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SPATIAL PERCEPTION ABILITY FROM TWO-DIMENSIONAL MEDIA

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Abstract. *Deterioration in the spatial visualisation ability of students entering University, being much researched in other countries has also been detected in Serbia. The Department of Architecture entrance exam includes a geometric exercise in spatial forms testing the students' capability to rotate, cut and frame objects drawn in axonometric projections and the design of a free form geometric composition. The results vary from poor solutions deprived of three-dimensionality to extremely rich three-dimensional free forms. Based on numerous pieces of research on the topic, and on the results of both entrance and subjects exams we felt that the traditional course of descriptive geometry had to be reformed. We carefully reviewed all the topics of the existing course by closely analysing the connections with most other subjects. The reforms are based on the characteristic views as well as characteristic elements of the structure of geometric forms, releasing the course from all unnecessary planimetric constructions and details. Therefore, a successful geometric understanding (from two-dimensional drawing to three-dimensional thinking) of the examined spatial form became possible only on the basis of the minimal information. This paper presents the concept of geometric problems' at the entrance exam and reformed course of geometry and perspective at our Faculty.*

Key words: *geometry and graphics of 3D forms, spatial visualisation ability, education.*

1. INTRODUCTION

The basic assumption we started from, is that the aim of the education is not in transmitting obsolescent packages of ready-made knowledge. Therefore, the proper education cannot allow the waste of precious time on the training of trendy algorithmic procedures. They are as a rule short-lasting, due to the continuous updating of accompanying commercialised technologies, and not due to the progress of science which the technology supports. On the contrary, the **fundamental aim of the education is the development of**

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ability and capability as well as the **intellectual promptness** to encounter various problems including those which might occur in the future.

The special skills being recognized by many engineering associations as crucial for successful practical work not only in engineering but in some other fields has become a topic for much research [1]. A deterioration of spatial visualisation ability (SVA) has also been detected at the some Faculties at the University in Novi Sad with large numbers particularly in the Faculty of Technical Sciences. The reasons for this might be sought in the fact that students entering this level of education barely demonstrated understanding of the spatial problem either in reading two-dimensional **(**2D) images or representing and visualising three-dimensional **(**3D) forms. Namely, at all grammar schools descriptive geometry (DG) has not been studied for more than twenty years, while at vocational schools (such as architectural, civil engineering, mechanical engineering secondary schools) DG is usually taught for not longer than one school year, unfortunately only as a set of rules for case studies examples. In this way the conceptual approach to the spatial reasoning is completely omitted. The authors of this research, being also examiners of vocational secondary school teachers for many years and having close contact with the curricula, have detected this problem through the first year students SVA obstacles. They appear not only at the entrance exam but also at most subjects that demand well developed SVA.

Therefore, on the bases of the first established curricula at the Department of Architecture and Urbanism, two years ago we applied a multidisciplinary approach concerning curricula tasks and started to develop deeper and more serious collaboration among the subjects, in order to harmonise the study of the vocational basic subjects.

Since DG and its methodology of step-by-step visualisation of 3D objects through their 2D representation is the key of the activation of the right brain hemisphere and that most SVA problems are in the "laziness" of the right brain hemisphere the urgent need to adapt the traditional approach in DG teaching to nowadays students' both needs and skills [2]. The fact that the DG simultaneously activates both left and right brain hemisphere, linking the analytic with the synthetic, i.e., the abstract with the concrete, and in that way develops mental processes improving creative abilities of students, is proved by experimental data that **students having passed the course of DG, more successfully pass exams in other subjects** (even those that have no direct connection with DG), in comparison with students that have never studied DG [3].

In this paper we present, on the bases of our long lasting and fruitful experience in teaching, examining and researching at the various Faculties in Serbia and abroad, the concept of geometric problems' examination at the entrance exam at the Department of Architecture and Urbanism, as well as the reforms implemented into some subjects crucial for vocational education.

2. ENTRANCE EXAM

2. I Test in Geometry and General Knowledge

The first part of the entrance exam at the Department of Architecture and Urbanism at the Faculty of Technical Sciences consists of 15 questions on general knowledge and three problems concerning geometry of spatial forms which lasts two hours (120 minutes).

