of the constructive solution, so educational modeling is frequently limited by solving space-planning and imaginary tasks. A problem of implementing calculation and designing software into the educational architectural designing has been considered.

## Keywords

Architectonics, Design of architectural and engineering structures, Educational program of architecture, Integrated system of strength analysis, Russian engineering education.



## 1. Introduction

A new stage in development of Russian architecture that started with the transition to mixed economy in the context of private property rehabilitation could not help but affect the system of architectural education. First, it affected the style of architectural projects. "Historicism" that had been informally prohibited for 25 years, covered the entire architectural "shop" in the country almost instantly. Projects reflecting the drive to search for new trends in architecture development released from decorative representation began to emerge as an alternative from neohistorism. There were also new design objects like temples, business centers, or elite apartment houses. In the 1990s, computer design was introduced to the training process for the first time. Contacts with foreign colleagues and universities intensified, and people got indeed acquainted with the latest construction technology.

The Town Planning Code and related legislative documents set a new sequence of town planning documentation development. As contrasted with the Soviet procedure of "top to bottom" urban planning, it is done from bottom to top. The Town Planning Code cancelled state standards and the original prescription of what needs to be designed and in what amount. Now self-government authorities decide how many schools and kinder-gartens, parking lots and trade places, sports complexes and squares should be built. The population is gradually becoming the main driving force for generating and implementing any town-planning ideas. Today, a city planner should be able to both solve financial, sanitary engineering and transport issues competently and form a beautiful urban environment. Despite some success, we must admit that, in general, Russian architectural universities have not adjusted to new requirements yet. According to corresponding member of the International Academy of Architecture M. G. Meerovich: "The teachers engaged in training cannot

do this (with rare exceptions), and to say more, they cannot explain to others how to do this". (Meerovich 2010).

Simultaneously with the development of standards, one should be able to formulate procedures to be implemented in real life. All the above are tasks of a modern architect and planner, or urban planner. These tasks should be solved together with representatives of other academic subjects, but within the scope of their personal professional responsibility. Where can we get these specific knowledge and skills? It is architectural education that initiates development of the new fields of activity and qualification of graduates.

In the past, an architect took decisions based on the "objectivity" set by standards, theoretical postulates, and possibilities of the construction industry base. Today, town-planning decisions become increasingly subjective - most often they are taken situationally, based on personal conviction and knowledge but not on general requirements and regulations. To implement such tasks, perhaps, a completely different personality is needed rather than one that the system of higher architectural education provides today. Today, we need people who are more likely to not draw but design and construct. They should know how to use mathematical formulas and calculation methods easily. It means that we need an engineer with skills in architecture, not an artist. Most top managers at factories that produce various building structures have the same opinion. This conclusion was made because we have monitored the opinions of top managers at industrial enterprises in St. Petersburg and Leningrad Oblast during field trips to the sites with students of St. Petersburg State Architectural and Construction University. To date, capacity of production facilities at these enterprises is enough to make real almost any intention of an architect with artistic skills. The problem is lack of qualified personnel to do drawings of proposed structures supported by cor-

responding calculations and recommendations. Top managers of any certain enterprise within the said territory are interested in creating departments for design and engineering at their enterprises and are very anxious about the issue related to selection of appropriate personnel.

The purpose of this study is to develop and substantiate scientific and methodological ground for training the future architects taking into account the engineering component of training.

The scope of the study is a special training of architects in the field of engineering.

The object of the study is a project of scientific and methodical support for teaching engineering to architects. According to the purpose of the study, the following tasks were set:

1. To study the condition of the investigated issue
2. To identify the place and importance of technical subjects in the framework of architectural education
3. To prove the need to introduce advanced technical subjects like Statics and Dynamics of Buildings and Structures, Building Materials, Performance of Construction Materials, and Construction Mechanics into the training course for students of architectural departments.
4. To define methodological principles of selecting and structuring the content of Architectonics.
5. To develop a methodological support project for Architectonics.

## 2. Theoretical analysis

### 2.1. Development trends of a 'technological' society that define new vectors of mentoring and educating architects

Transition to the "technological" society increases requirements for modern up-bringing and education that are formed taking into account current trends in society development. It contributes to formation of an integral personality – a creative, smart, and educated person who has strong attitude,

democratic views, and a proactive approach to life. The tasks faced by architectural education in the light of the problems in the 21st century leave no doubt as to the need for radical change in education. A real solution to this problem is to achieve the level of professional architectural consciousness that guarantees continuity in the conditions of active introduction to new achievements in science and technology.

The solution to such a problem cannot be implemented within the framework of separated scientific and technical subjects and by means of them. It can be implemented only within the framework of "human ecology" (Kaznacheev 1988). Currently, a new direction in architectural science is being considered. It is an interdisciplinary direction that determines relationship between nature and the human being.

