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Универзитет у Бањој Луци, Архитектонско-грађевинско-геодетски факултет

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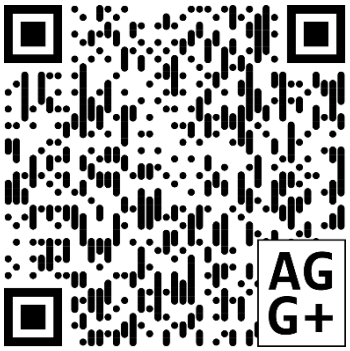
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Introduction 09(1)

Volume nine of AGG + journal is bringing five articles. Although the surveys belong to different scientific fields in terms of themes and methodology - Architecture, Civil Engineering and Geodesy, it is possible to recognise the common keyword of the three articles. The word is **infrastructure** - urban nerve system. Visually dominant or completely hidden, material or digital, infrastructure is always a large-scale tissue that connects the modern world in a global whole and makes it smaller. The articles in volume nine discuss ways to make infrastructure systems more effective or 'green', such as energy-efficient urban lighting and stormwater drainage systems, or big-data infrastructure networks such as the Global Navigation Satellite System.

The fourth article deals with learning methodology in the descriptive geometry courses of architecture students, considering the concept of spatial abilities. Thus, in the broadest sense, it contributes to the dialogue about the **education** of professionals dealing with space. While the fifth article discusses critical design practice, bringing forward the intriguing and striking architecture of the Memorial House in Sutjeska National Park. We could say that the essay awakens a neglected discipline of architectural **theory**, at least when it comes to the national context.

The editors hope that the readership will find articles constructive and enjoyable to read. Jubilee volume ten is coming out soon, therefore we welcome contributions from all over the world and invite researchers, academics, professionals, educators, and students to submit contributions.

Editors-In-Chief

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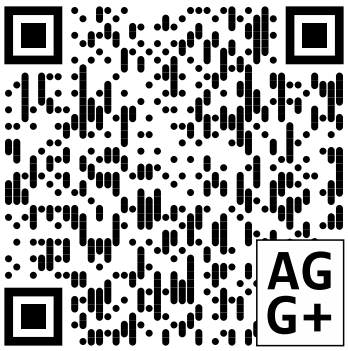
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THE INFLUENTIAL FACTORS IN IMPROVING THE SPATIAL ABILITIES OF ARCHITECTURE STUDENTS

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THE INFLUENTIAL FACTORS IN IMPROVING THE SPATIAL ABILITIES OF ARCHITECTURE STUDENTS

ABSTRACT

In this paper, the factors that influence the improvement of spatial abilities of architecture students were examined. The main question was whether the course in Descriptive Geometry at the Faculty of Architecture, Civil Engineering, and Geodesy at the University of Banja Luka had an impact on students' spatial abilities. The study examined 118 students of the first year comparing their success at Spatial Ability tests in relation to whether they attended the Descriptive Geometry course. The obtained results of the study showed a significant improvement in students' spatial abilities in general and that the Descriptive Geometry course did not have a substantial influence on spatial abilities development. The SPSS v.20 analytical-statistical software package is used for the statistical analysis.

Key words: *spatial abilities, descriptive geometry, architecture, statistical analysis*

ФАКТОРИ КОЈИ УТИЧУ НА ПОБОЉШАЊЕ ПРОСТОРНИХ СПОСОБНОСТИ СТУДЕНАТА АРХИТЕКТУРЕ

Апстракт: У овом раду испитивани су фактори који утичу на побољшање просторних способности студената архитектуре. Главно питање је било да ли је курс Нацртне геометрије на Архитектонско-грађевинско-геодетском факултету Универзитета у Бањој Луци утицао на побољшање просторних способности студената. Студија је испитала 118 студената прве године упоређујући њихов успјех на тестовима просторних способности у односу на то да ли су похађали курс Нацртне геометрије. Добијени резултати студије показали су значајно побољшање просторних способности студената уопште, као и да курс Нацртне геометрије није имао велики утицај на развој просторних способности. За статистичку анализу кориштен је аналитичко-статистички програмски пакет SPSS v.20.

Кључне ријечи: просторне способности, нацртна геометрија, архитектура, статистичка анализа

1. INTRODUCTION

1.1. SPATIAL ABILITIES AND THEIR IMPORTANCE FOR ENGINEERING STUDIES

Spatial cognition proved to be very significant for success in many STEM fields (Science, Technology, Engineering, and Mathematics), including engineering professions. It has been highly correlated with success in mathematics [1,2]. A direct correlation between spatial skills and the ability to solve several types of PISA mathematics problems was established from the study results in [1]. Architects communicate with others primarily by graphical means, so the spatial abilities of architecture students must be well-developed. The assessment and improvement of spatial skills is an essential research topic for the study of architecture.

It is necessary to understand the meaning of concepts and the difference and the connection between spatial abilities, spatial skills, spatial thinking, and spatial intelligence in understanding spatial abilities.

The spatial ability is the ability to retain, retrieve and transform visual images [3]. A person is born with such abilities. On the other hand, *spatial skills* have been learned or acquired through some formal or informal training [4]. There is not much difference between these terms in literature since there has not been any training of these abilities in formal education. *Spatial thinking* involves thinking about shapes, arrangements, and interrelations of objects in the space and spatial processes, such as the deformation of objects and the movement of objects and other entities through the space. *Spatial intelligence* can be defined as adaptive spatial thinking, and it is also central to many scientific domains. Spatial ability tests are commonly used to measure and determine the fundamental spatial thinking components/factors. This approach is used in most research on spatial skills [5, 6].

The question and challenge for researchers dealing with this topic are whether spatial abilities can be learned and improved and in what way and which factors influence the improvement of spatial abilities and skills.

For engineering students, an essential ability is to visualize 3D objects and perceive the way they look (appear) from different viewpoints or what their appearance would be if they were rotated or transformed in the space [7]. Some authors proved that spatial skills could be developed through practice or some courses at the University, such as Engineering Graphics [7, 8], Descriptive Geometry, or Preparatory course (Spatial Perception and Presentation course) for the entrance exam at the Faculty of Architecture [9].

For the past decade, the importance of descriptive geometry was pushed back in many curricula of engineering studies. Geometry education was often substituted by training in CAD software and representation techniques. This development leads to a deficiency in the spatial visualisation abilities of engineering students. The Descriptive Geometry course provides foundations for creating and understanding 2D drawings of 3D objects, and it helps develop spatial visualization abilities [10].

In this paper, we will focus on examining the factors that influence the improvement of spatial abilities of architecture students and whether the course in Descriptive Geometry is one of them.

1.2. SPATIAL ABILITY TESTS, SPATIAL ABILITY TRAINING COURSE, AND DESCRIPTIVE GEOMETRY COURSE

Since 1930, when spatial abilities became an important research topic in educational psychology [1], various tests for measuring spatial skills have been developed. Classical tests important to engineering teachers consist of tasks that measure the same factors, crucial to spatial visualisation.

There are many types of tasks that are used for assessing spatial abilities in literature, and the most common ones are the Mental Rotation Test (MRT), the Differential Aptitude Test: Space Relations (DAT: SR), and the Mental Cutting Test (MCT) [4].

The Mental Rotation Test (MRT): A 3D object is given, and the task is to choose the correct form from four alternatives that would result from the rotation of the given object.

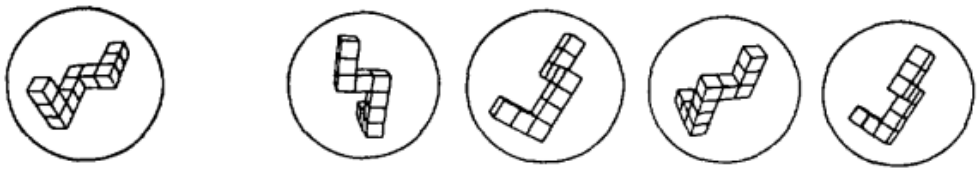

Figure 1. Vandenberg and Kuse Mental Rotations Test [11]

The Differential Aptitude Test: Space Relations (DAT: SR): The task is to choose the correct 3D object from four or five alternatives that would result from folding the given 2D pattern.

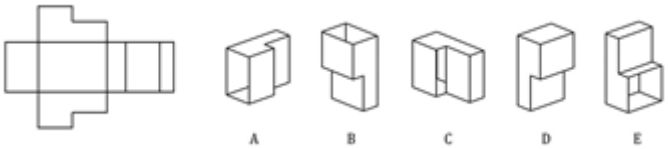

Figure 2. An example of the Differential Aptitude Test [4]

The Mental Cutting Test (MCT): The task is to recognize the correct shape of the section after a 3D object has been cut with a plane.

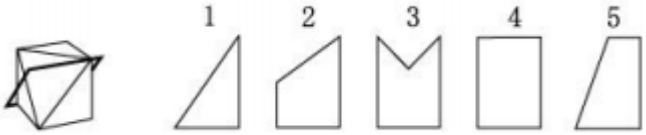

Figure 3. An example of the Mental Cutting Test [12]

Some forms of Spatial ability tasks have been included in the entrance exam at the Faculty of Architecture, Civil Engineering, and Geodesy in Banja Luka (FACEG) for the prospective students of architecture. These tasks are based on the aforementioned types but with some adaptations specifically aimed to assess higher levels of candidates' spatial abilities/skills. Since those skills

have not been trained in candidates' earlier education, the FACEG has been organising the Spatial Perception and Presentation course for the enrollment at the Faculty for the past ten years. The 20-hour course is held during the two weeks of June, just before the entrance exam, and this course combines spatial ability tasks and tasks from the previous entrance exams. Since this course is not obligatory and some candidates had an introductory course in Descriptive Geometry in their secondary education, the level of candidates' spatial abilities/skills differentiates very much by the time they enrol at the first year at the FACEG.

The Descriptive Geometry course at the FACEG has been held in the first year of architecture studies. It combines basic theoretical terms of a point, line, plane, and solids in Monge's projections. Students learn about the techniques of their precise construction, applying them in theoretical tasks drawn by hand. Even though students had some training in solving spatial tasks while preparing for the entrance exam at the Faculty, or some of them had this subject in their secondary education, the majority of them still find this subject one of the hardest in the first year of their studies.

In this paper, we examine the influence of those factors on students' spatial ability starting with the premise that the Descriptive Geometry (DG) course had an effect on improving those skills. Later we introduce the impact of the preparatory course and previous contact with Descriptive Geometry in high school (DGhs) on those skills.

2. RESEARCH METHODS AND ORGANISATION

To determine the influence of the DG course on students' spatial abilities, we conducted a spatial ability test designed for this research on two groups of students - those who finished the DG course and those who had not by the time the Spatial ability test (SAT) was conducted. We compared their success.

Usually, the Descriptive Geometry course is held in the second semester of the first year of architecture studies. Still, since last year, the generation of 2020/21 enrolled according to the new curriculum; unlike previous generations, they took a course in Descriptive Geometry in the first semester. At the same time, two spatial ability tests (SAT) have been conducted for the past three years - at the beginning and at the end of the first semester.

The SPA test was designed specifically for this research. It consisted of 8 tasks in total: four tasks were from the group of the Mental Rotation tests (MRT), two tasks from the Mental Cutting Test group (MCT), and two tasks from the Differential Aptitude Test: Space Relations (DAT: SR). The first four tasks were more accessible (evaluated with 1 point each), and the other four were advanced level tasks (evaluated with 2 points each). So, the maximum score on each test was 12 points.

Out of 175 students of the first year at the Faculty of Architecture, Civil Engineering and Geodesy at the University of Banja Luka enrolled in the academic years 2018/19, 2019/20, and 2020/21, a total of 118 students were tested. Students were observed as two groups, depending on whether they attended the Descriptive Geometry course in the first or second semester. The first group (Group 1) of students of the 2018/19 and 2019/20 generation attended it during the second (summer) semester, while the second group (Group 2) of the 2020/21 generation attended it in the first (winter) semester according to the new curriculum. All students were tested in the first semester of the year they were enrolled in. Students took the first spatial ability test - TEST 1 at the beginning of the first semester and the second

(control) spatial ability test - TEST 2 at the end of the first semester. The tests lasted 25 minutes each. The first and the second test were not identical, but they had the same structure and task types.

We used the SPSS v.20 analytical-statistical software package for the statistical analysis, using descriptive statistics for presenting and summarising data, the Paired Samples t-Test, nonparametric Mann-Whitney U test, $\chi 2$ test, and Spearman's rank correlation coefficient. The variables observed in this study did not have a normal distribution [13].

Table 1. *Number of students by years of enrollment and Descriptive Geometry course in high school*

			DGhs		
			Y	N	Total
YEAR	2018	Count	14	22	36
		% of Total	11.9%	18.6%	30.5%
	2019	Count	12	29	41
		% of Total	10.2%	24.6%	34.7%
	2020	Count	13	28	41
		% of Total	11.0%	23.7%	34.7%
Total		Count	39	79	118
		% of Total	33.1%	66.9%	100.0%

Table 1 shows that out of the total number of tested students, 33.1% (39) had a Descriptive Geometry subject in high school, and 66.9% (79) did not.

Out of the total number of tested students, 93 (78.8%) were female and 25 (21.2%) male.

The main questions of this research are:

RQ1. Does the course in Descriptive Geometry at the FACEG improve the spatial abilities of architecture students?

We compared the scores of the first and second spatial tests in two experimental groups of students. The aim was to determine if there was any significant improvement in the level of spatial abilities in the group that attended the DG course (second group) in relation to the first group.

After a general analysis of the results, the test structure was examined in more detail regarding the difficulty and task types to determine which tasks students had the most success with and whether there was progress in solving any particular kind of tasks.

RQ2. Does the course in Descriptive Geometry in high school or attending the Spatial Perception and Presentation course for enrollment at the Faculty impact success on the TPS1 test?

We compared the success of architecture students of all three observed generations on the first SAT (TEST 1) in relation to the attendance of preparatory classes and having the DG course in high school, in general, by groups, and by group types of tasks.

3. RESULTS AND DISCUSSION

3.1. THE ANALYSIS OF THE INFLUENCE OF DESCRIPTIVE GEOMETRY ON IMPROVING THE LEVEL OF SPATIAL ABILITIES

Table 2. *Overall success in the first and the second (control) test by years of study*

		N	Mean	Std. Deviation	Median	Min.	Max.
TEST 1	2018	36	.5244	.17682	0.54	.25	.92
	2019	41	.5139	.20151	0.50	.17	1.00
	2020	41	.5068	.16846	0.50	.08	.88
	Total	118	.5147	.18162	0.50	.08	1.00
TEST 2	2018	36	.6947	.21627	0.67	.25	1.00
	2019	41	.6210	.23208	0.58	.17	1.00
	2020	41	.5702	.20526	0.58	.21	1.00
	Total	118	.6258	.22217	0.63	.17	1.00

The Paired Samples t-Test showed a statistically significant difference in success between the first and second spatial ability tests in all students together (t=-5.256, df=117, p=0.000). Students achieved better scores in the second test (Table 2).

Table 1 shows that all three generations on the first test had about 50% success, and on the second test, they achieved significantly better success. The 2018 generation achieved the best success; they achieved a success rate of almost 70%.

Table 3. *Overall success in the first and the second (control) test by groups*

		N	Mean	Std. Deviation	Median	Min.	Max.
TEST 1	Group 1	77	.5188	.18920	.50	.17	1.00
	Group 2	41	.5068	.16846	.50	.08	.88
	Total	118	.5147	.18162	.50	.08	1.00
TEST 2	Group 1	77	.6555	.22641	.67	.17	1.00
	Group 2	41	.5702	.20526	.58	.21	1.00
	Total	118	.6258	.22217	.63	.17	1.00

The Mann-Whitney U test did not show a statistically significant difference in success on the Test 1 between students of the Group 1 (N = 77, Md = 0.5) and Group 2 (N = 41, Md = 0.5), (U = 1557.000, z = -0.122, p = 0.903), while on the Test 2 it showed a statistically significant difference in success (U = 1225.000, z = -2.004, p = 0.045). Students of the 2018 and 2019 generation (N = 77, Md = 0.67) showed better joint success compared to the 2020 generation (N = 41, Md = 0.58).

The obtained results indicate that Descriptive Geometry did not significantly impact the development of spatial abilities with students of the 2020 generation. This shows that their spatial abilities did improve during the first semester, but the reason for that might not lie in learning Descriptive Geometry.