The geometric part of the entrance exam comprises only three tasks. Since we wanted to get an idea of the applicants' spatial visualisation ability through these three tasks, we were of the opinion that the problems had to be particularly designed so that the probability of the randomly gained score i.e. of the randomly guessed estimation, diminishes. Therefore, for each task there is no information how many exact solutions to the problem exist, and he/she is supposed to study closely each offered drawing.

Through these three tasks we wanted to estimate the applicants' ability to understand the spatial relationships of points, lines and planes on a represented object, the ability to mentally rotate given objects, as well as to mentally intersect complex forms with a plane.

In the following we present the typical three problems that appear at the entrance exam. Each of them is supposed to be solved without using any additional help, such as additional drawing or model making.

In the first task, out of given patterns of a solid (a cube with particular signs on some of its faces and one of its corners cut of, as shown in Figure 1) an applicant is supposed to figure out each of the given patterns can make the given solid by mere folding marked edges.

In the second task (Figure 2) a complex 3D form, derived from a cube (by cutting off some of its parts), is intersected by a given plane. An applicant is supposed to detect all correct solutions.

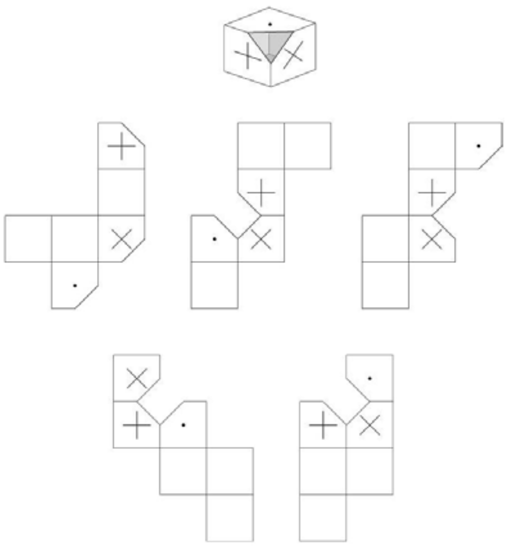

Fig. 1. Sample Problem - Spatial Relationship Understanding And Mental Rotation Of A Simple 3D Form

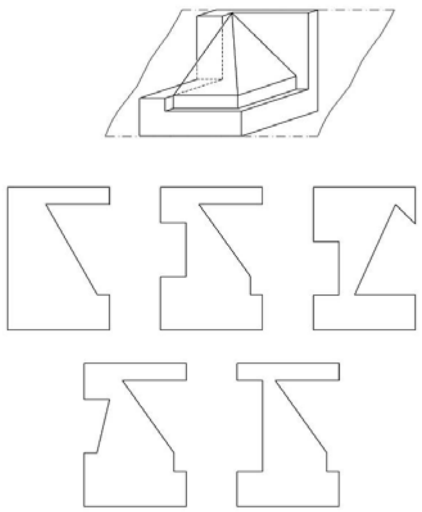

Fig. 2. Sample Of A Mental Cutting Problem

In the last problem (Figure 3) a given cube consists of two parts. When the upper part is removed the rest of the cube is shown in the neighbouring drawing. An applicant is supposed to detect, out of five offered parts, each one that will cover the lower part perfectly, making no vacancies inside the cube.

Through the last problem we estimate the applicants' ability to understand mutual relationships of various planes' positions as well as the ability of mental rotation of the whole part so as to fit the rest.

Out of 158 applicants 13 of them solved each task correctly while 19 did not solve any. 32 applicants solved the first task, 104 the second one and 110 the third task

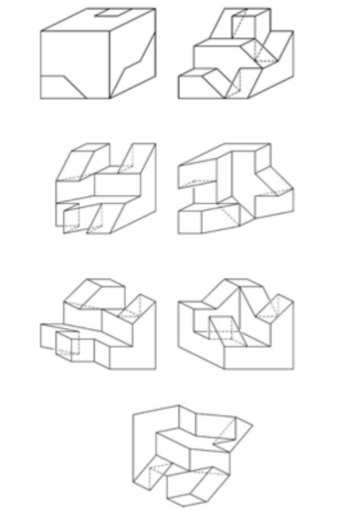

Fig. 3. Sample Problem - Spatial Relationship Understanding And Mental Rotation Of A Complex 3D Form