This means that architects of the future will need new knowledge, new skills, and new ideas. They will have to learn how to team work with engineers, biologists, physicists, and other professionals. Therefore, they will have to master the professional language in order to have at least a little idea about the basic concepts on which they build their reasoning. In any case, architects should stop locking themselves up and start communicating with the world.

According to the studies of biologists V. Meyer, F. Kahn, N. Bogolyubov and others conducted at different times (Kahn 1929, Maier 1968, Bogolyubov 1940), architectonics of supporting systems of living organisms is linked to providing a high degree of strength and lightness in elements that are characterized by cost-efficient distribution of material (Temnov 2001). Therefore, in recent years, architects and engineers in Russia (Y. Lebedev, S. Voznesensky, V. Temnov, etc.) and in Western countries (P. Nervi, A. Menges, E. Hampe, S. Calatrava, P. Portoghesi, etc.) have actively referred to the experience of living nature. This is due to the fact that structures of living organisms, as well as building structures, are strong,

rigid and resistant to gravitational, atmospheric and other force actions. This experience is successfully used in design and construction of buildings and facilities with modern forms and efficient structures.

Thanks to this interdisciplinary approach, an architecture that cannot be simply drawn but only created through deep understanding is being developed at the Institute for Computational Design in Stuttgart, Germany. Moreover, consideration and studying of the most unexpected objects is used for this understanding. For example, a shell of a spider (Architecture at your fingertips. Achim Menges develops software codes and makes a revolution in architecture 2014).

University of Massachusetts pays great attention to this field of research. In particular, a digitized process of making a cocoon by a mulberry-fed caterpillar was used there to construct various spaces. The Group Director Neri Oxman believes that when studying the natural processes like ability of silkworms to build their cocoons from silk threads, scientists will be able to develop methods of “printing” architectural structures in a more efficient way, which can be achieved by modern 3D-printing technologies. This group investigated the relationship between digital and biological products to be produced in architectural scales. A dome of silk fibers called “Silk Pavilion” was created at the interdisciplinary research laboratory “MIT Media Lab” of Massachusetts Institute of Technology (“Silk Pavilion” - silkworms and a robot weave together 2013).

At the same time, a natural object is not simply copied; what is copied is its very essence. On this basis, the Stuttgart Institute develops avant-garde projects. For example, bimaterials are used to simulate work of muscles. Alternatively, a living cell is created which is capable to build a given structure by reproducing and then fossilizing like a coral under certain conditions (Dmitrieva 2015).

Based on the information above, we can conclude that an architect of the

very near future will need universal knowledge to operate successfully. And they are all the more necessary when it comes to buildings related to adaptive architecture – there is simply no way to do this without well-developed engineering skills (Emmitt S. 2002, Emmitt S. 2004, Wiberg 2011, Schnädelbach 2016, Schnädelbach et al 2012, Fuchs 2013, Kontovourkis et al 2013, Jager et al 2016), since, in a certain sense, objects of adaptive architecture are machines. Therefore, we can assume that it cannot hurt for an architect to know the fundamentals of the basic subjects for mechanical engineers like machine elements and the theory of machines and mechanisms, as well as performance of construction materials. Of course, an architect will not have to independently calculate an assembly unit that ensures intended movements of structures. It is the work of a designer. However, an architect should know which assembly units already exist and which ones can exist in reality based on the laws of physics.

However, to acquire enough knowledge in design, an architect actually needs to be trained in design, and it seems almost impossible today. In addition, a good knowledge of behavior of structures is not yet a guarantee that an architect will be able to find expressive tectonic images. Therefore, an issue related to significant correction of study programs of architectural and design schools should be recognized as one of the current problems. At the same time, the current development of architect's skills in design can be achieved not at the expense of an increase in number of class hours, but improvement of content quality for special design subjects.

## **2.2. Problems of developing the syllabus of teaching educational programmes in the major of architecture at Russian universities**

The problem of arranging the content of educational programs for architects has always been of attention to many researchers. One can definitely

say that it is a crosscut-ting issue of pedagogy, which is topical at every stage of developing training courses for architects.

The following question is important: how the content of education of architects should be projected to the higher school. Let us turn to studying the issue of technology of designing the competence-oriented content of the architects' training courses.

The Russian system of higher education was formed based on paradigm of knowledge. The whole educational process was organized according to "knowledge – skills – abilities" triad where exactly knowledge was the first. It was believed that knowledge digestion process had potential for development by itself letting to form working knowledge and to put it to use. The logic of implementing the competence approach differs fundamentally from the previous knowledge paradigm by the fact that the goal of education in Federal state educational standard of higher education (HE FSES) is specifically formulated competences (general cultural and professional). In this regard, there are some contradictions:

- Between specific objectives of education in the form of competencies that shall be mastered because of studying the educational program, on the one hand, and an unclear idea of what the content of education should be in order to form these competencies.
- Between the integrative nature of competences, which requires appropriate complex means for their formation, on the one hand, and the disciplinary nature of the curriculum aimed at the formation of subject knowledge and skills, on the other hand.