3.1.1. Analysis by types of tasks

Analysing the tasks by types, we grouped them as follows:

a) four tasks from the group of the Mental Rotation Test (MRT) with a total of 6 points;
b) two tasks from the Mental Cutting Test group (MCT) with a total of 3 points;
c) two tasks from the Differential Aptitude Test: Space Relations (DAT: SR) with a total of 3 points

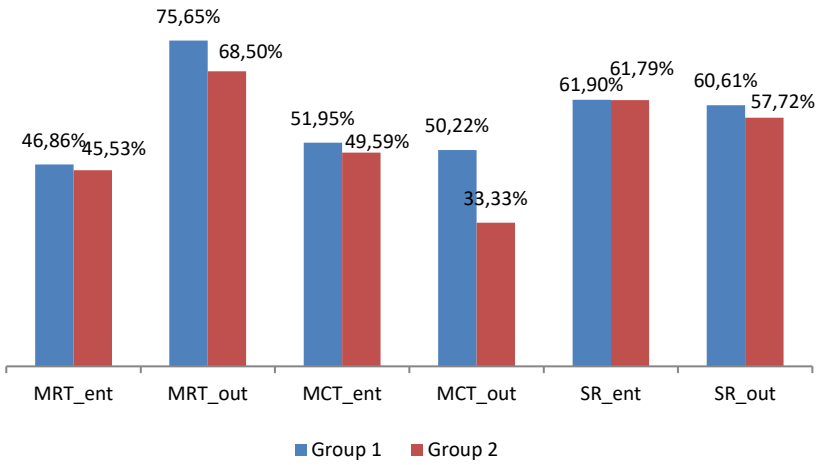

Chart 1. *The average success of both groups by types of tasks on tests (in percentages)*

Graph 1 shows the most progress in Mental Rotation tasks (MRT) for both groups. Group 1 achieved an average of 46.86% success in Test 1 on tasks of this type, and 76.65% in Test 2, while Group 2 achieved an average of 45.53% success in Test 1, and 68.50% in Test 2. The Paired Samples t-Test showed a statistically significant difference in success at MRT tasks between Test 1 and Test 2 (t=-7.683, df=76, p=0.000) in Group 1 and Group 2 (t=-5.699, df=40, p=0.000).

The Mann-Whitney U test did not show statistically significant difference in success at the mental rotation (MRT) tasks in Test 1 between Group 1 (N = 77, Md = 0.4167) and Group 2 (N = 41, Md = 0.4167) (U = 1534,000, z = -0.254, p = 0.799), nor in Test 2 (U = 1293.500, z = -1.639, p = 0.101). Both groups were equally successful in solving these tasks.

Regarding MCT tasks, Graph 1 shows that Group 1 had almost the same success in both tests (51.95% in Test 1 and 50.22% in Test 2), while Group 2 had less success on these tasks in the second test (49.59% on Test 1 and 33.33% on Test 2). The Paired Samples t-Test showed a statistically significant difference in success at MCT tasks between Test 1 and Test 2 (t=2.178, df=76, p=0.035) for Group 1.

χ^2 did not show a statistically significant difference in success between groups at MCT tasks in Test 1 (χ^2 = 2.184, df=3, p=0.535), but did in Test 2 (χ^2 = 8.271, df=3, p=0.041).

χ^2 did not show a statistically significant difference in success between groups at the Space Relations (DAT: SR) in Test 1 (χ^2 = 0.886, df=3, p=0.829), and in Test 2 (χ^2 = 5.650, df=3, p=0.130). Graph 1 shows that tasks of this type were done equally successful in both tests.

3.2. THE ANALYSIS OF THE RESULTS IN RELATION TO THE ATTENDANCE OF THE PREPARATORY COURSE AND DESCRIPTIVE GEOMETRY IN HIGH SCHOOL

Out of the total number of observed students, 58 attended the Spatial Perception and Presentation course (SPP) for enrollment at the faculty, and 60 of them did not. The Mann-Whitney U test did not show a statistically significant difference in success in Test 1 or 2 between students depending on their SPP course attendance (Table 4).

For students who attended a preparatory course in SPP, there is no statistically significant correlation between success in Test 1 and Test 2.

For students who did not attend the preparatory course in SPP, there is a statistically significant high positive correlation between success in Test 1 and success in Test 2 (r_S=0.539).

Table 4. *Overall success in the first and the second test according to the attendance of the preparatory course by groups*

	PPS	TEST 1				TEST 2			
Group	course	N	Mean	Std. Deviation	Median	N	Mean	Std. Deviation	Median
Group 1	Y	39	.5097	.18142	.5000	39	.6890	.23554	.6700
	N	38	.5282	.19887	.5000	38	.6211	.21427	.5800
	Total	77	.5188	.18920	.5000	77	.6555	.22641	.6700
Group 2	Y	19	.5358	.15316	.5800	19	.5968	.19568	.6300
	N	22	.4818	.18036	.4800	22	.5473	.21503	.5400
	Total	41	.5068	.16846	.5000	41	.5702	.20526	.5800
Total	Y	58	.5183	.17176	.5200	58	.6588	.22579	.6700
	N	60	.5112	.19206	.5000	60	.5940	.21572	.5800
	Total	118	.5147	.18162	.5000	118	.6258	.22217	.6300

3.2.1. Analysis by groups

For students who attended the SPP course, the Mann-Whitney U test did not show a statistically significant difference in success in Test 1 between students of Group 1 (N = 39, Md = 0.5) and Group 2 (N = 19, Md = 0.58) (U = 330.500, z = -0.666, p = 0.505), nor in Test 2 (U = 273.000, z = -1.622, p = 0.105) (Table 4).

For students who did not attend preparatory course in SPP, the Mann-Whitney U test did not show a statistically significant difference in success in Test 1 between students of Group 1 (N = 38, Md = 0.5) and Group 2 (N = 22, Md = 0.48) (U = 375.000, z = -0.663, p = 0.508), nor in Test 2 (U = 333.000, z = -1.310, p = 0.190) (Table 4).

For Group 1, who did not attend a preparatory course in SPP, there is a high positive correlation between Test 1 and Test 2 (r_S=0.508).

For Group 2, who did not attend a preparatory course in SPP, there is a statistically significant high positive correlation between success in the first and second test (r_S = 0.592).

By observing students' success in relation to whether they had a Descriptive Geometry subject in high school, positive correlations were obtained between success in the first and second test (r_S = 0.357) only for students who did not have Descriptive Geometry in high school.

Also, the Mann-Whitney U test did not show a statistically significant difference in success in Test 1 and Test 2 between students who had DG in high school.

4. CONCLUSION

The study results showed a significant improvement in spatial ability in students of architecture in general during the first semester of studies. However, they also showed that the Descriptive Geometry course did not have a significant influence on the development of spatial abilities, at least in the case of a traditional approach in mastering this subject - with abstract tasks and theoretical application, as such methods develop spatial thinking, rather than spatial abilities. A similar conclusion was obtained in the paper [4]. Furthermore, the results show no positive correlation between the spatial ability and the attendance of Descriptive Geometry subjects in high school. Both student groups achieved the most outstanding progress in mental rotation tasks (MRT). There was no statistically significant difference in success at the mental rotation tasks in both tests between Group 1 and Group 2. Both groups were equally successful in solving these tasks.

Also, there was no statistically significant difference in success in the tests depending on the preparatory course (SPP) attendance for enrollment at the FACEG. For students who did not attend a preparatory course in SPP, there was even a highly positive correlation between success in Test 1 and Test 2. This points to the fact that some subjects in the first semester may have affected the improvement of spatial abilities.

This question raises the issue in further research in defining the specific factors that assess spatial thinking. Since the significant improvement in spatial ability is evident, this also raises the question of looking for potential causes in other courses related to the architecture curriculum taught in the first semester.

In order to improve architecture students' spatial abilities, we recommend further actions simultaneously: including these task types (spatial ability tasks) in the Descriptive Geometry course syllabus and a possible adaptation of the current DG task to simulate and assess spatial ability factors.

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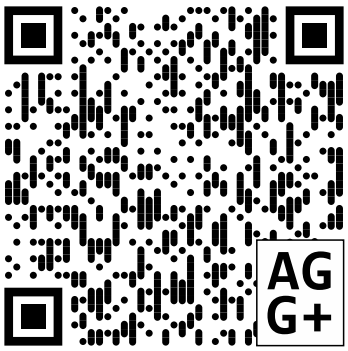
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JUSTIFICATION OF LIGHTING REDESIGN IN ENERGY SAVING ON THE EXAMPLE OF THE RIGHT BANK OF THE VRBAS RIVER BETWEEN TWO BRIDGES

ABSTRACT

Modern technologies are evolving in the direction of energy efficiency and artificial light sources that today meet such targeted requirements have many other advantages that are not always recognized in planning. Utilizing the total capacity of energy efficient light sources requires a redesign and a different approach to public lighting planning. Using a small coverage along the river as a representative example, the possibilities of fulfilling the set strategic goal of the city development were presented through a proposal for redesign of urban lighting, and then the energy and economic justification of such a proposal was examined using the APEE method, which is also implemented in public lighting reconstruction in Banja Luka.

Key words: *public lighting reconstruction, urban lighting, coastline, APEE*

ЕНЕРГЕТСКА ОПРАВДАНОСТ РЕДИЗАЈНА ОСВЈЕТЉЕЊА НА ПРИМЈЕРУ ДЕСНЕ ОБАЛЕ РИЈЕКЕ ВРБАС ИЗМЕЂУ ДВА МОСТА

Апстракт: Савремене технологије развијају се у смијеру енергетске ефикасности и вјештачки извори свјетлости који данас одговарају на овако усмјерене захтјеве имају многе друге предности које нису увијек препознате у планирању. Користити укупни капацитет енергетски ефикасних извора свјетлости, захтијева редизајн и другачији приступ у планирању јавне расвијете. На репрезентативном примјеру, малом обухвату дуж ријеке, представљене су могућности испуњења постављеног стратешког циља развоја града кроз приједлог редизајна урбаног осветљења, а потом испитана енергетска и економска оправданост таквог приједлога примјеном методе АПЕЕ по којој се и врши реконструкција јавне расвјете у Бањој Луци.

Кључне ријечи: *реконструкција јавне расвјете, урбано осветљење, приобаље, APEE*

1. INTRODUCTION

The aim of global energy policy is to slow down climate change, and the issue of energy consumption in residential buildings, industry and transport is at the centre of the European Union energy efficiency policy. Many studies are focused on the possibilities of saving energy from lighting in different fields of planning, and it has been established that public lighting is one of the major energy consumers. Therefore, there is a need for a detailed analysis of the existing public lighting systems and better planning of the new ones. Some Balkan countries have managed to harmonize their legislation with the EU standards and introduce mandatory energy audits for public lighting in settlements with more than 20,000 inhabitants [1]. Public lighting systems are city-owned and the costs for investments, reconstructions, system maintenance and finally for the consumed electricity in the best case amounts to about 3% of the total city budget costs [2].

In the Republic of Srpska, the public lighting alone participates in energy consumption with more than 20% [3] and it is necessary to carry out the reconstruction of the public lighting system in cities. The Law on Energy Efficiency was adopted in 2013 in order to legally regulate the area of energy efficiency and meet the requirements referred to in the Treaty establishing the Energy Community of Southeast Europe, and promote and implement measures to improve energy efficiency in final consumption [4]. The purpose of the law is to achieve sustainable energy development by applying energy efficiency policies and measures in final consumption. Among other things, this includes reducing the negative impact on the environment and rationalizing energy consumption, both at national and local level. In these laws and regulations, public lighting is viewed from the energy aspect through the management system, the system of light flux regulation and the use of energy efficient light sources. Over the past few years, the City Administration of Banja Luka has recognized the issue of public lighting and city lighting and the modernization of public lighting is in process, in accordance with the recommendations defined through the Energy Efficiency Action Plan of the Republic of Srpska (APEE) [4]. The practice of developing a lighting master plan has not yet taken root in the city of Banja Luka and there is no publicly available plan and unique document on lighting in the city.

The awareness on the importance and benefits of properly designed public lighting plans has been growing since the beginning of the 21st century. There were many factors that influenced this significant change, and in addition to the development of lighting technology and energy conservation, there are others such as branding, night image of the city, impact on the environment and human health, as well as people-oriented sociological aspects. The first major lighting projects emerged due to functional requirements in France (for the cities of Lyon, Caen and Niort) and in the United Kingdom (for Edinburgh) in the late 1980s [5]. Slowly, in the early 1990s, access to public lighting progressed from functional to cultural needs. To this day, the needs have grown and the public lighting quality can be evaluated from many aspects, so apart from the energy and economic aspect in planning process of city lightning it is also necessary to include other aspects important for quality urban life.

Based on a representative example, this paper presents energy and economic justification of urban lighting planning using the method of reconstruction of public lighting in local communities (APEE). The paper objective is to present the importance of lighting planning in specific urban areas on a small coverage along Vrbas River coastline, which includes different and specific needs for quality urban lighting, and to prove equal or better energy and economic effects.

2. PUBLIC LIGHTING RECONSTRUCTION IN BANJA LUKA ACCORDING TO RS APEE

According to the data obtained from the Department for Municipal and Communal Affairs, of the Banja Luka City Administration, the coverage of the city with public lighting is 96%, and the total number of lighting fittings in the city urban area is 17,500. The age of the lighting fittings dates from 2002-2004 when the last reconstruction of the lighting was carried out. Some of the problems the public lighting maintenance services are facing with include cable deterioration, malfunctions and energy supply, and public lighting maintenance works refer to regular maintenance and small-scale remediation and reconstruction works. Regular maintenance of public lighting includes replacement of light bulbs, ballasts, lighters, sockets, fuses, defects and resolving malfunctions, painting poles, replacement of destroyed poles and lamps in traffic accidents, replacement of damaged cables and foundations [6]. Small-scale rehabilitation and reconstruction and upgrading of lighting include the replacement of dilapidated poles and lamps, measuring cabinets, upgrading a smaller number of lighting places to the existing lighting system. The City budget regularly plans funds for public lighting for current and investment maintenance, reconstruction and construction. Table 1 presents the official data of funds planned for public lighting in the period from 2015 to 2020.

Table 1. Funds planned for public lighting in the City budget per year in the period from 2015 to 2020 [7] [8] [9] [10] [11] [12]

	2015	**2016**	**2017**	**2018**	**2019**	**2020**
Costs for current maintenance of public lighting (and traffic lights 2015,2016)	360.000,00	360.000,00	220.000,00	270.000,00	230.000,00	240.000,00
Costs for investment maintenance of public lighting		50.000,00	50.000,00	50.000,00	50.000,00	50.000,00
Costs for the construction of public lighting and cable canalization	50.000,00	50.000,00	40.000,00	50.000,00	45.000,00	54.000,00
Costs for the construction of public lighting - designated funds			50.000,00	40.000,00	90.000,00	96.000,00
Costs for the reconstruction of public lighting - designated funds	50.000,00	40.000,00	40.000,00	40.000,00	40.000,00	150.000,00
Total regularly planned	**460.000,00**	**500.000,00**	**400.000,00**	**350.000,00**	455.000,00	**590.000,00**
	- Costs for the construction of public lighting - according to the Decision on the distribution of the determined surplus and unspent designated funds for 2018 (surplus distribution)				123.000,00	
	- Costs for the construction of public lighting - according to the Decision on the distribution of the determined surplus and unspent designated funds for 2018 (assigned income)				167.00,00	
	- Costs for current maintenance of public lighting - according to the Decision on the distribution of the determined surplus and unspent designated for 2018 (surplus distribution)				50.000,00	
Total for public lighting	460.000,00	500.000,00	400.000,00	350.000,00	**795.000,00**	590.000,00

In 2019 was planned a significantly higher total investment in the construction of public lighting, almost twice as much as in the previous years, whereas in 2020, along with ongoing maintenance, more significant funds were intended for reconstruction. This sum was the result of a public lighting reconstruction project in Banja Luka. Namely, during 2016 was adopted the Energy Efficiency Action Plan (APEE) of the City of Banja Luka for the period from 2016 to 2019 [4].

The Energy Efficiency Action Plan (APEE) defines measures to improve energy efficiency in the services sector, thus reducing energy consumption for the operation of public lighting systems by installing energy efficient public lighting systems and introducing management systems. Effective public lighting management implies adequate use of available resources and implementation of measures and activities of local self-government units and other institutions, resulting in increased functionality and quality of public lighting and reduced costs necessary for public lighting systems. In this regard, the Republic of Srpska Association of Municipalities and Cities and the Federation of BiH Association of Municipalities and Cities, in cooperation with GIZ, developed a guide Public Lighting and Local Self-Governance. [13] The Guide provides a detailed economic analysis based on the replacement of one existing luminaire with an appropriate energy efficient replacement luminaire. The initial investment of the replacement was performed on the basis of replacing the complete lamp, and not only the light bulbs, since new sets of light bulbs with accompanying equipment cannot be installed in the existing fittings (housings). It was also taken into consideration that there are a large number of fixtures (fittings) in municipalities that are inadequately constructed and do not meet contemporary environmental criteria (spherical light scattering). For the economic analysis of lamp replacement, the technical parameters of the lamp are defined, namely the lamp power [W], energy consumption [kWh/year] and service life [hours] for the existing and replacement luminaire; economic parameters of the luminaire, namely for consumed energy [EUR/year] and maintenance costs [EUR] for the existing and replacement luminaire, as well as the initial investment [EUR] for the replacement luminaire; profitability analysis for initial investment [EUR], difference in exploitation before and after replacement [EUR] and unique payback period [year]. Since HID luminaires are present in Bosnia and Herzegovina, as well as in the entire Balkan region, the Guide suggests appropriate replacement luminaires (Table 2), and it also provides a calculator and an example of economic analysis of replacement (Figure 1), with the result in annual electricity and maintenance savings, as well as the payback period.

Local self-governance units that modernized the entire or majority of the public lighting network in accordance with this guide have significantly reduced the energy costs of public lighting and practically no longer have maintenance costs or have reduced them to a minimum [14]. There are data on the situation regarding the city public lighting after the first part of the reconstruction according to this guide, indicating that there are about 18,000 lamps in the city [15], which is 500 more than in 2018, and the number of lamps older than 30 years has been reduced, from 1000 to slightly less than 200 [15] in two years. During this period, a total of 1,834 lamps in 64 streets were replaced in the framework of the first part of the "LED 1" project [15]. During 2020, new lighting was installed in several streets in the city area in the length of 4.7 kilometres, thus initiating the second part of "LED2" project, and the plan is to replace approximately 1,400 existing lamps with LED lamps in 80 streets [15]. The Department for Communal Affairs believes that this type of reconstruction would reduce energy consumption for more than 60 percent.