2. 2. Test in Spatial Composition

One of the three entrance exams, The Spatial Composition (lasting two hours) should show which students have the capability to think from two dimensions in material, they are provided with, and transform it to 3D free forms. The meaning of 3D free forms is to be as much as possible far from already seen or experienced forms (such as models of buildings, sculptures etc.). The exam text underlines the proposition that free form composition has to be three dimensional and made from given materials by cutting, bending, curling, wrinkling, crumpling, squeezing, pressing or/and using any other way to make a new form of existing shape of the material using only glue, scalpel and/or scissors. During the process of thinking and creating the final 3D form applicants have to think in the same time, spontaneously and simultaneously how to connect new elements to new parts and components in order to create the whole. The way of joining elements and parts have to be the part of the entire assembly. In that sense, apart from using glue to join new parts and create complex form, applicants are free and encouraged to use various ways to connect parts of different materials by their mutual piercing, hanging, breaking trough, breaching, penetrating, tying, chaining, linking, intersecting etc. Possible variations depend on the characteristics and structure of each material which have different characteristics. In each academic year, given materials for this exam differ and sometimes include wooden or metal which have to be used in their original shape combining with other very flexible materials. The characteristics of provided materials also varied from year to year from transparent, soft, flexible to hard, non-transparent, linear or/and surface with different texture, colour, dimension, proportion and amount (Figure 4).

The results of nine years experience in this exam varied from generation to generation as well as from poor solutions deprive of three-dimensionality to extremely rich and imaginative 3D free forms. Due to the different background of the educational processes from which our applicants come, after the second year of applying this exam (in 1997) we introduced a special preparation course aimed at the future students to help them learn the possibilities of what to expect from different materials and how to change their given shapes, sizes and figures. The first research on this topic we carried out in 2002 and has continued each subsequent year. Our observations show that students who meet the material and problem in this exam for the first time are less successful than the students who passed the preparation course.

A major number of polled students underlined that some provided materials and colours have influence on their inspiration in seeing the different shapes and creating a 3D free form composition. An interesting remark is that there are no specific materials or colours that have negative or positive influence which might be an intriguing topic for psychologists.