Hence, the following problem arises: what should the projected content of architects' education be in order to form the needed competencies?

As the analysis shows, curricula for training bachelors consist of cycles of subjects and sections (Dreher 2013). The set of subjects in each cycle is determined by the types of professional activities with which undergraduates will deal, and the content of curricula is determined by the task of the most thorough and in-depth study of each

subject. Despite the fact that matrices of the correspondence of the subject and the competences formed within it are compiled in the course programs, this process is often of a formal nature. Teachers conduct this correspondence "by eye", mainly to accomplish the assignment of the management team. With such a planning system, subjects that do not meet the requirements of formation of assigned competencies are included into the course content, or, conversely, subjects that are necessary to form the assigned competencies are missing. Curricula and course programs are an important prerequisite for professional training. At the same time, the more rationally these documents are compiled, the higher the probability of successful student training. Individual subjects of the curriculum should be harmoniously interconnected; interdisciplinary continuity should be established between subjects and their topics.

The logic of the new generation of HE FSES requires movement from goals of results to the content capable of providing these results. Therefore, designing of the scope, level, content of theoretical and empirical knowledge, practical skills, and necessary experience are directly dependent on the results of education expressed in the form of competencies. You can neither "tear off" competencies from the content of education nor you should expect that you could ensure their acquisition only through the content of education.

In the process of teaching, the teacher and the student deal with a certain subject. What should it be in the context of competence approach implementation? The course program should contain information about objectives, structure, scope, content, and other methodological support of the subject (Ogorelkov 2013). Moreover, we proceed from the fact that a student should be introduced to the educational program as a whole from the very beginning of training, so that he/she could immediately understand what competencies should be formed in the course of studying the subject, during the term, year, or the entire period of study; what tasks he/she should per-

form in the course of studying, etc. In addition, in our opinion, it is necessary to move on to a different structuring of teaching aids based on the project and technological approach.

### **2.3. Methodological approaches to the engineering-focused training of architects**

The study data was collected in the course of analysis of the contemporary training of architects in Russia and abroad. The study data was collected in the course of analysis of the contemporary training of architects at Saint Petersburg State University of Architecture and Civil Engineering (SPbSUACE) (Predmetno-modulnaya matritsa obucheniya arhitektorov [Subject and Module Training Matrix for Architects] 2016), Moscow Architectural Institute (Primernaya osnovnaya professionalnaya obrazovatel'naya programma vysshego obrazovaniya [Model Main Professional Educational Programme of Higher Education] 2016), Nizhny Novgorod State University of Architecture and Civil Engineering (Annotatsii i rabochiye programmy distsiplin [Abstracts and Steering Documents of Academic Disciplines] 2018), Novosibirsk State Academy of Architecture and Civil Engineering (Osnovnye obrazovatelnye programmy [Main Educational Programmes] 2011), the Institute of Urban Science and Urban Environment, the Karlsruhe University (Germany), the University of Strasbourg (France) (Proekt Rossiya 82. Obrazovaniye 2016 [Project Russia 82. Education 2016]), the Institute for Computational Design and Construction of Stuttgart, University of Massachusetts, and the University of Niš (Study program – Architecture 2011).

In the contemporary dynamic international environment of architectural education, the Russian higher school is by no means always showing the signs of progress. Judging by the current state of the Russian architectural school, the question arises if we can expect any interesting and competently drafted projects at the Russian architectural universities, which demonstrate more and more signs of

stagnation. Many problems of teaching the architectural way of thinking in Russian schools are rooted in the predominance of artistic ‘frills’ when interpreting the architecture, wherein a quest for a showy envelopment remains the main issue. From the very beginning of teaching the profession, there have been artistic exercises aimed at creating that showy envelopment instead of designing a form using modern materials and techniques. The disastrously underrated role of the scaled down modelling of modern structures made of the same materials that are supposed to be used to build real-life facilities leads to Utopian projects. A failure to provide sufficient new equipment to mockup workshops prevents students from appreciating the sense of structure or from understanding how engineering materials work in real life, and that is what can be experienced during scaled down modelling.

In some foreign universities (Karlsruhe University (Germany), the University of Strasbourg (France), Helsinki University of Technology), teaching many engineering cross-disciplines (first of all, design) provides to students a fundamental training in terms of appreciating the sense of how to use materials with different properties. Spatial image of an item in the form of multilayer axonometric projections and sections with no envelopment gives an idea of how competently materials and structures are used to support highly demanded processes. Special attention should be paid to Juhani Pallasmaa's laboratory of prototype design where students study professional subjects through scaled prototypes that they make with their own hands.