Table 2. The most common situations in practice during the reconstruction or modernization of public lighting [6]

Postojeće stanje	Zamjena	Postojeće stanje	Zamjena	Postojeće stanje	Zamjena	Postojeće stanje	Zamjena	Postojeće stanje	Zamjena
Živa 80W	NVP FMB 70W	Živa 125W	NVP FMB 70W	Živa 250W	NVP FMB 150W	Živa 400W	NVP FMB 250W	NVP FMB70W	LED 73W*
Živa 80W	NVP ELB 70W	Živa 125W	NVP ELB 70W	Živa 250W	NVP ELB 150W	Živa 400W	NVP ELN 250W	NVP FMB150W	LED 73W*
Živa 80W	LED 73W*	Živa 125W	LED 73W*	Živa 250W	LED 73W*	Živa 400W	LED 150W*	NVP FMB250W	LED 110W*
Živa 80W	MH 70W	Živa 125W	MH 70W	Živa 250W	MH150W	Živa 400W	MH 150W	NVP FMB400W	LED 150W*

**Snaga zavisi od geometrije saobraćajnice i optike koja se nalazi u svetiljci.*

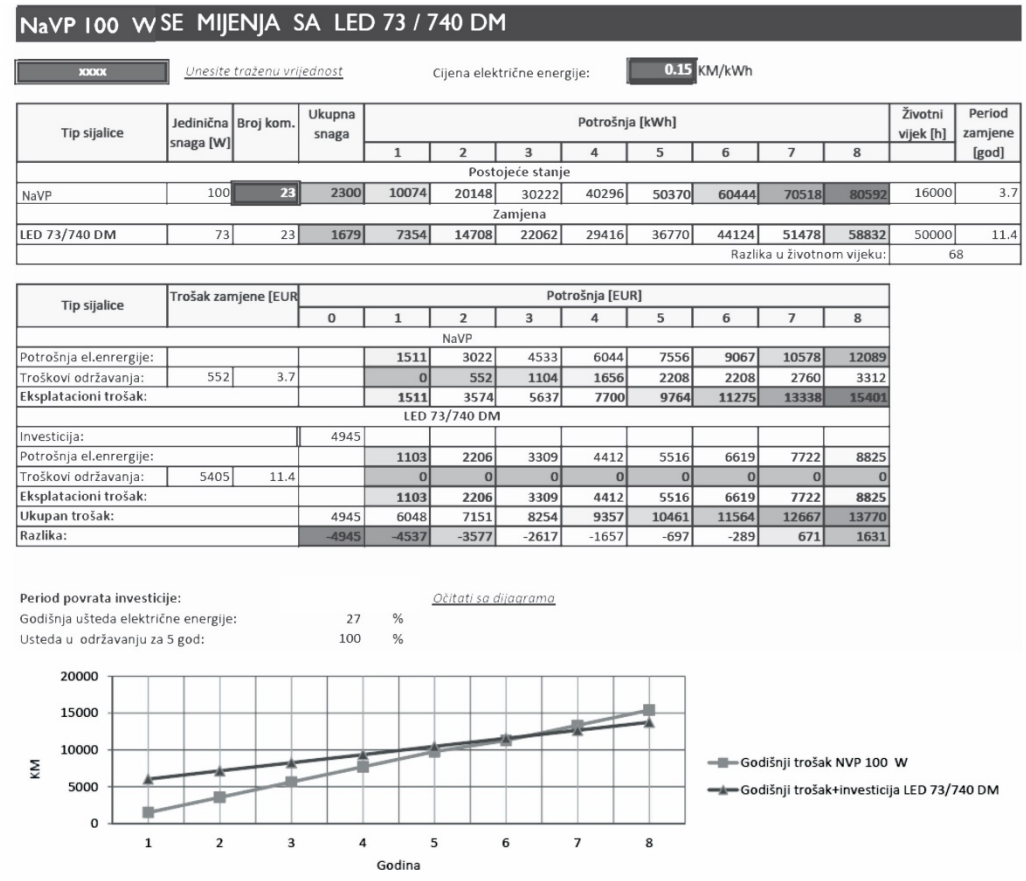


Figure 1. Economic analysis of lamp replacement with the recommended replacement lamp referred to in Table 2 according to the APEE reconstruction method. Calculator for local governments 2013-2014 [13]

In the document Joint Communal Spending of the Department for Communal Affairs for 2021, the budget for public lighting is significantly lower, with different relations in terms of maintenance and investment works. The document states that *the construction and reconstruction of public lighting in a number of streets in recent years resulted in a significant increase in the number of lamps, but that energy consumption costs for public lighting are lower, indicating the expected positive effects in cost savings on these grounds* [16]. Table 2 shows funds planned in the city budget as the current costs for electric energy used for public lighting per year in the period from 2015 to 2020.

These documents indicate that the reconstruction of public lighting in Banja Luka is in progress, and according to the economic analysis method, the reconstruction means the replacement of lamps as an investment, motivated by energy savings. The quality of the existing lighting system and its adequacy for the planned new sources are assumed, so the possible effects of a different

approach and planning of urban lighting according to the character and purpose of individual urban areas are missing.

Table 3. Funds planned in the City budget for joint communal spending (current costs) - public lighting energy consumption per year for the period from 2015 to 2020 [7] [8] [9] [10] [11] [12]

	2015	2016	2017	2018	2019	2020
Consumption of energy for public lighting	1.540.000,00					
Expenses based on energy consumption for lighting in public areas		1.600.000,00	1.605.000,00	1.900.000,00	1.885.000,00	
Expenses based on energy consumption in public areas						2.200.000,00

3. THE IMPORTANCE OF URBAN LIGHTING OF THE CITY ON VRBAS RIVER

One of the strategic development goals of the city on Vrbas River is "Ecologically sustainable, infrastructurally developed and energy efficient environment - Green City". In the document City of Banja Luka Development Strategy for the period 2018-2027 [17], the "green" city concept includes the arrangement of green urban areas, parks, recreational areas, Vrbas River banks and its headwaters and the management of natural resources in a responsible and creative way. Both aesthetic and functional aspects are considered, with particular emphasis on the urban environment protection, in the context of social and economic development. The city is strategically returning to the river and the coastline is recognized as an important location for the development of the "green" city, and over the last twenty years there have been individual attempts to build on the coastline with a changed attitude towards the water [18]. There is a unique approach to the coastline arrangement, since the City of Banja Luka Assembly adopted the "Regulatory plan for the development of Vrbas River coast" based on the results of the open public international urban and architectural competition in 2006 [19]. Unfortunately, the majority of the plan neglects the city's contact areas with water and treats only the narrow strip of coastline, as shown in the *Regulatory plan for the development of Vrbas River coast in Banja Luka* in the central part of the city between the two city bridges (Figure 2).

The landscaped coastline in Banja Luka represents an important meeting, recreation and resting point, as well as a place for various sports and artistic events, numerous activities during the day and in the evening. One of the few designed locations that allows the urban population to enjoy physical and mental benefits is the coastline stretch between the Venecija and the Rebrovac Bridge in Banja Luka. The presence of different user profiles and age groups only highlights the importance of this part of the coast. The stretch between Venecija and the Rebrovac Bridge is the longest pedestrian path along Vrbas River with landscaped green areas, sports fields and similar facilities. The dominant tree species in this area are autochthonous species such as white willow, white and black poplar, white elm, black alder, field maple, whereas other tree species such as plane tree, cottonwood, Norway maple and sophora were planted, so it could be observed as a linear park [20]. The natural coast is rich in vegetation in this part, and even though it is simply arranged, it is popular and intensively visited by the users for recreation. Considering the fact that one part of the park is connected to one large free

area, there is a potential for the development of additional park facilities. However, there is no plan or any logical continuity in the further development of this option, nor any architectural framework of space with the necessary contents that would support the active use of the urban coastline.

Figure 2: Part of Regulatory plan for development of the Vrbas coast in Banja Luka, including a narrow strip of coast

Cities located on riverbanks, also have bridges connecting two separate territories naturally separated by the river and they carry power in relation to the river flow strength. If observed generally and throughout the history, people have high respect of bridges and appreciate their role in unifying the divided territories, thus the bridges have a double role - physical unification and symbolic unity. The eastern and western banks of Vrbas River in Banja Luka are connected with bridges in the length of 27 km, including eleven road bridges, four bridges for pedestrians and bicycles and one railway bridge [18]. In this region, the bridges that enable communication between the opposite banks of the city are most often engineered rationally, without great design solutions and ambient features, and none of them have the feature of a public space of the city in the river [20]. The well-known everyday image of the city could be significantly changed if we carried out a quality plan of decorative architectural lighting of numerous bridges, especially those in the central city zone.

In the framework of the "Small Interventions" project, which is implemented on the territory of Banja Luka, was recognized the potential of the space underneath the bridge, and it was cleaned and adapted to pedestrians [21]. Since there is no lighting in that part, this space remains an unpleasant and dangerous place in the evening and its use has never come to life. Such important central city areas along the coastline, whether it is a pedestrian path along Vrbas with landscaped green areas, or an important meeting, recreation and resting point, or a place for sports and art events, are available to the citizens during the day, but due to inappropriate lighting, they are not safe and secure for an evening by the river.

3.1. ANALYSIS OF THE EXISTING PUBLIC LIGHTING SITUATION

There are 23 light poles along the coast stretch between the Venecija and the Rebrovac Bridge, at a distance of thirty meters from one another. Light poles represent the only source of direct lighting. The name of the luminaire installed on the site is K-lux, manufactured by the company Minel-Schreder, which finds its application in the lighting of parks, squares, walks, promenades and other pedestrian areas. The design meets the conditions necessary to avoid light pollution. The built-in light bulb is 100 W high pressure sodium. (Figure 3)

Figure 3. Characteristics of the existing luminaire with the source applied [22]

In this stretch, the luminous comfort was analyzed using the light inspection method or the "walk-through survey" method, which consists of a tour of the site, visual inspection and analyzing the site characteristics with minimal or no measurement. It was determined that there is a lack of available light at the location, both due to improper operation of lighting poles (Figure 4) and due to defective or insufficiently maintained luminaires, resulting in occurrence of dark islands (Figure 5). The 30 m distance between the luminaires is too large to provide a satisfactory level of illumination from existing luminaires, and the distance between the luminaires is not even and depends on physical structures that interrupt the continuity (sports

equipment zone and one hospitality facility near the Venecija Bridge). The lighting consistency is also smaller due to dirty lamps (especially those near the hospitality facility) and unmaintained vegetation that is too close to the lamps. Plant species that have grown over the years and formed some kind of shrubs and woody plants obscure the lamps with their branches and leaves, thus reducing the level of available light and affect the surface illumination evenness. Trees and leaves absorb light wavelengths, reduce light pollution, but also reduce the level of available light. A small part of the reflected lighting is obtained from the adjacent sports field, but it is insufficient because of the height of plants and trees.

The analysis of the coverage intended exclusively for pedestrians, through the analysis of technical lighting characteristics, physical structure, history of criminal activities in this part of the coastline, social and cultural aspects, traffic flows, flora and fauna, provided an insight into the effect of lighting quality on the environment and ambient values. The current condition of public lighting in the part of the coastline between the Venecija and the Rebrovac Bridge in Banja Luka does not meet the required level of luminous comfort from the functional aspect (the surfaces are insufficiently and unevenly lit). At the same time, the lighting solution is not in accordance with the character of the space. Urban city areas such as pedestrian zones, natural structures, river banks and parks require ambient lighting. Recreation zones and sports fields should be lit in accordance with high functional requirements, and yet harmonize it with the environment and the evaluation of the environment.

Figure 4. Fluctuations in the operation of the lamp at the transition between the two recreation zones (left) and the illumination level (right), measured using the Fusion Optix Android App [21]

Figure 5. Appearance of a dark island along the path (left) and the illumination level (right), measured using the Fusion Optix Android App [21]

3.2. URBAN LIGHTING PROPOSAL

City image changes at night and lighting plays an important role in city attractiveness and one's impression of it. With this regard, lighting is crucial in the night presentation of urban space, and it can significantly differ from the daytime image. Quality lighting is achieved using a plan that takes into account the city identity or one of its parts, as well as the hierarchy of its urban units [23]. First of all, urban lighting should be functional, but it should also create a certain atmosphere and new night spaces with ambient and decorative lighting. It is most often expected that certain functional lighting goals are achieved using street illumination and public lighting, and to emphasize aesthetic values through architectural lighting. In fact, it is possible to achieve that both architectural and ambient lighting respond to functional requirements and vice versa [23]. The impression of the urban environment is the result of the joint contribution of functional and architectural lighting, and well-designed urban lighting can bring visibility to things that are not visible during the day, thus creating completely new urban spaces. This is very important, especially in parts of the city with abundant activities, whereas in the dark they hide a structure that would highlight the city identity with architectural lighting and offer new urban places.

Following the analysis of the current situation, it was determined not only that there is a lack of adequate ambient park lighting of the promenade, architectural and decorative lighting of bridges, but also that functional lighting in the form of public lighting does not fulfil its primary assignment. The lighting in the part of the coast between the Venecija and Rebrovac Bridge needs to be redesigned in order to create atmosphere during the night, emphasize the attractiveness of the space and prolong its night use. Lighting design affects the feeling and the experience, and its improvement would result in increased number of visitors, activation of the space, extended usage time and a complete change in users' perceptions of safety. Considering all these matters, and respecting the recommendations for lighting of different areas and establishing a hierarchy in lighting specific parts, we suggested the pedestrian zone lighting redesign on the coastline.

The urban lighting (re)design proposal includes the reconstruction of the existing public lighting system, but also the introduction of new forms of lighting, responding primarily to the natural context of the coverage and its importance in the representation of the city at night (Figure 7). By recognizing different atmospheres, the character of the parts within the coverage, as well as the different requirements of all user profiles, the lamps were carefully selected for a unique presentation of the "green" city on Vrbas River. In addition to previously defined environment

and activities of different lighting needs, restrictions and requirements, as a replacement for the existing public lighting luminaire, we selected a LED luminaire for ambient urban lighting, with modern, simple and modest design. The lamp was selected in accordance with the technical lighting characteristics, the purpose of the space and the design solution, and all the proposed lamps have a colour temperature of up to 3000 K [24]. It was suggested to make a smaller distance between the lamps, and in the case of the selected lamp, the optimal distance would be 18m.

ARCLUCE 0864001A+730 SOUL 180 - Urban
3000mm - 27W
Article No.: 0864001A+730
Luminous flux (Luminaire): 1900 lm
Luminous flux (Lamps): 1900 lm
Luminaire Wattage: 27.0 W
Luminaire classification according to CIE: 100
CIE flux code: 20 58 95 100 99
Fitting: 1 x 0864001A+730 (Correction Factor 1.000).

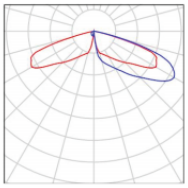


Figure 6. Characteristics of the applied replacement luminaire with source applied [25]

Urban lighting in such specific spaces, in addition to the suggested functional lighting of pedestrian paths, as replacement lamps for existing lighting, also includes architectural lighting, primarily bridges in this case. Bridges are most often constructed in exposed locations and are unintentionally marked as facilities desirable for lighting. Illuminated bridges attract attention, and with good lighting they can become one of the city symbols. As a rule, lighting is limited to the outlines or bridge contours, since there are no other surfaces in question other than the road itself. Lighting of the load-bearing structure, apart from public lighting on the road, is the most common and usually the best solution. Narrow beam reflectors attached directly to the structure offer the best solutions, provided that the atmospheric reflection on dark water should not be destructed by the overemphasized bridge structure [26]. Illumination of bridges helps to achieve the quality of decorative lighting without endangering the safety of traffic participants, and environment protection is achieved by directing light only to the lower surface of the bridge (Figure 8). In this way, the light connects the city divided by the river, and expands the public urban space, and illumination of the bridge construction contributes to the attractiveness of the location and emphasizes the identity of the city on the river. Illumination of the space under the Venecija Bridge would result in the continuity of the pedestrian path, since it is interrupted by a bridge and a heavy traffic road, but also emphasize the transition from one zone to another, that is the entrance to the observed location. In this way, introduction of lighting would increase the level of use and the attractiveness of the space, and the location underneath the bridge would get its own identity.