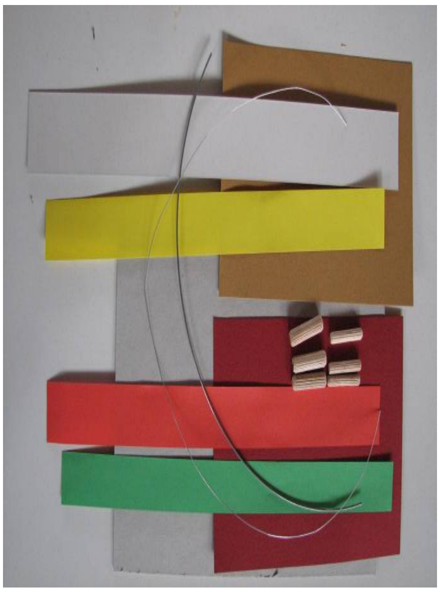

Fig. 4. Given Materials At The Test of Spatial Composition

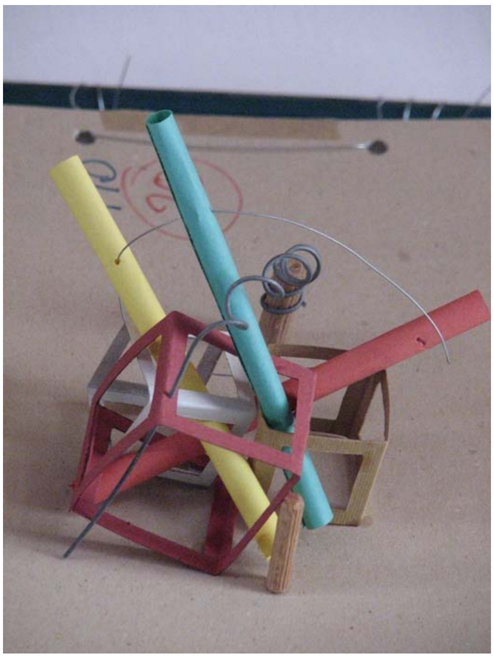

Fig. 5. An Example of an Applicant's Final 3D composition

3. First and Second Year Curricula – Subjects Influencing on Spatial Visualisation Ability

3. 1 Vocational Subjects that Comprises SVA

During the first year of study, and during two semesters, in the curricula on the Department of Architecture and Urbanism there are 8 subjects. Half of them are very much related to the SVA. The professional ones consist of several workshops and assignments in which students are instructed to use this ability. The main and initial problems which our students are facing is with the graphical presentation of their own ideas. They have crucial problems with how to transform the three dimensional space of building structure to 2D paper drawings. Among all professional drawings the most difficult for them are sections and isometric drawings. Even when they have the real elements of architectural anatomy in front of their faces a critical number of students do not know how to transform them to the flat paper space using the different scales. However, when the same problem is to be presented in the written form they, as a rule, do not face obstacles.

In the previous curricula (before reforming to the Bologna process) one of the first workshops in professional subjects (Architectural analysis, functions and typology and Architectural anatomy) was based on images of buildings and/or interior space in three orthogonal projections (layout, elevation and section). Most of the students were unable to "read" these images and to transform them to the isometric drawings. Furthermore, the same students were unable to present their own ideas of the space into the proper 2D pictures such as simple elevation. Therefore, in the new curricula we have made a multidisciplinary approach to students' tasks and have started to develop deeper and more serious collaboration among the subjects. In this way we avoid loosing the precious time through repeating the same topics in the different subjects and workshops.

3. 2 Particular Courses that Involve SVA development - The modified course of DG and Perspective - Geometry of Spatial Visualisation

In order to enhance the development of SVA, the traditional course of DG and Perspective (P) had to undergo some necessary changes. First of all we agreed that the major aim of this subject is to develop spatial visualization ability, space imagination and the ability to detect various spatial relations' of particular geometric forms on a 2D representation of both parallel and central projection. In that way the ability of identification and interpretation of spatial relations of the examined spatial forms from the corresponding 2D images as well as the knowledge of their geometric structures is supposed to be developed.

Thus the careful selection of topics to be studied was one of the most important tasks we had to carry out. This is particularly important since many students in Serbia at the University level of education meet the theory of projections for the first time, facing problems in visualising spatial forms out of orthogonal projections. (In 1998 entrance exam, when we tested applicants' ability to recognize the 3D object – given in various axonometric representations out of given orthogonal projections, the results were extremely poor, with very few of them able to fulfil the task).

The existing three semester course of DG and P is divided into three one-semester subjects, logically connected.

The first semester course begins with basic concepts of both elementary geometry and descriptive geometry, comprising points, lines and planes and their mutual relationships. It is studied through the following units (with 30 lessons of lectures and 30 lessons of workshops in groups of 25 to 30 students):

- BASIC ELEMENTS OF SPATIAL VISUALISATION: Projections, views' directions and images of basic geometric forms. Criteria for the understanding? the characteristic views' and disposition of objects for the sake of direct detection of both metrical properties and spatial relations of objects. Visibility concepts. Applications to complex forms (plane figures, polyhedrals, surfaces of revolution, etc.)
- SPATIAL VISUALIZATION AND GEOMETRIC STRUCTURE OF COMPLEX 3D FORMS: Criteria for plane and mutual sections' analysis of ruled surfaces (polyhedrals and parabolic quadrics) and surfaces of revolution rotation?. Specific elements of these sections. Visibility criteria and visual realism.