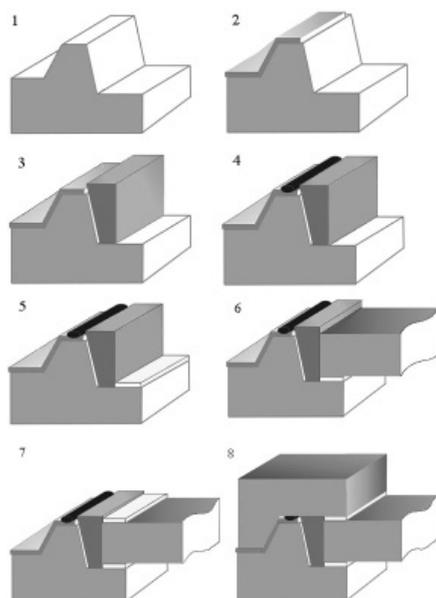
The analysis has revealed that the current training of architects is, with rare exceptions, more involved with computers thus distancing the students from reality. Modern teaching methods do not involve manual count of engineering structures either. Numerous recent computer graphics textbooks are primarily focused on simulating the geometry of designed objects and solving the drawing and graphics problems. At the same time, there are almost no textbooks focused on auto-

mated calculations and applied design assignments.

The drawbacks of architects' training in Europe can also be as follows; for example, the University of Sheffield teaches an operating method not specific skills while independent student activities seem to be too much of a share there; Delft University of Technology seems to pay little attention to design as such; the Institute for Advanced Architecture of Catalonia does not always adapt the engineering aspect of design to real life situations (Proekt Rossiya 82. Obrazovaniye 2016 [Project Russia 82. Education 2016]). However, the bottom line is that contemporary teaching methods provide neither good construction skills nor professional intuition in future architects.

### 3. A project for methodological support of Architectonics

The authors suggest introducing a new subject called Architectonics into the curricula of architectural and designing specialties as an integrated course of the following subjects: Building Materials, Architectural and Building Constructions, Statics and Dynamics of Buildings and Structures, Performance of Construction Materials, and Structural Mechanics. In architectural science, artistic and



**Figure 1.** An animated demonstration of creating an “open” joint of external wall panels in a technological sequence.

imaginative comprehension of forces invisible to the eye is called Architectonics (from Greek ἀρχιτεκτονική – the art of building) (Weisman 1899). The following national scientists carried out rigorous theoretical studies on the topic of Architectonics: B. Nikolaev, A.I. Nekrasov, V.F. Markuzon, V.P. Zubov, A.G. Gabrichevsky, Y.S. Lebedev, V.G. Barkhin, A.E. Gutnov, M.V. Shubenkov, etc. (Nekrasov 1994, Nikolaev 2006, Shubenkov 2006, Zubov 2001).

The project of methodological support of the subject of Architectonics provides a solution of interdisciplinary tasks in architectural design. The objective of the project for the scientific and methodological support of Architectonics is to create the most acceptable from practical point of view methods of visualization of the most frequently encountered elements of building structures subjected to calculations. The need to bring the solution of each problem to a finite numerical result often leads to various simplifications, which validity in each case is confirmed experimentally or by mathematical analysis.

During the development of the project for scientific and methodological support of Architectonics, the authors were guided by the fact that one should strive to both apply complex mathematical calculations and receive a deep understanding of the essence of occurring physical phenomena and carry out simplified computational modeling (schematization) of them. Therefore, to successfully master Architectonics, students shall necessarily get skills of both machine and manual calculation for most common elements of building structures along with design skills.

The scientific and methodological support of Architectonics should include the following:

- The course program (please find it attached)
- Methodical recommendations for course studying
- Methodical instructions for the practicals
- Complex individual tasks for computational and graphic works
- Educational, didactic, and reference materials

- The method to control the level of mastering the subject based on the rating technology of knowledge assessment

#### 4. Methodical recommendations for the course of Architectonics

Methodical recommendations for the course of Architectonics

The following actions should be taken for successful implementation of the course program in Architectonics:

The first section of the subject - Architectural Constructions (AC) should include lectures and exercises. Presentation of lecture material in Architectonics shall be accompanied by a presentation created, for example, in Power Point (Fig.1).

Practicals should be carried out only as field trips:

a) Across the university's academic buildings.

b) To existing buildings outside the university, including residential, public and industrial buildings and structures.

c) To construction sites.

d) To factories of building materials and structures. Presentation of a photo album with situational pictures shall be an indispensable requirement for a student's report.

Architectural Days shall be provided for in the curriculum for the successful mastering of the first part of Architectonics. An Architectural Day is a day within a working week on which students shall only deal with Architectonics. It is reasonable to study by this scheme during two terms of the first year.

The second section of the subject is the Basis for Calculation of Architectural Structures (BCAS). It shall include lectures and practicals.