Figure 7. Proposal of the redesign lighting solution of the right bank of Vrbas River between the bridges Venecija and Rebrovac [21]

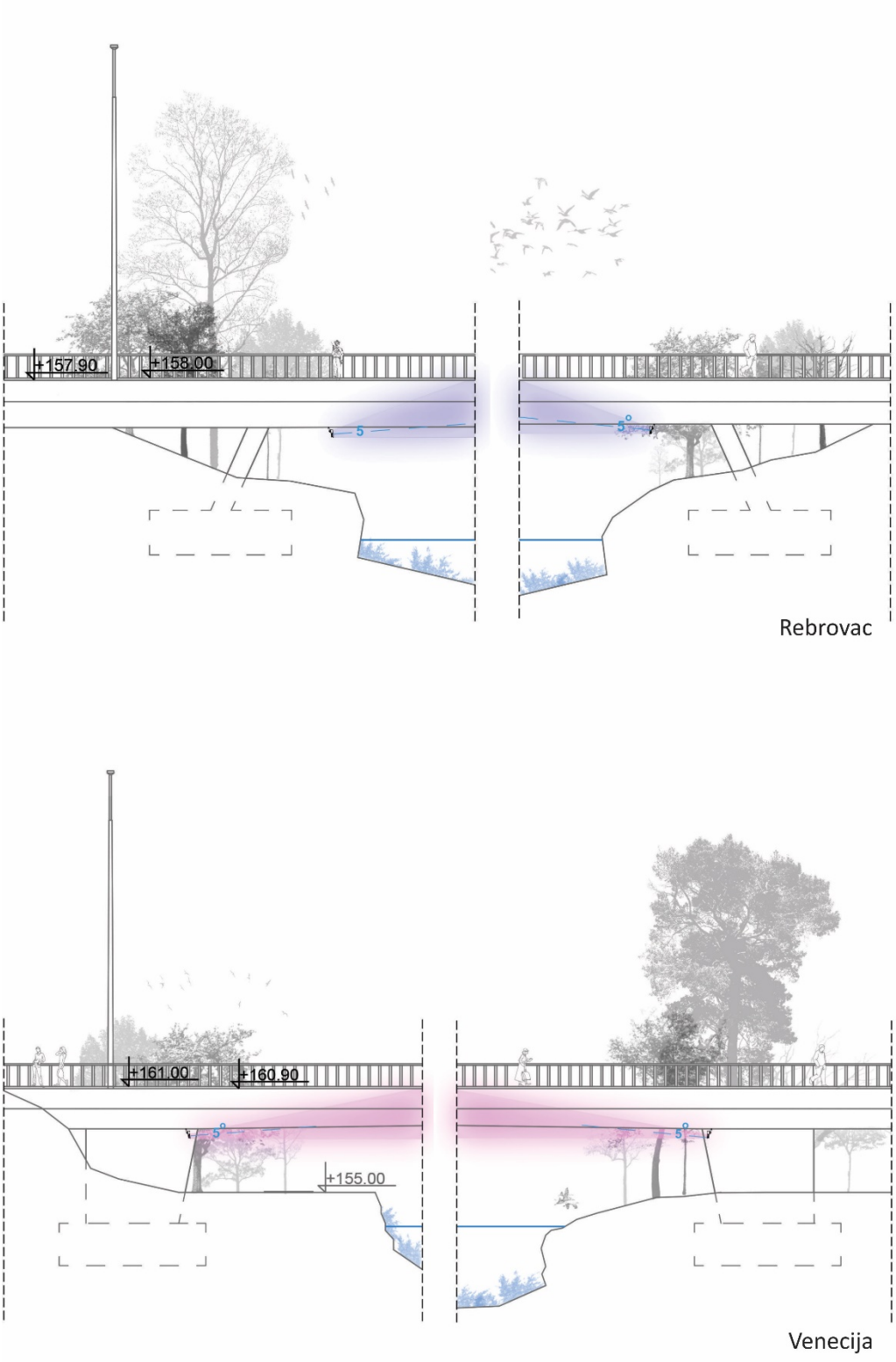


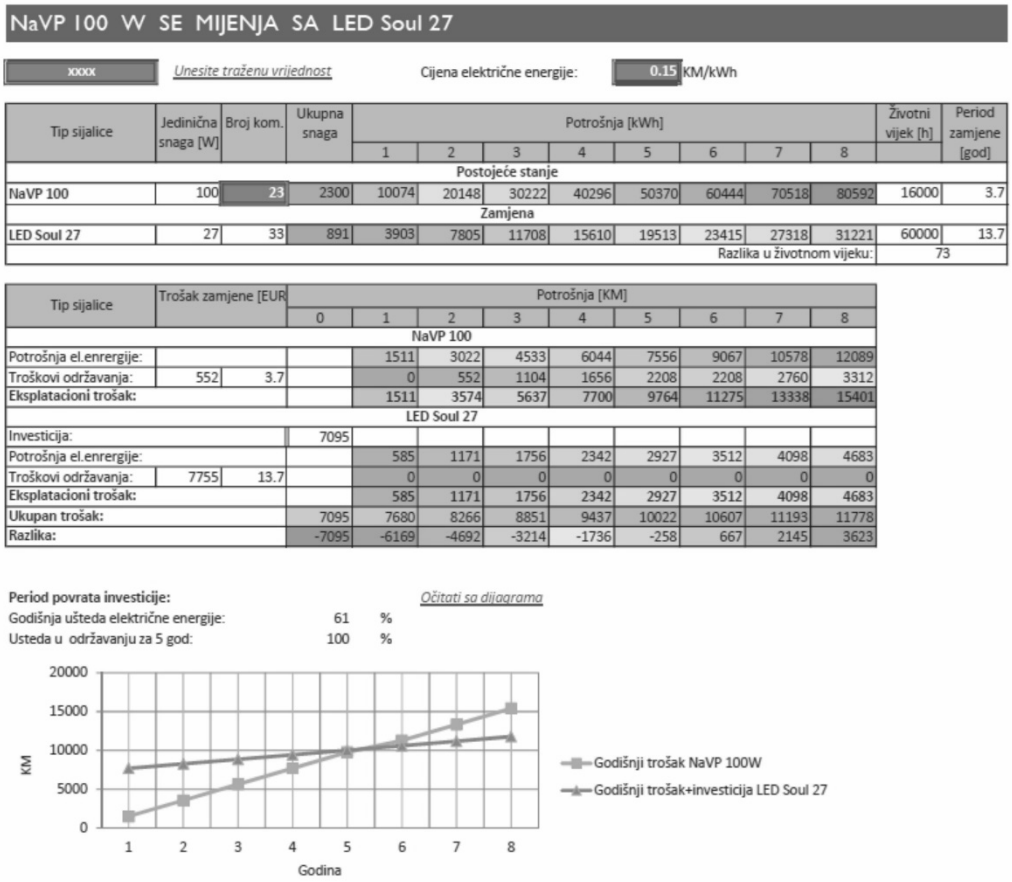
Figure 8. Proposal of the lighting redesign solution of Venecija Bridge (above) and Rebrovac Bridge (below) [21]

This small coverage along the river was used as a representative example to examine the possibilities of fulfilling the set strategic goal of the city development, with particular emphasis on urban lighting planning. In addition to the urban lighting design of this stretch, minimal urban and architectural landscaping interventions have also been suggested, offering adequate lighting. Apart from suggesting new lighting fixtures that meet the elementary needs of users and activities within the area, it also provides new opportunities to night users, in the form of direct and safe access to Vrbas River. Therefore, in addition to new public lighting lamps and architectural lighting of the bridge, there is also ambient lighting of the pathway down to the river, using ecological lamps. Views from the bridges or from the neighbouring coast to the observed location reveal the existence of activities along the coastline. The idea is to use interventions in space and increase the level of visual comfort through the regulation of lighting, thus affecting the man, and the city itself, to connect with the nature, river and the coast. On the other hand, by establishing a hierarchy in lighting, bridges stand out and their light recognition has a wider significance than it does for the observed coverage. In the end, the goal of good lighting is not only to provide a system with exactly calculated level of brightness without glare and good contrast, but also to integrate urban design, architecture and landscape.

3.3. POSSIBLE ENERGY SAVINGS ACCORDING TO APPE

In order to examine the energy and economic justification urban lighting re-design, we used the *Calculator for local self-governments - Public Lighting* (APEE). We compared the characteristics of the existing public lighting luminaires (power, number, annual energy consumption and lifetime) with the suggested replacement luminaires for the paths, and then with the total, replacement and additional luminaires of the coastal urban redesign proposal between the bridges Venecija and Rebrovac in Banja Luka. We also analyzed the energy consumption in kWh for 23 existing 100W high pressure sodium lamps and for 33 replacement lamps, or a total of 79 LED lamps of different power, suggested in accordance with the redesign, for a period of eight years. We calculated the energy consumption, maintenance costs and operating costs for all lamps and then the obtained results were compared and graphically displayed in the Pay-back period chart.

In the first case of replacement according to the Guide, 23 NVP100W lamps were compared with the corresponding 23 73W LED lamps according to Table 1. The obtained results show annual energy savings of 27%, and the payback period is shown in the chart in Figure 1. In the second case, it was proposed to replace 23 NVP100W lamps with 33 LED Soul 27W lamps, selected as appropriate for lighting walking paths in the framework of urban lighting redesign. The obtained results show annual energy savings of 61%, and the payback period is shown in the chart in Figure 9. In the end, we examined the energy saving options for full redesign lighting, and in this third case, 23 NVP100W luminaires were compared with 79 LED luminaires of different power. The obtained results show annual energy savings of 39%, and the payback period is shown in the chart in Figure 10. In all three cases, the five-year maintenance savings are 100%, and the initial investment for a greater number of luminaires is relatively higher. The existing NaVP 100 W lamps consume more energy than the suggested lighting from new LED lamps of different powers. Additionally, the suggested lighting is more energy efficient in terms of longer lifetime and the number of working hours, not only in relation to existing but also in connection with the replacement lamps suggested in the Guide. Another advantage of these lamps includes a longer replacement period.



NaVP 100 W SE MIJENJA SA LED Soul 27

xxxx *Unesite traženu vrijednost* Cijena električne energije: 0.15 KM/kWh

Tip sijalice	Jedinična snaga [W]	Broj kom.	Ukupna snaga	Potrošnja [kWh]								Životni vijek [h]	Period zamjene [god]
				1	2	3	4	5	6	7	8		
Postojeće stanje													
NaVP 100	100	23	2300	10074	20148	30222	40296	50370	60444	70518	80592	16000	3.7
Zamjena													
LED Soul 27	27	33	891	3903	7805	11708	15610	19513	23415	27318	31221	60000	13.7
											Razlika u životnom vijeku:		73

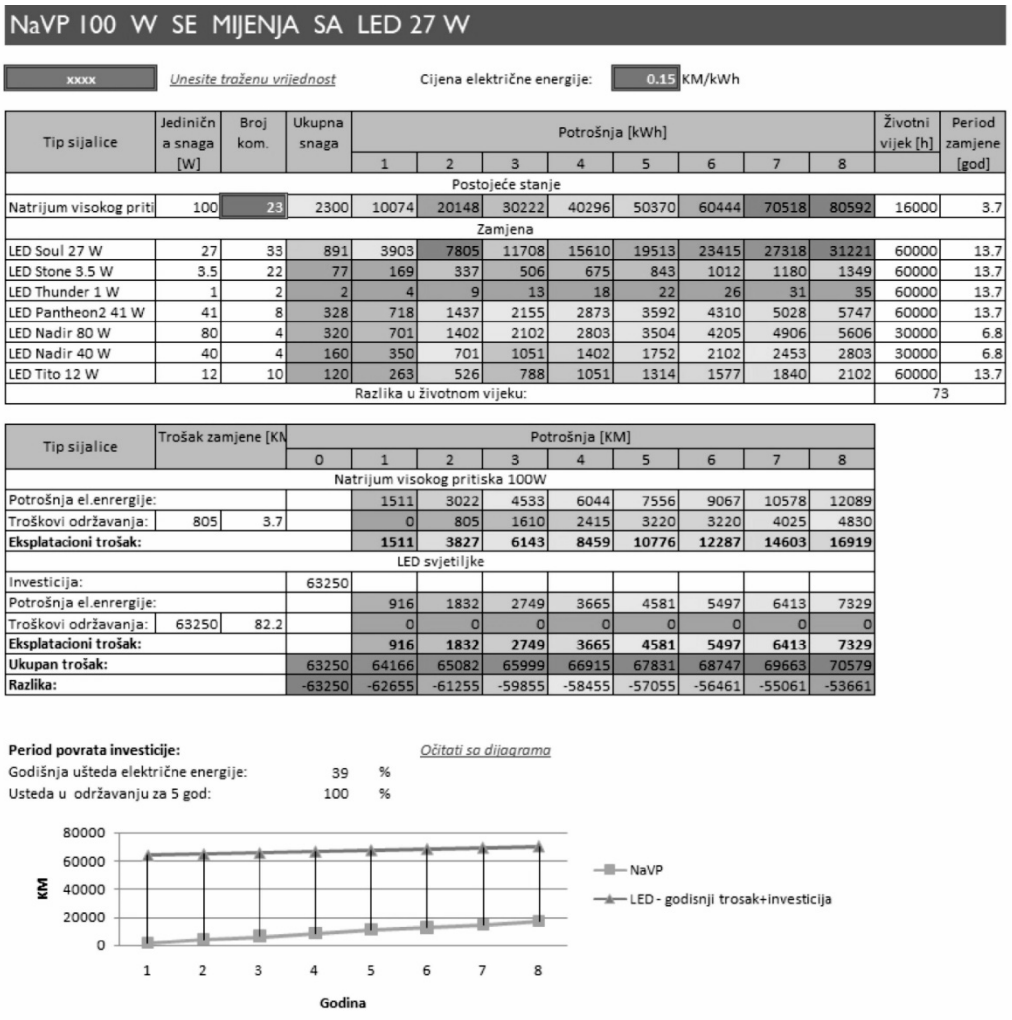
Tip sijalice	Trošak zamjene [EUR		Potrošnja [KM]								
			0	1	2	3	4	5	6	7	8
NaVP 100											
Potrošnja el.enrergije:				1511	3022	4533	6044	7556	9067	10578	12089
Troškovi održavanja:	552	3.7		0	552	1104	1656	2208	2208	2760	3312
Eksplatacioni trošak:				1511	3574	5637	7700	9764	11275	13338	15401
LED Soul 27											
Investicija:			7095								
Potrošnja el.enrergije:				585	1171	1756	2342	2927	3512	4098	4683
Troškovi održavanja:	7755	13.7		0	0	0	0	0	0	0	0
Eksplatacioni trošak:				585	1171	1756	2342	2927	3512	4098	4683
Ukupan trošak:			7095	7680	8266	8851	9437	10022	10607	11193	11778
Razlika:			-7095	-6169	-4692	-3214	-1736	-258	667	2145	3623

Period povrata investicije: *Očitati sa dijagrama*

Godišnja ušteda električne energije: 61 %

Usteda u održavanju za 5 god: 100 %

Figure 9. Energy and economic analysis of urban lighting redesign of the coverage in the part of the pedestrian path according to the APEE reconstruction method. Calculator for local governments 2013-2014 [13]



NaVP 100 W SE MIJENJA SA LED 27 W

xxxx *Unesite traženu vrijednost* Cijena električne energije: 0.15 KM/kWh

Tip sijalice	Jedinična snaga [W]	Broj kom.	Ukupna snaga	Potrošnja [kWh] 1	2	3	4	5	6	7	8	Životni vijek [h]	Period zamjene [god]
Postojeće stanje													
Natrijum visokog priti	100	23	2300	10074	20148	30222	40296	50370	60444	70518	80592	16000	3.7
Zamjena													
LED Soul 27 W	27	33	891	3903	7805	11708	15610	19513	23415	27318	31221	60000	13.7
LED Stone 3.5 W	3.5	22	77	169	337	506	675	843	1012	1180	1349	60000	13.7
LED Thunder 1 W	1	2	2	4	9	13	18	22	26	31	35	60000	13.7
LED Pantheon2 41 W	41	8	328	718	1437	2155	2873	3592	4310	5028	5747	60000	13.7
LED Nadir 80 W	80	4	320	701	1402	2102	2803	3504	4205	4906	5606	30000	6.8
LED Nadir 40 W	40	4	160	350	701	1051	1402	1752	2102	2453	2803	30000	6.8
LED Tito 12 W	12	10	120	263	526	788	1051	1314	1577	1840	2102	60000	13.7
Razlika u životnom vijeku:												73	

Tip sijalice	Trošak zamjene [KM		Potrošnja [KM] 0	1	2	3	4	5	6	7	8
Natrijum visokog pritiska 100W											
Potrošnja el.enrergije:				1511	3022	4533	6044	7556	9067	10578	12089
Troškovi održavanja:	805	3.7		0	805	1610	2415	3220	3220	4025	4830
Eksplatacioni trošak:				**1511**	**3827**	**6143**	**8459**	**10776**	**12287**	**14603**	**16919**
LED svjetiljke											
Investicija:			63250								
Potrošnja el.enrergije:				916	1832	2749	3665	4581	5497	6413	7329
Troškovi održavanja:	63250	82.2		0	0	0	0	0	0	0	0
Eksplatacioni trošak:				**916**	**1832**	**2749**	**3665**	**4581**	**5497**	**6413**	**7329**
Ukupan trošak:			63250	64166	65082	65999	66915	67831	68747	69663	70579
Razlika:			-63250	-62655	-61255	-59855	-58455	-57055	-56461	-55061	-53661

Period povrata investicije: *Očitati sa dijagrama*

Godišnja ušteda električne energije: 39 %

Usteda u održavanju za 5 god: 100 %

Figure 10. Energy and economic analysis of urban lighting redesign of the coverage according to APEE reconstruction method. Calculator for local governments 2013-2014 [13]

4. CONCLUSION

Banja Luka is a city on the river and the left and right bank are connected with numerous bridges. The development strategy of the city has changed during its history and the coastline itself has been on the city margins for many years, and one of the contemporary strategic goals is ecologically sustainable, infrastructurally developed and energy efficient environment - green city on Vrbas River. In the framework of the Action Plan for Energy Efficiency of the City of Banja Luka, the reconstruction of public lighting was carried out in two stages, but it is not possible to determine the success of these operations on the basis of available documentation. The annual costs of the City for consumed public lighting energy are either the highest when least expected or the results of successful reconstruction are not pointed out enough, or they are simply insignificant and invisible in such short period of exploitation. Additionally, the Vrbas coastline was not in the scope of the reconstruction, and there were no unique documents of the city lighting or a project that would integrate different aspects of urban lighting.