During the second semester (through 30 lessons of lectures and 30 lessons of workshops in groups of 25 to 30 students), when the basic facts of the subject are adopted, students are presented with the following:

- GEOMETRIC STRUCTURE AND VISUALISATION OF COMPLEX 3D FORMS. Space and plane curves as direcrtices and generatrices for surfaces' generation. Specific views and direct detection of geometric properties of the surfaces: developable and nondevelopable surfaces; ruled (quadrics, conoids, cylindroids etc.), helical and convolute; arcs, vaults and domes; roofs; etc.
- SPATIAL VISUALISATION OF OBJECTS IN COTED PROJECTION. Real terrain - topographic surface, objects with accompanying fills and cuts. Sections, profiles in vertical projecting surfaces. Water protection analysis of objects.
- SHADING AND BASIS OF VISUAL REALISM: Basic principles of shading. Illumination dividing line and iso-photic lines of a surface. Detection of specific elements of shadows in orthogonal, oblique and axonometric views.

In the third semester students deal with, at this stage already known geometric 3D forms, in perspective images (through 15 lessons of lectures and 30 lessons of workshops in groups of 25 to 30 students):

- SPATIAL VISUALISATION OF GEOMETRIC OBJECTS IN PERSPECTIVE IMAGES. Central projection of basic geometric forms (points, lines and planes). Three-point perspective. Image elements for the direct detection of metrical properties. Criteria for the direct recognition of spatial relations of objects. Rotation and quasi true sizes. Visibility concepts. Applications to more complex forms (plane figures, polyhedrals, surfaces of revolution, plane and mutual intersections of surfaces etc.)
- SPATIAL VISUALIZATION AND GEOMETRIC STRUCTURE OF COMPLEX 3D FORMS IN PERSPECTIVE IMAGES. Angle of visibility and perspective image's setting. One-point and two-point perspective images. Analysis of architecturally applicable surfaces: ruled surfaces, arcs, vaults, domes, roofs etc.
- SHADOWS AND REFLECTIONS. Central and parallel illumination. Specific elements of illumination rays for direct shading at perspective image. Reflections in horizontal, vertical and oblique mirrors.

- RESTITUTION OF A PERSPECTIVE IMAGE. Criteria for perspective images' analysis: detection of metrical properties and spatial relations of objects represented in a perspective image.

Through the following example we present one of the major methodology modifications carried out in each of the previously mentioned courses.

Due to the computer technologies it is apparent that nowadays there is no more need to train the students' skills in drawing techniques but to train their abilities in picture analysis, in defining criteria for characteristic elements and views detection, as well as spatial visualisation of objects out of their orthogonal views. Thus, when analysing, for example, a complex vault, consisted of two intersecting cylinders, shown in Figure 6 in a pair of characteristic orthogonal projections (in which all metric and spatial relations are directly detected), we are of the opinion that only the detection of characteristic elements (both view dependent – contours and view independent – generated by geometric structure of the 3D form) are to be analysed.

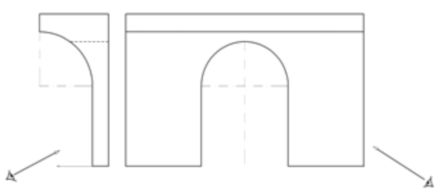

Fig. 6. Orthogonal Projections' Layout of a Complex Vault That Is to Be Represented in a Frontal Oblique Projection for the Given Line of Sight

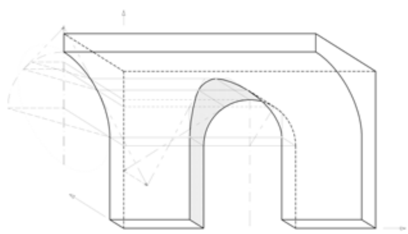

Fig. 7. The Solution to the Previous Problem

Thus, at lectures students are presented with the analysis of the geometric structure of the vault and its spatial visualisation only on the basis of its view dependent properties, geometric structure dependent properties imposed by the mutual disposition of its components.

Instead of traditional construction of an oblique projection out of orthogonal views we use an appropriate rotation of the oblique profile plane (Figure 7).

When students are to analyse the same problem on their own (during either workshop or exam), they are given, apart from the layout in Figure 6, a semi solved drawing as in Figure 8 which is to be filled in with characteristic generatrices, points and tangents to the intersecting curve.