Presentation of lecture material shall necessarily be accompanied by a presentation, since theoretical issues related to statics and dynamics of structures are particularly difficult to understand and shall be accompanied by any form of visualization, including electronic presentations. It is expedient to start studying a certain subject with a selection of photo materials from the photo albums with situational shots (for example, Fig. 2, 3, 4, 5).

Therefore, students will not solve related abstract problems (as it is done now) and calculate real structured taken from practice. An example is calculation of a statically definable metal frame required for the restoration of a destroyed building wall (Fig.6).

To successfully master the second part of Architectonics, the curriculum shall include 4 academic hours (2 hours of lectures and 2 hours of practicals) every week for three terms of the



*Figure 2. Photo of a balcony console for calculations of transverse bending.*



*Figure 3. Photo of an arch for calculations of transverse bending.*



*Figure 4. Photo of columns for calculations of stability.*

second and third year. It is reasonable to combine manual and computer calculations. Automated calculation involves usage of the calculation extensive features and design software SCAD Office that is notable for its high degree of visualizing the calculation results.

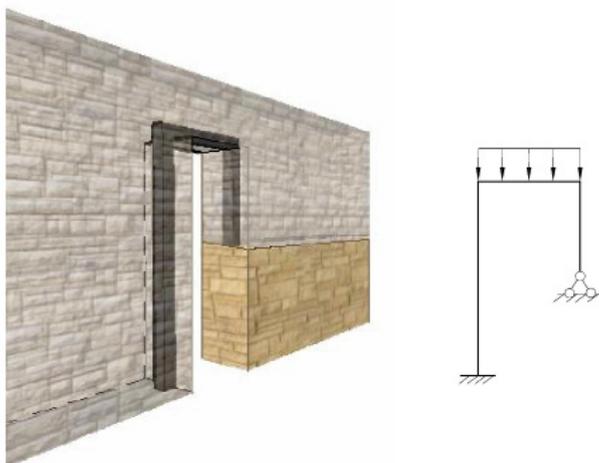
The architectural form is material and has one very important feature, which has not been sufficiently studied, in our opinion. This feature is associated with the presence of hidden forces that arise in the material because of influence of all kinds of physical load. These forces are studied in detail by various branches of physics, the theory of elasticity, strength of materials, theoretical mechanics, and so on. The specific nature of the topic is that in-

visibility of internal forces results in the necessity to attract complex engineering calculations or intuition. By covering spheres of logical and imaginative thinking and revealing points of their contact, the topic of Architectonics is among the most difficult ones in architecture. It is considered that a professional architect should be able to cover both these areas of activity; however, such interaction is carried out with great difficulty in the modern educational process and often in practice (Fisher 2006, 2008, 2013). In the vast majority of cases, it is very difficult for students to grasp the relationship between the logic of architectural forms making and precise analytical calculations based on abstract modeling of physical processes (Melodinsky 2004).

Now there are new software products that allow working in the mode of complex design getting the result in a quick and accurate way, in a visual and intuitive form, which is important for future architects. Quite a many programs have already been used in architectural and building design: "Lira", "Monomah", COSMOS, ANSYS, NASTRAN, etc. (Radzjukevich & Kozlov 2001). Thanks to these programs, architects have a possibility to solve almost all design tasks that can be formalized and algorithmized. Almost all sections of construction physics (heat protection, sound insulation, acoustics, insulation, etc.) and structural mechanics (theory of strength of materials, theory of stability, theory of plasticity), theory of structures (statics, dynamics, stability of structures), building structures, geophysics, etc. can be referred to them. All kinds of dynamic processes are also modeled, and it is important for building design taking into account seismicity. However, despite such a huge variety of software products that can be used to solve different project tasks, in the majority of cases students of architectural institutions develop only drawings and 3D models followed by designed projects visualization. In fact, the computer is used only as a tool for geometric modeling and is a tiny fraction of real capabilities of modern software. The main difficulty of the problem lies in the fact that studying of new products



**Figure 5.** Photo of envelopments and frameworks for calculations of combined strength.



**Figure 6.** The scheme of calculation of a statically definable metal frame developed by a student on the example of reconstruction of a destroyed building wall.

and their adaptation to the learning process are a separate large organizational, scientific, and methodical job that requires participation of a diversified group of specialists.

The topicality of this work is related to the fact that many textbooks (the theory of strength of materials, theoretical mechanics, structural mechanics, etc.) run their course, because visualization of conditions and the behavior of a projected object are presented in them in an extremely abstract form. Often such textbooks contain only formulas, graphs, curves, and diagrams that students perceive with some difficulty (Azizyan et al 2002, Beljaev 2001, Bespalov 2011, Stasyuk et al 2004).