A small coverage along the river was used as a representative example to present the possibilities of fulfilling the set strategic goal of the city development through urban lighting re-design proposal Further on, we examined the energy and economic justification of such proposal by implementing the APEE method, which is also used in public lighting reconstruction in Banja Luka. Following the analysis of the current situation, it was determined not only that there is a lack of adequate ambient park lighting of the promenade, architectural and decorative lighting of bridges, but also that functional lighting in the form of public lighting does not fulfil its primary assignment. Respecting the recommendations for lighting of different areas and establishing a hierarchy in lighting specific parts, we suggested the pedestrian zone lighting redesign on the coastline. Redesign includes the reconstruction of the existing public lighting system and introducing new lighting types, primarily responding to the natural context of the coverage. After recognizing different environmental atmospheres, character of specific parts of the coverage and diverse demands of all user profiles, we carefully selected the lamps and luminaires for a unique presentation of the 'green city' on Vrbas river.

The paper presents three cases of replacing the existing luminaires. The first case refers to replacement luminaires suggested in the Guide, the second one to replacements from the redesign and the third one to total lighting of the coverage, all with the purpose of justification required by the APEE. Considering the fact that the solution of urban lighting reduced the distance between the lamps and thus increased their number, it was necessary to correct the formula for the investment calculation. The calculator assumed that the number of lamps did not change during the reconstruction, so the unit price of a replacement lamp was multiplied by the number of existing ones, not the replacement ones. Economic analysis according to APEE does not identify other changes than simple replacement of lamps and only for the most economically justified energy efficient replacement lamps. This confirms the fact that the reconstruction of public lighting assumes the quality of the existing system and does not question its adequacy for new sources and forms of lighting or considers any other aspects.

Justification of urban lighting redesign in terms of energy savings has been confirmed on example of the right bank of Vrbas River between two bridges, whether in minimal (in stages) or in full scope. The results indicate that the investment costs of complete redesign are relatively high. However, these expenses should not be considered only form economic perspective. They should be also considered in the context of total effects, first of all environmental and architectural, bringing significant contribution to the total development and branding of the city and long-time improvement of the life quality in the urban environment.

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CRITICAL RESISTANCE OF A HUT—IN SIX POINTS (CULTIVATION OF CRITICAL PRACTICE THROUGH THE MEMORIAL HOUSE DESIGN BY THE ARCHITECT RANKO RADOVIĆ)

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CRITICAL RESISTANCE OF A HUT – IN SIX POINTS (CULTIVATION OF CRITICAL PRACTICE THROUGH THE MEMORIAL HOUSE DESIGN BY THE ARCHITECT RANKO RADOVIĆ)

ABSTRACT

This paper deals with the importance of critical design practice in order to nurture, cultivate and build architectural culture. The main goal is to analyse the Memorial House in the Sutjeska National Park, designed by the architect Ranko Radović, through the scientific description, using Kenneth Frampton's theoretical text "Towards Critical Regionalism - Six Points for an Architecture of Resistance" as an analytical method. In a broader sense, the paper aims to draw attention to the idea of critical practice in modern circumstances by researching the design methodologies and principles based on tradition.
The research result is important for contemporary architectural theory and practice in our region and beyond. It indicates the importance of learning architecture based on knowledge and transferring the knowledge gained through the critical practice of our architectural heritage as one of the possible ways to rethink the architectural profession in contemporary conditions of its evident marginalisation under the force of the capital and universalisation of the built environment.

Key words: *critical design practice, Architecture of Resistance, critical regionalism*

КРИТИЧКО ОДОЛИЈЕВАЊЕ ЈЕДНЕ КОЛИБЕ – У ШЕСТ ТАЧАКА (КУЛТИВИСАЊЕ КРИТИЧКЕ ПРАКСЕ КРОЗ ПРОЈЕКАТ СПОМЕН ДОМА АРХИТЕКТЕ РАНКА РАДОВИЋА)

Апстракт: Овај рад бави се питањем важности критичке пројектантске праксе у циљу његовања, култивисања и грађења архитектонске културе. Основни циљ јесте да се кроз научно описивање, користећи као аналитички метод теоријски текст Кенета Фремптона „Ка критичком регионализму – шест тачака ка архитектури отпора", анализира пројекат Спомен дома у Националном парку Сутјеска, архитекте Ранка Радовића. У ширем смислу рад има за циљ да се истраживањам пројектантских методологија и принципа утемељених на традицији скрене пажња на идеју критичке праксе у савременим околностима.
Резултат истраживања је од значаја за савремену архитектонску теорију и праксу, у нашем региону и шире, јер указује на важност учења архитектуре које је засновано на знању и преношењу знања критичке праксе нашег архитектонског насљеђа, као једну од могућих начина у преиспитивању архитектонске професије у савременим условима њене евидентне маргинализације под силом капитала и универзализације грађене средине.

Кључне ријечи: *критичка пројектантска пракса, архитектура отпора, критички регионализам*

1. INTRODUCTION

This paper aims to actualise the importance of critical design practice in order to nurture, cultivate and build architectural culture. It is also a detailed study of the most significant design by the architect Ranko Radović, realised in 1971 —the Memorial House in Sutjeska National Park. It is considered here a *discursive practice* [1:26] and is re-examined according to the postmodernist theory of critical regionalism of the famous American architectural critic Kenneth Frampton.

Therefore, the main goal of this paper is to scientifically describe, systematise and explain the critical work of Ranko Radović on the example of his most significant work in the context of the critical regionalism theory, and thus to contribute to the idea of critical practice in contemporary circumstances. In a broader sense, this paper, deals with the problem of research of contemporary design methodologies and principles, which are based on knowledge and knowledge and tradition transfer through epochs, in terms of preserving and actualising critical design practice.

We think it is essential to keep architectural culture vital and alive today when the phenomenon of universalisation in architectural practices have more than ever erased any form of authenticity or what Paul Ricoeur calls “the ethical and mythical nucleus of mankind” [2: 314].

The paper consists of two primary segments. The first segment sets the theoretical framework and discusses the meaning of the term “critical regionalism” and the circumstances that conditioned its appearance. The theoretical corpus is based on the texts of the most relevant regional and world authors (theorists, historians and architectural critics) Kenneth Frampton, Michael Hayes, Ljiljana Blagojević, Charles Jencks, and Ranko Radović himself. The critical regionalism framework with specific characteristics, which Kenneth Frampton explained as the concept of an “**Architecture of Resistance**”, was especially analysed.

The second part is conceived as qualitative research of Radović’s architectural achievements and his design approach in accordance with the theoretical framework of critical regionalism. The backbone of the theoretical analysis of the building is Kenneth Frampton’s text “Towards a Critical Regionalism: Six Points for an Architecture of Resistance” [3]. The conclusion summarises the previous analysis and sets new guidelines for research into critical design practice.

We also believe that the research result is important for contemporary architectural theory and practice in our region and beyond because it indicates an autonomous force of resistance to the universalisation of the space. It is an example of how to nurture critical design vitality in the development of architectural culture.

2. CRITICAL-THEORETICAL FRAMEWORK OF THE PAPER

Ranko Radović’s design, critical and theoretical practice is one of the most complex multi-media legacies of the Yugoslav postmodernist culture. Radović develops an authentic discursive practice of “deviation from the canon of high modernism” [1:25] through internationally recognised, active and critical engagement by expanding the field of understanding of the architectural practice to other media, which significantly contributed to the popularisation of architecture, positioning it in a broader cultural sphere. Professor, theorist and architect Ljiljana Blagojević emphasises Radović’s work as crucial in the articulation of the “architectural discourse (...) of postmodernism of the 1980s in (...) the former Yugoslavia” [4: 184]. As a

particular value of that legacy, "the theoretical line of Radović's work" [4: 183] was set, which included his academic and architectural design work, and at the same time, it overlapped with his active critical engagement in the field of culture and media (Radović created TV shows on architecture, published critiques in newspapers, held public lectures, acted through academic work and design practice) [4: 184]. Emphasising "the right to critical thinking left by Ranko Radović as a responsibility to his intellectual heirs" [4: 184], Blagojević simultaneously encourages us to reveal the heterogeneity of his work and also subtly provokes a critical interpretation and new actualisation of his theoretical thought. All of the above is in the spirit of then (and now) modern tendencies in architectural discourse, presented in the 1960s by an architecture professor and historian, Michael Hayes. In the introduction to the anthological collection of theoretical texts "Architecture Theory since 1968"[5], Hays sets out the principles of architectural culture, emphasising that architectural culture cannot be expected to emerge spontaneously through a theory as a practice of mediation. Nevertheless, it must be constructed, deconstructed and reconstructed again. In this spirit, Radović considered it unnecessary to divide architecture into theory and practice. Instead, he saw the permeation and intensive flow of theoretical and practical work in the place of their division.

When we talk about the overall work and significance of Radović, it is necessary to state that Charles Jencks, in his book [6: 50-51] "The New Paradigm in Architecture", on the map including relevant representatives of postmodernist practice in the second half of the 1950s, and all until the 2000s, sets Radović in the "Romantic revival" in the evolutionary tree. It is also interesting that the main language determinant of this Jencks' evolutionary tree line is a metaphor as a feature of the architectural narrative, with the most significant protagonists. On one side, there is Le Corbusier with the church in Ronchamp encoded in several visual and implied metaphors (with a roof and nave being just some of them) and Daniel Libeskind with the Jewish Museum in Berlin on the other side of the timeline. Somewhere in between, Jencks sets Radović. He seems to be using the "revival of the romantic" to designate the usage of traditional codes in the architectural language, such as the gable roof of the Memorial House.

However, Ljiljana Blagojević suggests that Ranko Radović's works should be classified and observed primarily "as a radical critique of modernism" [4: 194], and certainly not as a "revival of romanticism", as Charles Jencks, the historian and theorist of modernism and postmodernism, designated it. Furthermore, Blagojević characterises the Memorial House design as if "the design anticipates the theoretical elaboration of critical regionalism" [4: 194]. In the period of re-examining the principles of modernism and the coming postmodernism, Radović takes a possible synthesis position, i.e. a synthesis of the accomplishments of modernism and the local architectural heritage. We find this position *in between* both in his textual and visual records, as well as in his realised works.

Professor Ljiljana Blagojević states that the Sutjeska Battle Memorial House was conceived through a conscious re-examination of the "modernist paradigm in relation to the natural environment and cultural-historical context" [4: 194], confirming Radović's position that the general principles of modern architecture are not disputed, but the way of their application in the reality of special conditions [7]. In this way, Radović emphasises the phenomenon of a specific place, insisting on critical reflection and respect for the contextual reality, taking the position of research freedom in terms of interpreting the context.

Precisely in this complex period of changes within the architectural paradigm of the second half of the twentieth century in a climate of a constant conflict between the global and local, critical

regionalism emerges as a new concept that should reconcile these two corpora of thought and approach.

The most significant credit for spreading the concept of critical regionalism goes mainly to the American theorist, architecture critic and historian Kenneth Frampton, who first presented his vision of critical regionalism in 1983 in his essay "Towards a Critical Regionalism: Six Points for an Architecture of Resistance" [3].

In this essay, Frampton elaborated on the concept of critical regionalism. Yet, his crucial work to fully understand this concept is "Modern Architecture: A Critical History", in which he uses the term critical regionalism to describe "peripheral" phenomena as a form of cultural, economic, and political independence in an evidently forthcoming universalised world [2]. In the fifth chapter entitled "Critical regionalism: Modern Architecture and Cultural Identity", Frampton especially emphasises the fact that the realisation of modern architecture implies the respect for the importance of modern technology achievements and local peculiarities of a particular climate. Thus, Frampton does not link critical regionalism to vernacular architecture but to "**architecture that resists**", i.e. the one "whose primary goal is to reflect and serve the distinct (localised) units in which it is founded". According to Frampton, critical regionalism is primarily a strategy for suppressing universal civilisation by indirectly introducing elements rooted in the characteristics of a particular climate [2:21].

At this point, as a basis for his arguments, Frampton refers to a French philosopher Paul Ricoeur and his essay, "Universal Civilisation and National Cultures". In this essay, Ricoeur interprets the phenomenon of universalisation destroying not only traditional cultures but also what he calls the "creative core of great civilisations and great cultures". According to him, the forthcoming mass consumer culture weakens and completely breaks ties with the cultural past. In this context, Frampton sees salvation in the idea that architecture must retain social values and preserve the meaning of the past but in accordance with the imperatives of the future. Therefore, regional culture must not be taken as something given and relatively unchangeable but as something that should be thoughtfully cultivated. [8].

It is important to remember that critical regionalism is not yet another style, nor do its protagonists in the architectural language necessarily foster many similarities. Nevertheless, they all foster a critical attitude towards globalist modernisation processes. According to Frampton, critical regionalism is primarily a strategy for suppressing a universal civilisation by indirectly introducing elements rooted in the characteristics of a particular climate. Frampton believes that architects should search for regional variations instead of continuing to design conforming to global uniformity. In this context, Radović himself believed that the "spark of new research" is yet to come shedding light on the global margin practices, such as the architectural practices of the Yugoslav period.

3. THE ANALYSIS OF THE MEMORIAL HOUSE DESIGN OF THE ARCHITECT RANKO RADOVIĆ: SIX POINTS OF AN ARCHITECTURE OF RESISTANCE OF A CRITICAL REGIONALISM

The Sutjeska National Park, an area of magnificent nature, surrounded by the mountains of Zelengora, Volujak, Maglić and the Perućica primaeval forest, is the oldest national park in the Republic of Srpska and Bosnia and Herzegovina. It was proclaimed a national park in 1962 by the National Assembly of Bosnia and Herzegovina, which enacted the Law on Declaring the

Sutjeska area a national park. This region is characterised by traditional settlements, spontaneously formed through generations and according to living conditions, whose morphology organically merges with the rich natural environment. Consequently, structures creating the spatial-structural arrangement of the group form have uniform architectural properties and represent an image of traditional life and the actuality of this region.

Within the National Park, in the Sutjeska River valley, there is a site called Tjentište - an important historical place known for the battle of Sutjeska in the Second World War. In the very centre of Tjentište, there is a memorial complex called the Valley of Heroes, the monument of the academic sculptor Miodrag Živković, and the Memorial House on Sutjeska by Ranko Radović, realised in 1971, which was painted with modern frescoes by the painter Krsto Hegedušić after the realisation. These two monumental works won the first prize in the competition for the Memorial Complex in Sutjeska, in 1964, according to which they were realised. Today, this exceptional natural whole represents an authentic cultural landscape with its architectural tradition and historical monuments.

Figure 1: *The Memorial House in Tjentište (left) and the Monument, Sutjeska National Park (source: Marina Radulj)*

3.1 SIX POINTS OF AN ARCHITECTURE OF RESISTANCE OF A CRITICAL REGIONALISM

In his aforementioned essay, "Towards a Critical Regionalism: Six Points for an Architecture of Resistance", Frampton describes critical regionalism as a concept of "architecture of resistance" because it represents a reaction against universal standards, cultural commodification, and technology worship. In other words, critical regionalism as a concept should encourage the process of integration between tradition and modernity. Therefore, Frampton develops a theoretical framework with specific characteristics that portray critical regionalism, which he explained in the following six points: Point 1: **Culture and civilization**, Point 2: **The Rise and Fall of the Avant-Garde**, Point 3: **Critical Regionalism and World Culture**, Point 4: **The Resistance of the Place-Form**, Point 5: **Culture Versus Nature: Topography, Context, Climate, Light and Tectonic Form**, Point 6: **The Visual Versus the Tactile** [3:21].

It is important to note that with these six points, Frampton does not intend to give a recipe for designing in the spirit of the region but to provide broader conceptual guidelines for establishing a good practice of critical regionalism. Also, these six points can be considered as a comprehensive starting point for a critical analysis of an architectural work.

The remainder of this chapter will analyse the Memorial House, designed by Ranko Radović in Tjentište, according to Frampton's six points—as values of the critical regionalism position.

Point 1: **Culture and civilization**

"The phenomenon of universalisation", Ricoeur writes, "while being an advancement of mankind, at the same time constitutes a sort of subtle destruction, not only of traditional cultures, which might not be irreparable wrong, but also of what I shall call for the time being the creative nucleus of great cultures, that nucleus on the basis of which we interpret life, what I shall call in advance the ethical and mythical nucleus of mankind" [9:47]. By quoting Ricoeur, Frampton in this point draws attention to the space-time context of architecture, where due to ubiquitous land speculation and the accelerated universalisation and production of space, national cultures are neglected, and the "boundaries" of locality and peculiarity are "erased". In such an environment, architecture also manipulates, in fact, with reduced number of specific elements or through superficial masking (facades). The resistance of critical regionalism here implies a paradoxical situation—the creation of a regional culture based on global culture, which is manifested through the interpretation of some vernacular elements that do not necessarily have to be local (such as the isled basilica shown in Figure 2). So, the example of the Memorial House is an interpretation of the traditional local roofing with details, but also the projection of "minimalism in the spirit of Japanese aesthetics" by using forms proportionally close to pyramids (Radović travelled to and taught in Japan).