Thus, we avoid the occurrence of graphical imprecision which, as we faced before, usually discourages students from further work on the problem. Furthermore, only having to fill in the drawing with characteristic elements, students pay much more attention to the geometric structure of the 3D form and thus more easily visualise 3D object out of given orthogonal views. At the end visibility of the whole is to be solved with respect to the given line of sight and coordinate axes, since only total contours are shown as visible lines.

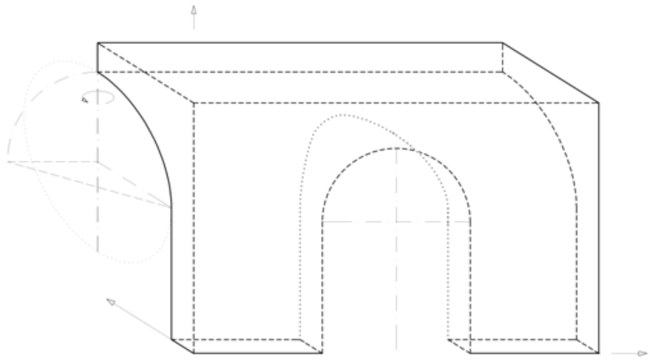

Fig. 8. Students Work Sheet For Characteristic Elements' Detection

4. Conclusion

Trough this research we would like to point out that spatial visualisation ability, being one of the most important mental abilities for the successful professional work in various engineering fields has been deteriorating among our students. The necessity for constant curricula adaptation towards the changing students' population has to be encouraged in each educator so as to satisfy the major aim of the proper education: the development of abilities and capabilities as well as the intellectual promptness for encountering all kind of professional problems and challenges.

Furthermore, even experts in some other professional fields (like medicine, dentistry, even arts) also need much higher development in SVA than they presently have. This is particularly important for the diagnostics process to visualise 3D space form on a base of 2D picture. For example using different equipments like magnetic resonance (NMR), computer tomography (CT), ultra sound (US), X-ray etc. only a few of this machine (new generation like multi detector computer tomography MDCT) provide users with 3D images of observing objects. Thus there is still real need for 2D-3D mental communication since investigation on the optimal computer aided visualising medical volumes is just nowadays actual [4].

With respect to this situation, our further research is to involve not only experts in engineering professions but also experts in different scientific fields such as psychologists and medical doctors as well as with physicists into this very important topic: the improvement of learning and developing SVA and skills.

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SPOSOBNOST PROSTORNE PERCEPCIJE NA OSNOVU DVODIMENZIONIH MEDIJA

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Pojava opadanja sposobnosti prostorne vizuelizacije kod studenata koji upisuju fakultete, a o kojoj se u drugim zemljama vrše brojna istraživanja, je takođe detektovana i u Srbiji. Prijemnim ispitom na Departmanu za arhitekturu proverava se sposobnost studenata da zadate objekte, prikazane u aksonometriji, mentalno rotiraju, seku i međusobno uklapaju, kao i da od datog dvodimenzionalnog materijala kreiraju slobodnu prostornu kompoziciju. Rezultati se kreću od vrlo skromnih rešenja, lišenih trodimenzionalnosti, do veoma bogatih prostornih geometrijskih oblika. Bazirajući se na rezultatima mnogih istraživanja na ovu temu, kao i na sopstvenim rezultatima kako sa prijemenih ispita tako i iz pojedinih predmeta, smatrali smo da je "tradicionalni" pristup nacrtnoj geometriji neophodno prilagoditi današnjim potrebama inženjera. Pažljivo smo revidirali sve nastavne teme povezujući ih sa ostalim predmetima i reformu bazirali na uvođenju karakterističnih pogleda i karakterističnih elemenata geometrijskih struktura, oslobađajući kurs svih nepotrebnih planimetrijskih konstrukcija i detalja. Na taj način je uspešno razumevanje i shvatanje izučavanih prostornih formi (od dvodimenzionalnog crteža do trodimenzionalnog razmišljanja) omogućeno na osnovu samo minimalnog broja adekvatnih informacija. U ovom radu se predstavlja i koncept geometrijskih problema sa prijemnog ispita kao i detalji vezani za reformisani kurs iz Nacrtne geometrije i Perspektive na našem Fakultetu.