In this regard, in our opinion, the attempt to study some computational software products for their “integration” into the educational process undertaken at Novosibirsk State Academy of Architecture and Fine Arts (NSAAFA) deserves attention (Radzjukevich & Palchynov 2009). A comparative analysis of software products showed there that SCAD Offis (Structure CAD Office) is most preferable for educational design. If determined accurately, it is an integrated system for strength analysis and structural design. A store of NSAAFA experience in this direction makes it possible to identify a number of possibilities of new software products. First, it should be noted that it became possible to visualize the distribution of equivalent stresses both on the surface and inside the analyzed structural element. An object is automatically painted with different colors using the color indication or the so-called von-Mises scale. It is conventionally assumed that the less the stress in the material is, the “colder” the color (dark-blue, blue) is. And vice versa, areas working under high loads are painted with “warm” and “hot” colors (yellow, red). In this case, information about the operation of the element acquires extreme clarity, which is very important for students of architectural and design profile to perceive the material studied.

Obviously, to ensure complete design, in addition to creating “beautiful pictures” it is also necessary to do physical modeling, i.e. to turn certain phys-

ical properties to geometrical models for their investigation. Therefore, the material form can be considered a certain derivative of its internal physical properties and given external conditions to which it is adjusted or adapted. Modeling of such a form that coincides with the spatial structure of stresses makes it possible to introduce a new method of form making, which can be conditionally called adaptive-tectonic (Charleson 2005, Charleson & Pirie 2009).

It is possible to set conditions to detect a conditionally optimal form for such elements as “support”, “console”, “counterfort”, “beam”, “wall opening”, “shell”, etc. In addition, for more adequate artistic understanding of design, it is promising to create a typology of tectonic units like:

1. Load receipt unit (column cap, counterfort abutment to the wall, etc.);
2. Unit of load transfer by distance (column shaft, pilaster, post, spacer, etc.);
3. Unit of load transfer to the base (base, socle, etc.);
4. Unit of changes in the direction of line of force (counterfort angle).
5. Unit of load transfer from some loaded sites to another quantity of restrained sites (branching in trussed systems).

Obviously, it is a far from complete list of situations reflecting the operation of hidden forces in a material. Development of this area of research is only beginning. Carrying out such virtual experiments with material and loads makes it possible to bring out the process of architectural form making and, accordingly, design to a qualitatively new stage. An architect receives a tool that allows looking through the material and it, in turn, can provide the basis for a significant approximation of artistic-intuitive and engineering-design approaches to design and form making.

Detailed studying of the program showed that it makes it possible to carry out calculations accompanied by visual graphic presentation of structural layout operation, indicate loads, and allows choosing optimum structural elements. This product interacts seamlessly with many other software prod-

ucts and allows working correctly with imported geometric models, which is very important when using graphic software products.

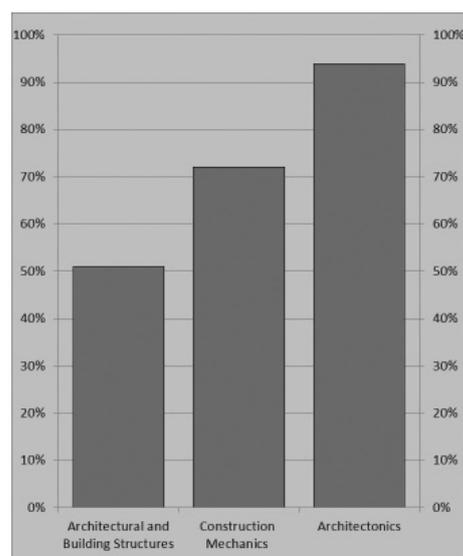
The results of machine and manual calculations shall represent mutual verification of the correctness of the result received. However, in our opinion, manual calculation shall prevail, since it allows “feeling” the structure, not to mention the fact that in some cases machine calculation cannot even be used.

### 5. Recommendation

The projected methodology of teaching Architectonics can be used to train architects at construction universities and architectural and art academies, because it is an effective way to increase the level of knowledge of students and form their professional activities.

It is recommended to:

- Include mathematics and physics into the list of entrance examinations for architectural specialties as the basic general subjects.
- Equip the park of the educational architectural workshop with any of architectural and construction design programs - “Lira”, “Monomakh”, COSMOS, ANSYS, NASTRAN, etc. - that allow to work in the mode of complex design getting results in a quick and accurate way, in a clear and intuitive



**Figure 7.** Averaged results of the pass/fail examinations in Architectonics, Architectural Engineering Structures, and Structural Mechanics.

form, which is important for future architects.

- Equip the park of the educational architectural workshop with a laser scanner that allows carrying out high-precision and high-performance measurements of architectural and building structures.

- Equip the park of the educational architectural workshop with a 3D printer with the help of which students can get a demonstrable result of their architectural and planning solutions.

- Use 3D printer features to print both as mockups of entire construction projects and 3D copies of piece architectural structures, that can be used like Lego elements to “put together” mockups of, for example, skeleton-type structures.

- Adhere to the proposed study program of Architectonics.

### 6. Conclusions

1. The developed project of scientific and methodological support of Architectonics for architects training is an important and relevant material of the theory and practice of general technical subjects teaching.