Figure 2. *Left: a detail of the overhang and the wide drain around the Memorial House; proportions of a Japanese temple (source: Marina Radulj) Right: basilical and constructivist interior of the Memorial House (Jen Lukehart) retrieved from https://www.sosbrutalism.org/cms/19405697 on 27 October 2021)*

Point 2: **The Rise and Fall of the Avant-Garde**

"The emergence of the avant-garde is inseparable from the modernisation of both society and architecture. Over the past century-and-a-half avant-garde culture has assumed different roles, at times facilitating the process of modernisation and thereby acting, in part, as a progressive, liberative form, at times being virulently opposed to the positivism of bourgeois culture" [3:18].

At the beginning of the 20th century with the appearance of progressive avant-garde movements—futurism, purism, neoplasticism and constructivism, and with the triumph of science, medicine and industry, the promise of modernism project was confirmed. However, the popularity of the movement and its placement in the capitalist machine, and thus in politics as well, made it intellectually sluggish. The space production itself became a response to their needs, i.e. manifesting itself in response to commodification or marketing needs, without the

input and reflection of new programmes. This led to Jencks' classification and critique of post-modern architecture that is striving either for pure technology (through the high-tech movement) or pure scenography. In these circumstances, "technics becomes the universal form of material production, it circumscribes an entire culture, it designs a historical totality—a "world") [9: 20].

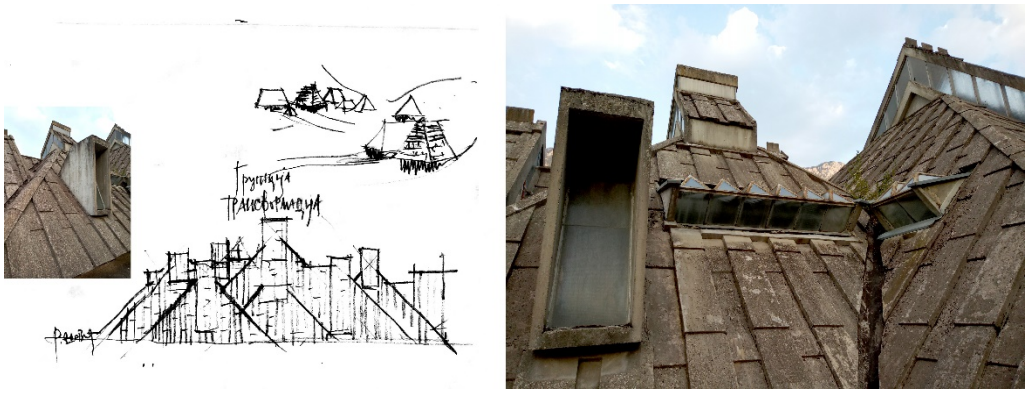
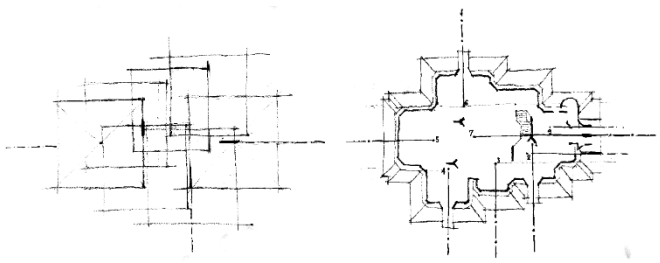


Figure 3: *A traditional hamlet (above) and sketches of clustered roof transformations (below). A detail of Radović's interpretation of a (traditional) roof, dormers and aperitures (right) (source: Marina Radulj)*

The Memorial House and the entire Radović's research and work represent an indisputable value based on local qualities interpreted by modernist processes and postmodernist means. This approach is noticeable in the methodology of transposing local qualities into a completely modern and unique authorial expression. From the spontaneously formed assembly (Figure 3), which acts as a dynamic and compact architectural ensemble, Radović builds a concept manifested in two ways in the solution: through a design language and spatial organisation. In one form, it is primarily perceived in the formation of the oscillating roof volume. In the other form, it is present in the spatial structure of the house built of a cubic element composing one group form by drawing an analogy to the fragmented organic structure of spontaneous clusters of Dinaric houses. This grouping of elements can be further interpreted by a modernist method of modular composition and geometric logic of a spatial plan.



Slika 4. *Geometric analysis of the Memorial House plan–realignment of the axes 7 and 5; fusion of different architectural codes–modernist spatial matrices of simple geometry vs. an isled basilica (source: Marina Radulj)*

The analysis of the Memorial House spatial matrix confirms this method. It is built of simple geometric shapes (squares and rectangles) that translationally realign in two directions. At the same time, the longitudinal (main) axis of the house also "realigns " (Figure 4), doubles in order to achieve spatial opulence. In a three-dimensional sense, the same method was used to

achieve a rich spatial experience, initially by using a simple geometric shape of a gable and hip roof in such a realigned spatial matrix.

Architecture that resists, even if it is practised in marginal places (in terms of popularity), and as a phenomenon on global margins as well, is interpreted here as the only expression of resistance. Therefore, the Memorial House and the entire Radović's research and work represent an indisputable value based on local qualities interpreted by modernist processes and postmodernist means.

Point 3: **Critical Regionalism and World Culture**

In this point, Frampton links the idea of resistance to the critical arriere-garde (out of date), a place where a critical practice should simultaneously resist "the optimisation of advanced technologies and the ever-present tendency to regress into nostalgic historicism", i.e. to agree neither to populism nor to sentimental regionalism and decorativism. The process of making this place can be interpreted as creating an architectural theory (according to Michael Hayes) as a practice of double mediation—between the influence of universal civilisation and the indirect usage of specific elements of the locality in which it is built.

In the Memorial House, transposition, or as Frederick Jameson calls it, "transcoding" [10:40], is visible on several levels—the idea of a house and temple in this place intersect in building a new programme of architecture. In the materialisation of the House, the use of advanced technology is visible—raw prefabricated concrete imbrex (the technology and texture typical of late modernism and the so-called brutalism in architecture). At the same time, the roofing patterns with displaced, overlayed tiles are transposed from traditional wood shingle roofs. The displaced tiles here mimic the style of planks on a traditional roof, with accentuated vertical overlays for water drainage, and they perform the same function.

Figure 5. *Brutalist interpretation of roofing patterns—landscape references (left), a detail of tile overlay (in the middle), roof hip details (right) (source: Marina Radulj)*

Point 4: **The Resistance of the Place-Form**

Here, architecture is expected to focus on the territory in which it originates, emerges, by establishing borders, and thus relations with it, and not just modernistically appears as a self-sufficient free-standing structure. "Place-form" means resisting location-specific forms created in a specific place rather than space. In fact, resistance here refers to the opposition to continuous flux, the so-called Megalopolis.

Professor Ljiljana Blagojević states that the Battle of Sutjeska Memorial House was conceived through a conscious re-examination of the "modernist paradigm in relation to the natural environment and cultural-historical context", which confirms Radović's position that the general principles of modern architecture are not disputed, but the way of their application in the reality of special conditions [7]. In this way, Radović emphasises the phenomenon of a specific place, insisting on a critical reflection and respect for the contextual reality, taking the position of research freedom in terms of context interpretation. The Memorial House points to the thoroughly thought-out transpositions of the regional tradition of log cabin architecture from the surrounding area into a completely modern and significant interpretation. Speaking about his design, Radović says: "…there could be no talk of folkloristic formalism ... (but) in my deep conviction we could not avoid that authentic spirit of the climate, inspiration by ethical and material beings of the world of cruelty and purity" [11: 14]. "The morphology of the Memorial House was initially formed as a group of traditional roofs, but in the experimental design process, it was transformed into a completely modern and unique expression. As such, it is in dialogue not only with the traditional forms of localities, but also with the dynamic forms of the mountain massifs of Tjentište" [12: 338]. The form built in this way from the specifics of the place climate is a proof of values from point 4. The obvious connection with postmodern language (according to Jencks) should be noted. In the chapter "Towards Subtle Urbanism" [6: 167-173], Jencks analyses examples such as Radović's Memorial House, which have their form developed through a multitude of urban codes. In the same way, Radović, in this natural environment, "clusters" roofs of huts that undoubtedly resemble an entire "settlement", even though it is a single house, i.e. building. Radović breaks the pulsatory form of repeated components through two longitudinal facades on which he illustrates the settlement. He breaks the symmetry with very similar but not identical components, so there is no sense of a free-standing megalith, even though the Memorial House is almost 40 meters long, while a traditional house is about 8.5 m long.

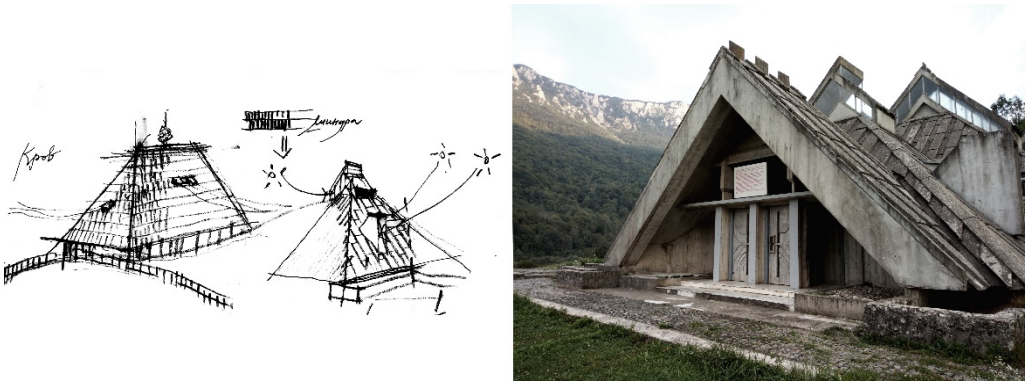


Figure 6. *A sketch of a traditional roof with dormers and aperitures—relationship with natural illumination and ventilation (left), an archetypal shape of the Memorial House facade (right) (source: Marina Radulj)*

Point 5: **Culture Versus Nature: Topography, Context, Climate, Light and Tectonic Form**

Critical regionalism strives to cultivate a dialectical relationship with the environment and nature, rather than creating abstract spaces, the so-called tabula rasa, either through the terrain topography, some climate elements, light and sunlight, or through the tectonics of the form itself. In this way, the culture of the region is inscribed in the very form of the building. In the case of the Memorial House, the terrain is relatively flat, so there are no levelling changes

in the structure. However, the external form is in connection with the surrounding mountain massifs. The context read in this way is interpreted through a harsh climate, with a lot of wind and snow. Consequently, the building form is transposed into a homage to the drainage of pluvial water(s)—in one complex element—the roof lowered to the ground, with a wide ground-level gutter all around the house.

The attitude towards nature and the local culture of construction is reflected in the orientation of the building along the longitudinal north-south axis (north for the entrance) in order to make maximum use of the natural angle of sunlight incidence through roof lanterns, roof windows and crystal forms. The specificity of the fenestration comes from the interpretation of spikes, crosses or the so-called apertures and dormers—elements of traditional architecture that appear on the ridge and have a pronounced symbolic and decorative meaning—most often associated with the house protection from spells, magical or religious rituals.

Like Laugier's primitive hut, Radović's structural elements such as a pillar, capital, beam, and roof draw maximum attention—these are real structural elements whose function is further emphasised by an expressive design that seems to illustrate the transfer of forces and loads, and the way of resisting gravity. The tectonic forms of these elements surpass the mere materiality of the construction, and through the master's skills, it transforms them into an art form.

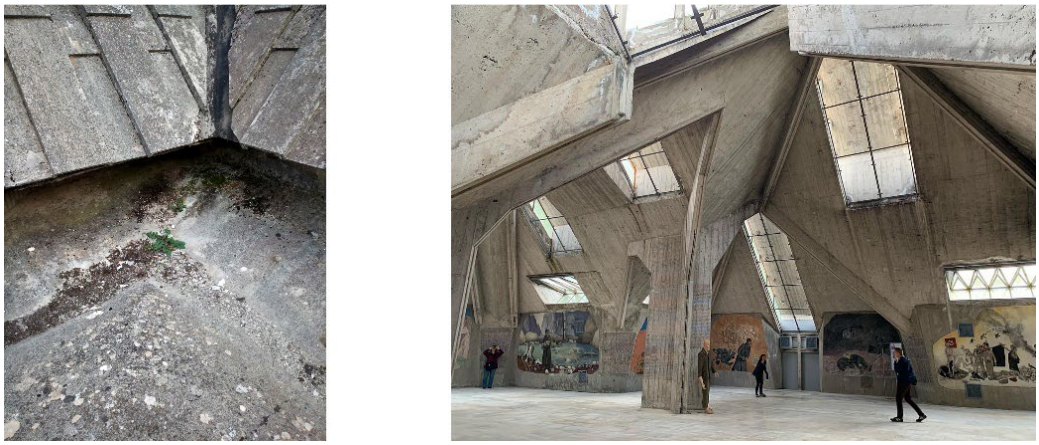


Figure 7. *A detail of the roof valley with ground-level gutter—"a homage to the drainage of pluvial water(s)" (left) (source: Marina Radulj); basilica-like interior and illumination (right) (Jen Lukehart) retrieved from https://www.sosbrutalism.org/cms/19405697 on 27 October 2021)*

Point 6: **The Visual Versus the Tactile**

Supporting the dominant sense of sight directs the architectural practice towards a spectacular and scenographic approach, while critical regionalism is returning the focus from the visual to the tactile. This/These value(s) of architecture and space can be experienced only through real experience in the space. Frampton claims that the capacity of our body to experience these qualities by being in a space, moving through it, is a potential strategy to resist the universal technology dominance as well.

From the natural meadow surrounding, Radović slowly, "from the feet up", introduces concrete thresholds laid in the grass as a tactile sign of access to the building. The entrance to the building is through a heavy, concrete door with a cold steel pipe in place of the handle. The

interior of the building is dominated by raw concrete as a building and finishing material with a polished stone floor, which adds up to the original experience of the "concrete cathedral". To the touch, it has a cold, rough texture, as do the rocks of the surrounding mountains. The return to the tactile allows a deviation from the scenography, bringing back architects to the construction of the structural poetics, i.e. the creation of tectonic values.

Figure 8. *A detail of the front door with a handle (left) (source: Marina Radulj), basilica-like / dramatic illumination of the interior stone floor (Jen Lukehart) retrieved from https://www.sosbrutalism.org/cms/19405697 on 27 October 2021), a detail of the access to the Memorial House (source: Marina Radulj)*

4. CRITICAL RESISTANCE OF A HUT

In a contemporary, especially "critical" sense, "critical regionalism" is seen as an approach to designing. By respecting the context, it seeks to avoid making local architecture unfounded in order to give it meaning and a sense of particular place.

The theory here (whether it is about realised designs or texts) is set as a production of a relationship between an architectural work and a wider social or societal context. However, it is set "in such a way as to show that an architectural work has a certain autonomous force, because of which it can be visible that it denies, distorts, suppresses, compensates, or even produces, or reproduces that context itself" [4: 183]. In our case, it is the re-usage of the idea and form of the so-called primitive hut reinterpreted in the spirit of the time in which it is created.

The symbolic sign of a gable roof in the northern hemisphere usually means "home" in the cultural code. Used in the Memorial House in the Sutjeska National Park, this cultural code carries the metaphor of a hut in our country. "A hut is essentially a simple building with a mostly rectangular plan and a gable roof (...) the initial house was usable, functional protection from the climate and animals. However, at the same time, it was a place, a world, a symbol with which a man decorated his spiritual position and controlled space and time. Becoming aware of himself and nature, his strengths and weaknesses, himself as an individual and as a society, he took his house-hut as a means, an instrument of survival, but also a means of symbolisation and self-proof" [13:13]. Further, in the same text, the author, critic and theoretician of architecture, Ranko Radović, comments on the resilience and resistance of the hut through the centuries of architecture as a "prominent sign and metaphor" of the duality of architecture existing and becoming between the technique and art, idea and form, utilitarianism and spirituality, that every (good) architecture carries in that very complexity.

The simplicity of the form itself—from the archetypal form of a gable roof supported by four columns connected by beams—is a prerequisite for resisting in time, changing, decomposing

and reshaping. At the same time, the original symbolism in each interpretation cannot be "hidden".

In his book "Essay on Architecture" [14], the Jesuit priest Laugier deals with a man's original need for shelter and, in those intentions, he builds a house – a dwelling for himself, his family, cattle, "that protects him but does not bury him" [14:13]. The illustration by Charles Eisen (Figure 9), accompanying the essay, illustrates a hut made of trees found in the woods, and a female figure as a symbol of Architecture, casually resting in her baroque dress and among the discarded, broken capitals and decorative wreaths. She is pointing her finger to an angelic child (personification of the new) at this simple form as the source from which "all beauties and wonders of architecture arise" [13: 15].

Slika 9. *Engraving by Charles Eisen of a primitive hut, used as the frontispiece to the second edition of Marc-Antoine Laugier's Essai sur l'architecture of 1755. Retrieved from https://issuu.com/fernandogonzalezpiris/docs/essay_on_architecture_laugier on 29 October 2021*

Radović's Memorial House design represents, like any theoretical text, the mediation between a man and nature. It carries these dualities and metaphorical meanings (especially in the horizontal and vertical projection—plan and cross-section), and it expands these values—in the exterior, undoubtedly bringing the roof form of primitive hut-houses, and in the interior, building the experience of a cathedral and being in the woods. The sign "roof over your head" is an unambiguous metaphor expressed through the form used in modest construction houses, with modest living needs, and in the harsh locality of the Sutjeska River valley, surrounded by the mountains of Zelengora, Volujak, Maglić and Perućica primaeval forest. The designed experience of a cathedral, on the other hand, achieved through the so-called implied metaphor (Jencks) in the light play of zenithal illumination through numerous lanterns and crystal forms and with sculpturally treated columns, skillfully works on the plan of the unconscious in making a "place", "world", a symbol of comprehending the world and the spiritual self in it.

By mixing Radović's codes, with the heterogeneity inherent in postmodernism, he projects the utilitarian (useful) and spiritual dimension of architecture, transforming the idea of a house –

primitive hut – habitat – apartment – roof, into a spiritual house – pyramid – memorial house – as the "house of all people of one community" [13].

The rootedness in the place and its inventive and hybrid interpretation in the spirit of contemporary culture distinguishes the Memorial House as an architectural work that possesses a certain autonomous force. It also determines Ranko Radović as a sensible architect who finds his primary inspiration in things around him in developing the vitality of architectural culture.

It can be said that this way of creative thinking is another confirmation of the anticipation and modern interpretation of critical regionalism, which according to Jadhav, is found somewhere between neo-historicism and neo-avant-garde. According to him, neo-historicism is based on a strong and complete connection with the past. Neo-avant-garde, on the other hand, is realised as an inventive vision of the past, which should not be based on, but it should derive creative impulse from it [15]. As it can be seen in the example of the Memorial House, both ancient and modern cultures are not the product of one heritage, but a hybrid of several cultures that have intertwined in the past in a particular region. Frampton points out that regional or national cultures must be constituted as local forms of "global culture" manifestation [2].

5. CONCLUSION

This paper aimed to actualise the critical design practice of one of the most important cultural figures of the former Yugoslavia, architect Ranko Radović, through a detailed presentation of his most important design—the Memorial House in the Sutjeska National Park. The applied method in the paper is a detailed analysis according to the theoretical text of Kenneth Frampton. It is shown and proven that the Memorial House has all the features of the so-called critical regionalism, focusing on the values of resistance to the universalisation of the space and architectural forms, i.e. returning to its humanistic essence. The paper emphasises the need to maintain the vitality of architectural culture today more than ever due to the dominance of capital over human needs, due to the emergence of universalisation in architectural practices that have erased any form of authenticity. As a result, the role of architecture, art, and the humanities is completely marginalised in society. There is not enough resistance, resistance to global universalisation processes. There is no autonomy.

It is precisely this place and time (given that histories are written some 50 years after a certain phenomenon) to revitalise discursive practices like Radović's, from the former Yugoslavia, which have an autonomous force of resistance to the universalisation of the space and which reflect critical design vitality in developing architectural culture.

In this way, among other things, we want to point out the importance of learning architecture based on knowledge and transferring the knowledge gained through the critical practice of our architectural heritage, as one of the possible ways to reconsider the architectural profession in modern conditions of its obvious marginalisation under the force of capital [16].

We conclude the paper with a comment and a new challenge set by Ljiljana Blagojević. She sees Radović's practice "as a radical critique of modernism", whose formulation could be linked to a relatively recent discussion between Rem Koolhaas and Charles Jencks, which will direct our further research.

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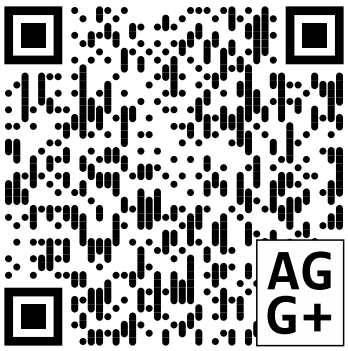
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ASSESSING THE BENEFITS OF NATURE-BASED SOLUTIONS IN A STORM DRAINAGE SYSTEM – A CASE STUDY

ABSTRACT

In most developing countries, stormwater drainage practice consists of a conventional storm drainage system designed to collect and convey excess runoff to the recipient as soon as possible, without any attenuation or peak flow decreasing effects. This paper aims to show the overall need for change in the urban drainage paradigm by showing the effects of reconstruction of the existing conventional stormwater drainage system into a new one by including green elements. Part of the existing system is replaced with vegetated swales, and two detention ponds are added in the common green areas (parks). Effects are analysed through a comparison of results from a mathematical rainfall-runoff model for the existing and reconstructed stormwater drainage system for both water quality and quantity at the sub-basin outlet point. The cost-effectiveness of the applied measures is quantified by comparing construction prices for the existing and the reconstructed system. The obtained results clearly show an urgent need for stormwater drainage practice improvement in countries where the conventional approach is still in use.

Keywords: *green infrastructure, rainfall-runoff model, water quality, stormwater drainage system*

ПРОЦЈЕНА ПРЕДНОСТИ ПРИРОДОМ ИНСПИРИСАНИХ РЈЕШЕЊА У СИСТЕМУ КИШНЕ КАНАЛИЗАЦИЈЕ – СТУДИЈА СЛУЧАЈА

Апстракт: У већини земаља у развоју пракса одвођења кишних вода у градовима се базира на конвенционалним системима који су пројектовани тако да вишак воде од падавина што брже сакупе и одведу до реципијента, без икаквог ефекта задржавања или ублажења отицаја. У овом чланку се указује на потребу за промјеном парадигме одвођења кишних вода у градовима кроз ефекте који се постижу реконструкцијом постојећег конвенционалног система каналисања кишних вода увођењем природом инспирисаних рјешења. Дио постојећег система је замијењен затрављеним каналима и два детенциона базена су додана у систем на мјесту заједничких зелених површина (паркови). Ефекти су анализирани поређењем резултата математичког модела падавине-отицај за постојеће и реконструисано стање система кишне канализације, по питању количине отицаја али и квалитета на излазној тачки са слива. Исплативост примијењених мјера је квантификована поређењем трошкова изградње постојећег и реконструисаног система. Добијени резултати јасно показују хитну потребу за побољшање постојећих система кишне канализације у градовима гдје је конвенционални систем каналисања још у употреби.

Кључне ријечи: *природом инспирисана рјешења, модел падавине - отицај, квалитет воде, систем кишне канализације*

1. INTRODUCTION

In most developing countries, the usual stormwater drainage practice assumes a conventional stormwater drainage system design by the inherent principle of removing excess water from the surface "as soon as possible". Hence, the stormwater drainage system aims to collect the storm runoff from the surface, which is usually done by connecting all impervious surfaces directly to the system. An adverse effect of this practice is that it does not allow groundwater recharge, and consequently, drains are over-designed to convey all excess stormwater irrespective of natural processes (i.e. percolation, seepage and groundwater recharge). In this instance, we mainly consider excess water from roofs, parking areas and other urban impervious surfaces that should be rather directed to nearby pervious areas such as parks and other green areas.

Conventional storm drainage systems are seen as ineffective in the event of torrential rains [1] and largely interrupt the natural hydrological cycle. With the goal of restoring natural hydrological cycles in urban areas, many new concepts offered novel drainage systempractices, i.e. Sustainable Urban Drainage System (SUDS) [2], [3], stormwater Best Management Practices (BMPs) [4], Water Sensitive Urban Design (WSUD) [5], Low Impact Development (LID) [6], [7], Blue Green Dream (BGD) [8] and many more. Many authors quantified the hydrological and pollution benefits of nature-based solutions (NBS) in order to prove their effectiveness in the meaning of water quantity or quality control. For example, Stovin et al. [9] found in their study that green roofs attenuated peaks during significant storms by over 60%, while Wang et al. [10] concluded that the reduction of total suspended solids (TSS) with these elements was around 63%. Studies in China [11] found that the highest stormwater volume reduction in bioretention systems was 68%, while peak flow was reduced by 86%. The same elements are found to reduce phosphates by 81% and nitrates by 69% [12]. Young et al. [13] found that vegetated swales reduced the runoff from the highway on average by 87%, while removal of TSS, chemical oxygen demand (COD), total nitrates (TN) and total phosphorus (TP) was by 90%, 57%, 32% and 20%, respectively. Some of the review and comparative analysis of different NBS elements can be found in [14]. The economic benefit of the NBS is usually evaluated in terms of economic and social benefits by investing in these solutions [15].

This paper aims to prove the effectiveness of a simple reconstruction of a conventional drainage system to decrease the water quantity entering the stormwater drainage system and improve the water quality. Economic aspects of cost-saving with this reconstruction are also highlighted as a very important decision-making tool in developing or low-income countries.

2. RESEARCH SETUP

In this paper, the complete analysis and conclusions rely upon model simulations of a few variants of a drainage system. Different drainage system models are developed as: (i) the existing one, (ii) the existing one with disconnection of impervious surfaces from the system and connection to pervious zones, and (iii) reconstructed system with the inclusion of green elements, more specifically, dry detention ponds and vegetated swales. The rainfall depth, sub-basin characteristics and pollution parameter inputs are the same for all models, so the results are easily comparable. Finally, the costs of the systems are compared to prove that the inclusion of green infrastructure not only gives a better technical solution and cleaner collected water, but it is also economically more favourable.

Different storm drainage systems are analysed using a rainfall-runoff modelling software called StormNET®® [16]. Simulations include both water quantity and water quality modelling in several different sewer system setups.

As a case study, the urban settlement of Veseli Brijeg in the city of Banja Luka, Bosnia and Herzegovina, has been chosen. Data for the existing drainage system at the site was collected, and the corresponding drainage system model was developed. This drainage system is referred to hereinafter as Conventional, and it represents the reference model to which others are compared by changing the drainage practice and changing/adding elements.

The second model keeps the same settings as the Conventional model but with one change: all impervious areas such as roofs and parking areas are connected to pervious zones instead directly to the drainage system. This is the conventional system with source control included as the first in the line of sustainable urban drainage practices. Hereinafter it is called Conventional + source control.

The third model is an alternative one constructed from the conventional model by replacing parts of the drainage pipes with vegetated swales and including two dry detention ponds in the catchment that need to be located appropriately. Hereinafter, this model is called Alternative.

Additionally, the basin has also been modelled as a natural one, i.e. without urbanisation, for additional comparison of outflow hydrographs before and after urbanisation and with conventional and NBS elements in the urbanised drainage system. This comparison highlights the NBS for mimicking natural site conditions. This model is called Pre-development.

3. RAINFALL-RUNOFF MODELLING

StormNET® is a physically-based model with dynamic hydrologic and hydraulic calculations. The concept for rainfall-runoff modelling is based on the interaction of several main factors of the environment [16]:

- atmosphere/precipitation, modelled with rain gauges;
- land surface, modelled with sub-basins;
- groundwater system which is modelled with the aquifer and
- network elements that accept and convey the computed runoff, modelled with nodes and links.

In addition to the above, there is a water quality modelling that can be defined together with a water quantity model generation.

This program offers several different computation methods for calculating components of the rainfall-runoff processes. In this analysis for the water quantity modelling, rainfall-runoff processes are calculated using the EPA SWMM [17] [18] (Environmental Protection Agency Stormwater Management Model) model that dynamically generates the runoff based on rainfall, evapotranspiration and potential infiltration data. The surface runoff is calculated by the non-linear reservoir method, while the Green and Ampt method based on continuity and mass conservation equations (known as Darcy's Law) is used for the calculation of infiltration. The pipe flow calculation uses St. Venant's equations, specifically the diffusion wave with inertial part omitted from the mass conservation equation. In addition, the software includes calculations for sustainable urban drainage elements, such as NBS, for both quantity and quality control.

For all three model setups, one rain gauge station is assigned. Various synthetic rainfall events were analysed in terms of catchment response to find out the most unfavourable runoff for the system element design. It was concluded that for the analysed watershed, the maximum peak runoff occurs for the rainfall duration of 15 minutes while the maximum runoff volume is generated with the 1-hour rainfall, which is an important factor for the attenuation element design.

The temporal variability of rainfall was also checked in order to find the maximum runoff peak appropriate for drainage element design. Four various temporally distributed synthetic rainfall events were considered, according to StormNET® rainfall designer options [19]:

- constant intensity over the duration (block storm),
- cumulative rainfall with decreasing intensity (advanced storm),
- cumulative rainfall with increasing intensity (delayed storm) and
- cumulative rainfall with almost uniform intensity (same as one but differently defined in StormNET® software).

After simulating runoff hydrographs for all temporal rainfall distributions, the cumulative rainfall with decreasing intensity was adopted for further analyses. Three different return periods of synthetic storms were considered:

- Synthetic storm of 2-year return period or 50% probability of exceedance, representing local design practice,
- Synthetic storm of 10-year return period or 10% probability of exceedance, corresponding to the design practice in most developed countries,
- Synthetic storm of 5-year return period or 20% probability of exceedance as a “middle of the road” solution between the previous ones.

In urban stormwater drainage systems, the main sources of contamination are pollution wash-off with runoff from the catchment surfaces and pollutants that have accumulated in the sewers during dry weather [20]. The pollution modelling available within StormNET® is a common two-stage process: a pollution build-up during dry periods and pollution wash-off during wet weather. This causes the simulation to be continuous with both dry and wet weather periods to capture pollution loads because normally, pollution loads increase with the increasing antecedent dry period.

According to an experimental study [21], after a rain event, the pollution wash-off builds up again relatively quickly to the previous amount on the surface. This implies that during the comparison of pollution resulting from different drainage model setups, the distribution of the specific pollution load during simulation time is not so relevant. Green drainage elements will reduce only a maximum of the pollution load during the analysed time since they do not affect the pollution build-up on the surface during dry weather. In this paper, detailed pollution modelling was not in focus, and it was only used for relative comparison purposes between different drainage systems. Input parameters, since there were no measured ones, were adopted as typical values given in StormNET® [18], [22], [23].

Urban stormwater pollution sources such as the atmospheric deposition, catchment surface attrition/elution or urban land use activities produce various amounts of pollution parameters, varying from site to site. It is recognized [24] that the most common parameters of urban non-point source pollution are: total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN), biological oxygen demand (BOD), chemical oxygen demand (COD), Lead (Pb), Copper (Cu) and Zinc (Zn).

In this study, three pollution parameters are analysed: TSS, TP and BOD.

Sub-catchments characteristics are kept the same in all models as well as the conveyance system lengths. The pollution input data remain constant in all three models to ensure comparability of the simulation results.

4. DEVELOPMENT OF STORMWATER DRAINAGE MODELS: CASE STUDY

4.1. STUDY AREA AND DATA

As a case study, a catchment in the city of Banja Luka called Veseli Brijeg was chosen, with an area of 9.2 ha. The land use is typically residential, with mainly dense apartment blocks and some individual households. The drainage system is of a separate type, so the stormwater drainage network could be individually analysed without the influence of municipal wastewater.

The models are developed with 12 sub-catchments. The main input data is given in Table 1, while the study catchment is shown in Figure 1 [25].

Table 1. Sub-catchments input data

Sub-catchment ID	Area	Equivalent width	Average slope	Impervious areas Model I	Impervious areas (without roofs) Model II and III
	(ha)	(m)	(%)	(%)	(%)
1	0.27	70.89	4.3	30	20
2	0.47	87.43	6.1	30	20
3	1.04	148.52	4.3	35	25
4	0.91	225.86	6.1	38	28
5	0.65	114.34	4.3	30	20
6	1.05	118.77	4.3	40	30
7	0.72	168.44	4.0	25	15
8	0.52	106.93	1.3	35	25
9	0.56	114.73	3.2	30	20
10	0.53	57.08	4.0	40	30
11	0.37	44.58	3.2	40	30
12	0.33	139.66	4.3	40	30
Other input data for sub-catchments					
Pervious area depression depth					4 mm
Impervious area depression depth					1.5 mm
Soil conductivity					36 mm/h
Manning's roughness for pervious					0.35
Manning's roughness for impervious					0.018
Suction head (for the Green-Ampt method)					61 mm
Initial moisture deficit (porosity minus initial moisture content)					0.25

Sub-catchment areas and slopes are derived from the DEM (Digital Elevation Model), while impervious/pervious areas are estimated from digital ortho-photo maps. Other data (given in the lower part of Table 1) are estimated upon recommended values published in various global literature sources and embedded in the software [26][27][28][29].

Unfortunately, there was no data for the model calibration. Instead, the parameter variability and sensitivity analysis were performed to estimate the range of output results of varying parameters within the expected range.