2. Peculiarities of industry training of students of construction institutions were singled out based on the principles of integration, systematization, polytechnic education, etc.

3. Requirements for the selection of the content of basic technical training of architects in Architectonics were formulated taking into account peculiarities of vocational education.

4. A project for the methodological support of Architectonics at a construction university was developed.

5. The course program in Architectonics was partially tested during the autumn term in 2015-2016 academic year. The results were as follows:

- a) The interest of students in studied subjects like Architectural and Building Structures, Performance of Construction Materials, Construction Mechanics was heightened, and it is confirmed by an increase in attendance as compared to previous years;

- b) Summarizing the results of the survey, we can say that students appreciate the innovations, because now they cannot only draw, but also cal-

culate architectural constructions, i.e. solve real issues in the field of architecture and construction.

c) Having analyzed the current and intermediate knowledge assessment, we can say that students' performance has improved because of rhythmic work during the term, which, in turn, was due to their interest in the subjects studied (Fig. 7). The comparative analysis data was collected in the course of the winter examination periods 2014/2015 and 2015/2016. In January 2016, the first pass/fail examination was held in Architectonics as an experiment in three groups. The results were compared with those shown by the three student groups at pass/fail examinations in Architectural and Building Structures and in Construction Mechanics. Previously, there had been no Strength of Materials on the curriculum for architects.

Therefore, the performed exploratory work allows concluding that the application of the proposed scientific and methodological support for Architectonics as an important basic technical subject is bound to improve the quality of teaching of students of architectural universities. The timeliness of introduction of an integrated course of art and basic technical subjects is in full agreement with national priority project "Education" currently being implemented (Prioritetnij national'nij proekt «Obrazovanie» [National Priority Project "Education"] 2016). When creating large educational and research-and-production complexes, it is possible to suggest the organization of a department for Architectonics at architectural faculties of architectural and construction universities.

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## Appendix

### Course program suggested for Architectonics:

Introduction

Part 1. Architectural

constructions (AC)

1. General principles of design of bearing and enclosing structures of buildings

1.1. General principles of design of the load-bearing frame and its elements

1.2. Selection of load-bearing frame materials

1.3. Enclosing structures, requirements to them. Methodology of their design solutions.

2. Architectural designs of low-rise residential buildings

2.1. Foundations of low-rise buildings

2.2. Frames of low-rise buildings made of stone

2.3. Frames of low-rise buildings made of wood

2.4. Frames of low-rise buildings with the use of metal and plastic

2.5. Floor slabs and floors

2.6. Roofs and roof coatings of low- and medium-rise buildings

2.7. Elements of low-rise construction (verandas, terraces, vestibules, internal wooden staircases)

2.8. Household ovens and fireplaces

3. Architectural designs of single-storey industrial and civil buildings

3.1. Load-bearing frame systems

3.2. Elements of the load-bearing frame of single-storey industrial buildings (columns, crane girders, bracing, side-framing columns)

3.3. Coverings of single-storey buildings

3.4. Flat roof framing without horizontal thrust. Beams and trusses.

3.5. Spacer flatwork

3.6. Beam-and-girder systems

3.7. Thin-walled space structures

3.8. Suspension structural systems

3.9. Pneumatic and tent coverings

3.10. Wall railings of heated and non-heated buildings

3.11. Skylights

4. Architectural designs of multi-storey buildings

4.1. Load-bearing frames of civic multi-storey buildings

4.2. Load-bearing frames of multi-storey industrial buildings

4.3. Foundations of multi-storey buildings

4.4. Wall enclosing structures of multi-storey buildings

4.5. Structural components of multi-storey buildings (balconies, recessed balconies, window bays, ceiling slabs, staircases, ramps, construction elements of carrying and lifting equipment)

4.6. Translucent vertical structures

4.7. Doors and gates

4.8. Partitions

4.9. Prefabricated large-size units of floor and ceiling slabs

4.10. Suspended ceilings

4.11. Floors

5. Construction of buildings in areas with special conditions

- 5.1. Construction in seismic areas
- 5.2. Construction in the Far North and in hot climates
- 5.3. Construction in areas with collapsing and anthropogenic soils

## Part 2. Basics of Calculation of Architectural Structures (BCAS)

### 1. The most important requirement for architectural structures

- 1.1. Tasks and objective of structural mechanics
- 1.2. Real structure and design diagrams. Basic assumptions of structural mechanics
- 1.3. Geometric characteristics of plane sections. Center of gravity of plane figures
- 1.4. External and internal forces
- 1.5. The concept of stresses. Normal and shearing stresses.

### 2. Axial tension and compression

- 2.1. Stresses and deformations. Hook's law
- 2.2. Calculation of statically determinate systems
- 2.3. Peculiarities of calculation of statically indeterminate systems
- 2.4. The concept of strength calculation. The method of allowable unit stresses. Calculation using ultimate breaking loads. Calculation using limit states
  - Practicals
    - Selecting the section of the lower chord of a welded trapezoidal truss of an industrial building
    - Selecting the section of reinforcing steel of a reinforced concrete column of square cross-section with consoles
- 2.5. Influence of own weight
  - Practicals
    - Determination of the required number of concrete end-bearing piles of a grillage
    - Determination of the volume of brickwork of a stepped brick column loaded with an axial compressive force
- 2.6. Calculation of ideal cables
  - Practicals - stress-rupture testing of the load cable of an aerial ropeway

### 3. Shift

- 3.1. Stresses and deformations
- 3.2. The concept of shear fracture and bearing stress
  - Practicals

- Determination of the required height of reinforced concrete column consoles based on shear resistance
- Determination of the required length of embedding of a round plain reinforcing bar in concrete under pulling loads

- Determination of the height of square in the plan of the foundation for the centrally compressed reinforced concrete column based on its strength of punching (shear) by the column

### 3.3. Calculation of welded joints. Butt joints. Lap joints. Combined joints.

#### Practicals

- Testing of welded joint strength
  - Determination of the stretching stress that a welded joint can withstand
- ### 3.4. Calculations of riveted and bolted connections for shear, compression, stretching

#### Practicals

- Determination of the required number of rivets
- Calculation of fastening of the compressed diagonal of a truss to the gusset plate
- Bolted connection calculation
- Determination of the ultimate tensile stress that a bolted joint of the lower chord of a truss can withstand

### 3.5. Calculation of halving joints

- Practicals - calculation of the heel joint of a skew notch for a truss made of squared beams

### 3.6. Calculation of glued joints

#### Practicals

- Test for simple shear and breaking of the joint of two wooden boards by means of double straps
- Determination of the load-bearing ability of a glued joint in units of tubular elements of a fiberglass arch truss

### 4. Torsion

- 4.1. The concept of twisting and torque moments
- 4.2. Stresses and deformations during round bars torsion
- 4.3. Calculations for strength and stiffness

### 5. Plane transverse bending

- 5.1. General concepts of bending. Types of supports and beams. Types of loads. Determination of reactions of support.

5.2. Internal force factors in beam cross-sections

5.3. Normal stresses under bending. Strength condition

Practicals

- Test for the strength of a steel beam freely supported by two supports
- Selection of the cross-section of wooden beams across which the inserted floor of the building is arranged
- The cross-section of a collar beam over the gateway

5.4. Shearing stresses under bending and their verification in the course of beams calculation

Practicals – selection of cross-sectional dimensions of a bridge sleeper made of pinewood

5.5. Main stresses under bending

Practicals – selection of the cross-section of a metal console and carrying out of a strength test

5.6. Calculation of the strength of hybrid beams

5.7. Determining displacements under bending.

Practicals – determining deflection at the free end of a steel console using the method of initial parameters

5.8. Calculation of stiffness of beams and frames

Practicals

- Selection of the cross-section of a steel console by strength and stiffness
- Calculation of the stiffness of a statically determinate frame

5.9. The concept of calculation of single-span statically indeterminate beams

Practicals - selection of the cross-section of a steel statically indeterminate beam

6. Resistance to combined stress

6.1. Skew bending

Practicals

- Test of the strength and stiffness of wooden girders supporting the roof that rest on upper chords of wooden triangular trusses
- Selection of the cross-section of a steel girder supporting roofing slabs that rests on the upper chord of a steel truss at a roof slope of 1:12
- Calculation of a horizontal

three-layer curtain wall panel with aluminum casing and foam filling

6.2. Bending with tension or compression

Practicals - selection of the rectangular cross-section of wooden rafter spars of rafters for the roof

6.3. Off-center compression

Practicals

• Determination of the required size of an industrial building that is square in plan view of the foundation of a reinforced concrete column

• Test of the strength of a rigid wooden eccentrically loaded strut of a rectangular cross section

• Construction of a kern area for a rectangle, a circle, an I beam

7. Buckling

7.1. The concept of flexible bar stability. Critical force. Critical stress

Practicals

• Test of a compressed pine strut for strength and stability

• Selection of the cross-section of a centrally compressed steel column

• Selection of the cross-section of the compressed upper chord of a metal truss

• Selection of the cross-section of a bi-stable welded centrally compressed through column

• Calculation of a brick column for strength and stability

8. The concept of dynamic loads.

Impact strength. Free vibration with

one degree of freedom. Forced

vibration of a system with one

degree of freedom. Resonance.

Practicals

• Selection of the cross-section of a steel beam lying on two supports, onto which a weight falls from a certain height

• Calculation of the impact strength of a frame

9. Calculation of curved structures

• Calculation of an arch bar

• Calculation of a triangular arch stiffened on the supports

• Calculation of a statically definable arch without stiffening