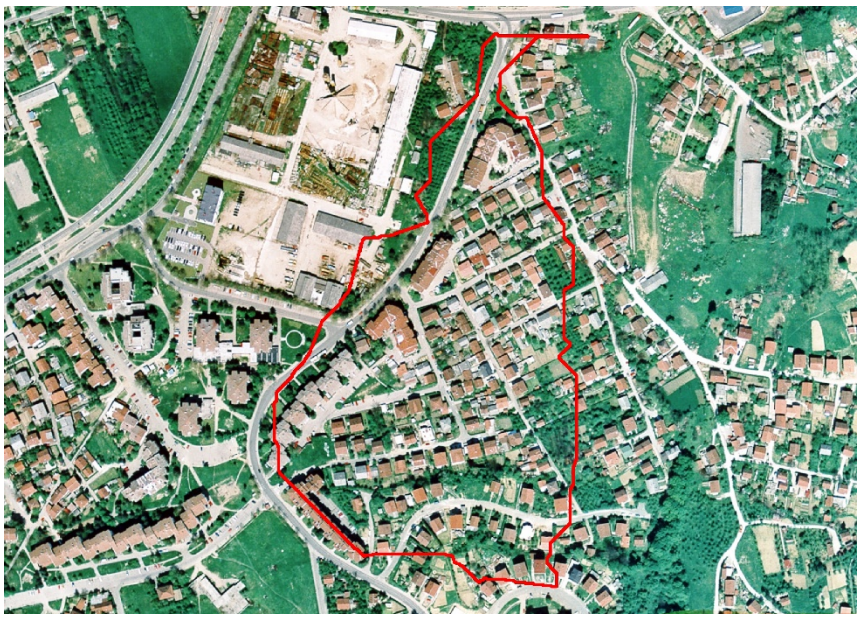

Figure 1. Study area of Veseli Brijeg, Banja Luka

4.2. EXISTING STORMWATER DRAINAGE SYSTEM – CONVENTIONAL MODEL SETUP

The conventional drainage system layout is designed by standard procedures that are part of the state regulations and with standard elements. The system is very simple, and it is comprised of circular pipes, standard manholes with an inner diameter of 1000 mm and one outlet where the runoff hydrograph is computed and data tracked for further analysis and comparison.

The drainage network junctions and pipe data are taken from the existing network design, with all their physical properties (e.g. geographic coordinates, invert and ground/rim elevations and offsets, length and diameters for the existing system) as they are built on site.

4.3. CONVENTIONAL MODEL WITH SOURCE CONTROL SETUP

This model is the same as the previous one, except for the inclusion of simple source control. This is done by disconnecting the roof runoff from the drainage system and connecting it to pervious areas instead, such as lawns and gardens. The model is changed by assigning less impervious areas to each sub-basin by reducing the percentage of the overall roof area. This is considered to be accurate because the routing roof runoff to the pervious zones first, from where it will be conveyed to the drainage network, makes these areas act as pervious. The used impervious area percentage for each sub-basin is shown in Table 1 (last column).

4.4. RECONSTRUCTED MODEL WITH NBS ELEMENTS

This model presents the re-designed conventional model, with the source control measure from the previous model and two additional dry detention ponds within the site included. In addition, from three sub-basins, S1, S2 and S3 (Figure 1), the runoff is collected and conveyed with the grassed swales modelled along the roads. The swales are 1 m wide and 40 cm deep. The schematic representation of the conventional and alternative model setup is shown in Figure 2.

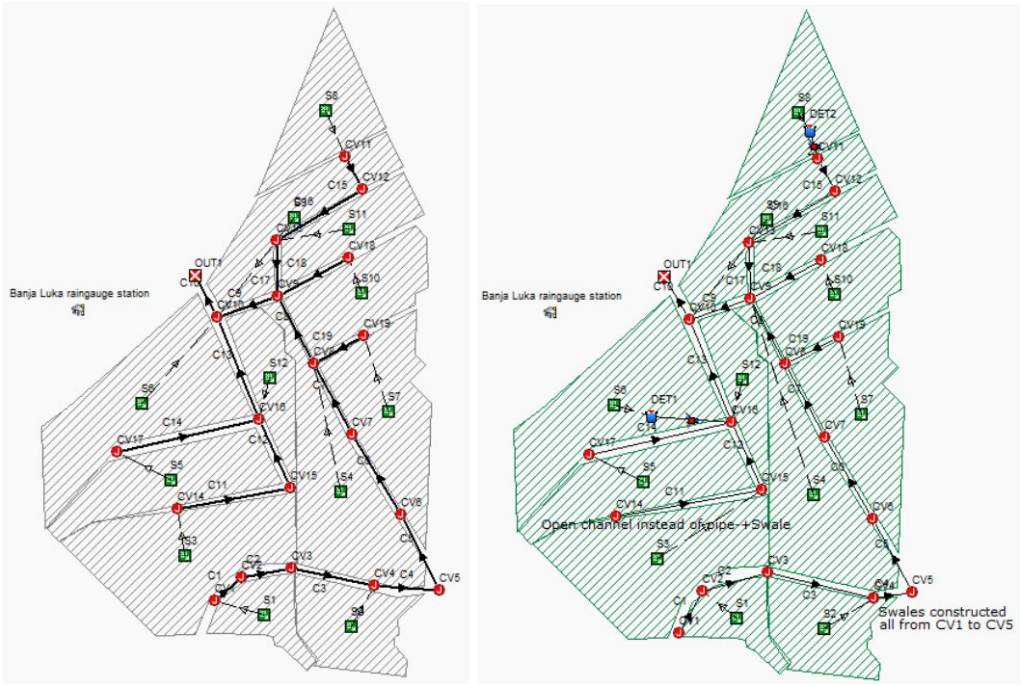

Figure 2. Schematic representation of storm drainage network models in the case study area: conventional (left) and alternative (right).

Detention ponds are sized according to the runoff volume from the conventional model results for that particular sub-basin. The first detention pond is placed on the sub-basin S6 with a volume of 131 m^3 and the second on the sub-basin S8 with a volume of 35 m^3. Both locations are chosen to be green areas between buildings, with a proper topographic configuration because the surrounding runoff gravitates towards them. Both ponds are designed to accept the sub-basin runoff volumes, and with the outlet control structure, they can slowly drain to the downstream part of the drainage network.

The control structure element called the “outlet” from the computer model is used as detention pond outlets. It is possible to completely control the flow rate by defining the head-outflow rating curve for this element.

Water in ponds can exfiltrate to the ground at all water levels, so it is assumed that there is no liner in the pond. The exfiltration method used is the Horton equation for all wet pond surfaces with the following parameters:

(1) maximum exfiltration rate is 8 mm/hr,

(2) minimum exfiltration rate is 1.6 mm/hr and

(3) decay constant is 4 h^1.

According to some research [30], the efficiency of green elements in the pollution removal varies from one element to another. It is found that for both dry detention ponds (using data collected from 8 studies) and for swales (using data collected from 20 studies), the range of percentages of typical pollution removals are:

- for TSS 30-65%,
- for TP 15-45% and
- for BOD-30%.

According to these findings, input data for the pollution removal in green elements included in the Alternative model were adopted to be: 20% for BOD, 30% for TSS and 50% for TSS. With such efficiencies, the model simply calculates the pollution concentration downstream of the element by decreasing pollution values in each time step by a defined percentage.

4.5. NATURAL CONDITION MODEL

In the reviewed literature, various methods for peak runoff estimation for a site with natural conditions are recommended and set within the state regulation [3]. Notwithstanding, it is possible to model natural site conditions and compare the results with the post-development conditions in order to assess differences in the runoff rate and hydrograph shape.

In this study, the pre-development system is modelled as a whole catchment with a very small percentage of the impervious area (5%). This model is made for the estimation of the difference in pre- and post-development runoff rates, as well as for sizing the storage facilities at the site.

4.6. MODEL PARAMETER VARIABILITY AND SENSITIVITY ANALYSIS

Since there was no data for model calibration, a sensitivity analysis was performed to determine how model results vary in response to changes in input parameters. In simple models, the sensitivity is readily apparent. However, in a sophisticated sewer model, the model response at one location relative to changes in flows or parameters at another location may not be that obvious. Combinations of parameters may have unpredictable interactive effects.

In this paper, data variability and sensitivity analysis were performed on the alternative system by making simulation runs while varying relevant input parameters. These parameters are varied for a range of expected values, and the effect on the output results was analysed.

Parameter variability and model sensitivity analysis is performed using the 15-minute rainfall of the 10-year return period. While varying one parameter, the rest are kept to the fixed model value (i.e. column two in Table 2). Consequently, values of varied parameters and the corresponding deviation of the model results are given in Table 2.

From these results, it can be concluded that for the developed simulation model, two parameters have the most uncertainty, namely: hydraulic conductivity and the initial moisture deficit, which are both soil characteristics, controlling infiltration and percolation processes.

Table 2. Overview of parameters variability and outflow sensitivity analysis.

Variable parameter	Exact model value	Uncertainty	Range of parameter		Deviation (max minus min obtained runoff) (l/s)
			min value	max value	
Hydraulic conductivity [mm/hr]	36	30	6	66	91.18
Impervious areas depression storage [mm]	1.5	1	0.5	2.5	2.59
Pervious areas depression storage [mm]	4	3	1	7	8.44
Manning coefficient for pervious n [m-1/3s]	0.35	0.05	0.3	0.4	0.61
Manning coefficient for impervious n [m-1/3s]	0.018	0.003	0.015	0.021	1.1
Initial moisture deficit [-]	0.25	0.20	0.05	0.4	15.07
Suction head [mm]	61	12	49	73	2.64

4.7. COST ANALYSIS

In addition to the technical aspects of improving the drainage system, it is useful to consider the difference in costs between the two models because this is the most important factor for the decision-makers in the developing countries (as well as in the developed countries). The simplified cost structure is developed and compared based on pipe lengths in the two models and with additional ponds and swales construction.

For the conventional pipe system, prices include all works from the construction site preparation, earthworks, manholes construction, laying of sand substratum, hydraulic test etc. In the Alternative model, the pipe length and number of manholes are reduced by substituting them with the swales-grassed shallow parabolic channels. The NBS elements used in this model include swales and detention ponds, which are among the cheapest in terms of construction and maintenance. This is intentionally adopted to reflect known problems encountered with the local community/municipality.

5. RESULTS AND DISCUSSION

The simulation of all model setups described previously show various catchment responses and the runoff at the catchment outlet. In Figure 3, runoff hydrographs for 15-minute 2-year return period storms are shown. It can be clearly seen how simple replacement of conventional elements (pipes) with the vegetated swales and inclusion of runoff attenuation elements (detention ponds) can affect the runoff from the catchment. Simple source control decreases the peak runoff by its third while the alternative model produces only a near-half of the conventional model runoff.

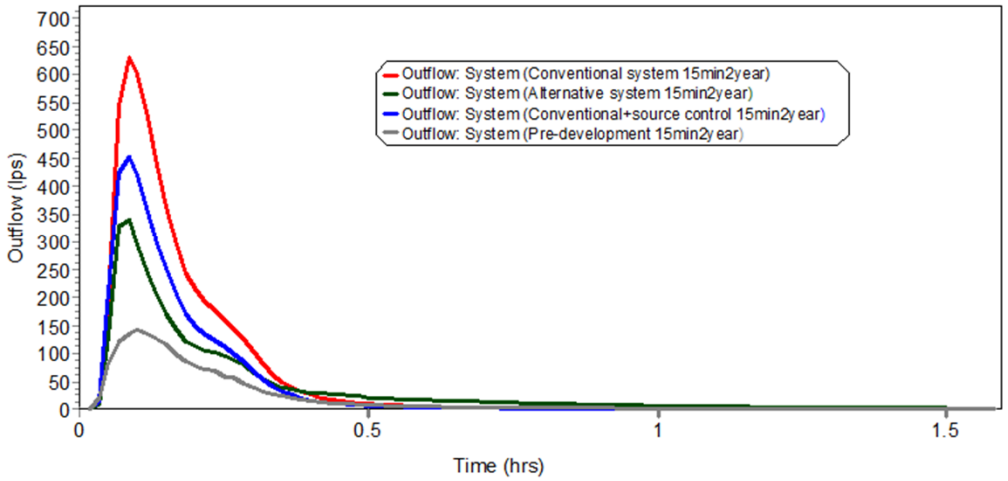

Figure 3. Comparison of runoff hydrographs for different storm drainage models (results for a 15-minute storm of a 2 years return period)

Figure 4 shows the resulting runoff at the system outlet as a function of the rainfall duration and return period. Different flow controlling measures can be seen to decrease the peak flow (i.e. through source control, detention ponds and swales). Figure 5 shows the percentage decrease of the peak flow for a 15-minute storm and runoff volume for a 1-hour storm for two models, namely the Conventional + source control and the Alternative one, compared to the conventional model.

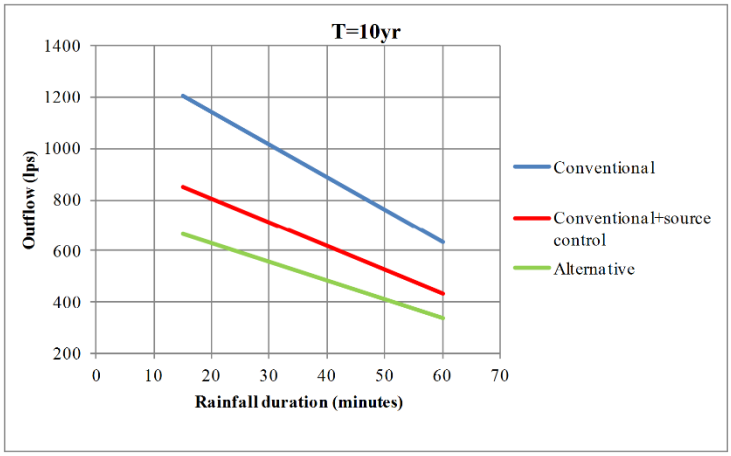

Figure 4. Runoff at the catchment outlet vs. rainfall duration for different storm drainage models and three different return periods

Directing the roof runoff towards pervious areas around buildings instead of into the storm drainage system leads to a decrease of the impervious areas by approximately 10% and it decreases the peak runoff by around 30%. With the inclusion of detention ponds and swales, this decrease is by up to 47%.

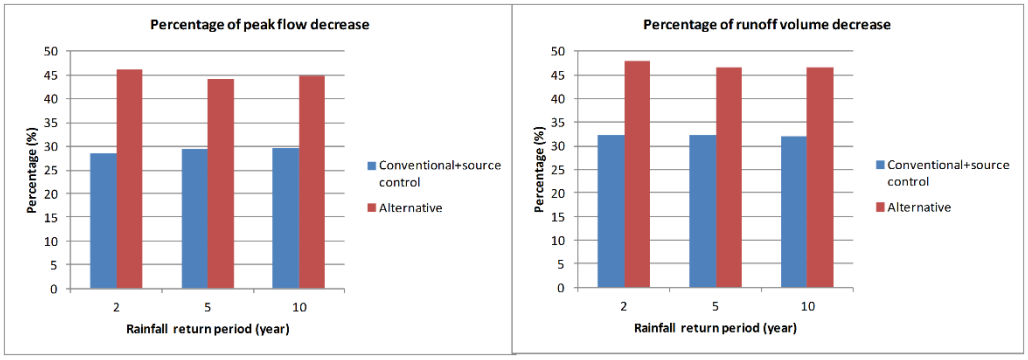

Figure 5. Percentages of decrease in peak flow and runoff volume for two models - Alternative and Conventional + source control in comparison to the conventional one.

To clarify what is happening with the flow, Figure 6 shows the flow through link C2, which is a pipe in the conventional system and a swale in the reconstructed one. The flow is substantially attenuated in the wide vegetated swale compared to the conventional system. This is because infiltration is allowed and even encouraged using vegetated swales with the especially porous underlying soil. Similar results in the pipe downstream of the detention ponds can also be expected, since ponds are designed to capture the local flood volume and release it slowly and uniformly downstream.

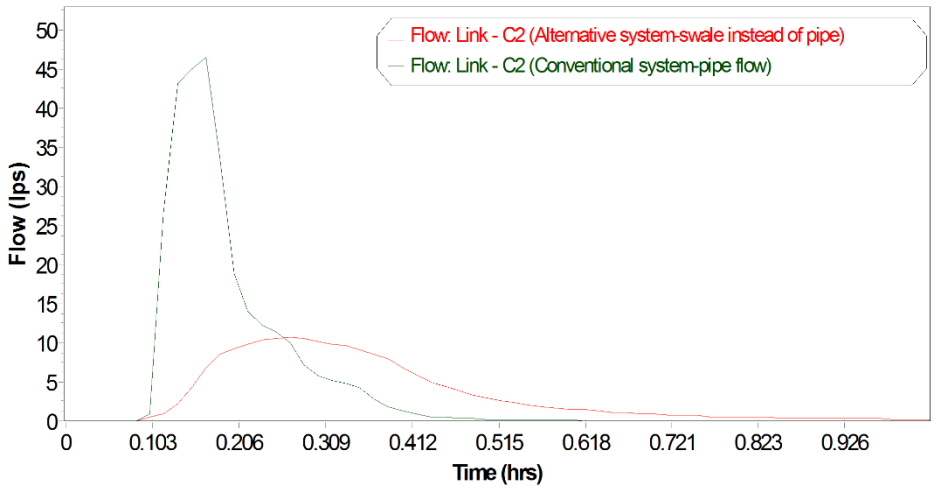

Figure 6. Flow hydrographs through link C2 – pipe vs. swale as an alternative

As mentioned previously, during the comparison of different drainage models, the setup, the pollution results, and the distribution of the specific pollution load during simulation time are not so relevant. Therefore, event mean pollution concentration is compared at the catchment outlet for conventional and alternative systems.

Figure 7 provides graphs of BOD, TP and TSS concentrations for 15-minute storms and different return periods. Pollution reduction in the model with source control only (conventional + source control model) is not so significant, since it mainly represents a reduction of pollution from the roofs, that does not enter the system but is discharged instead onto pervious areas

such as grass. Conversely, with detention ponds and swales, the decrease in pollution is significant.

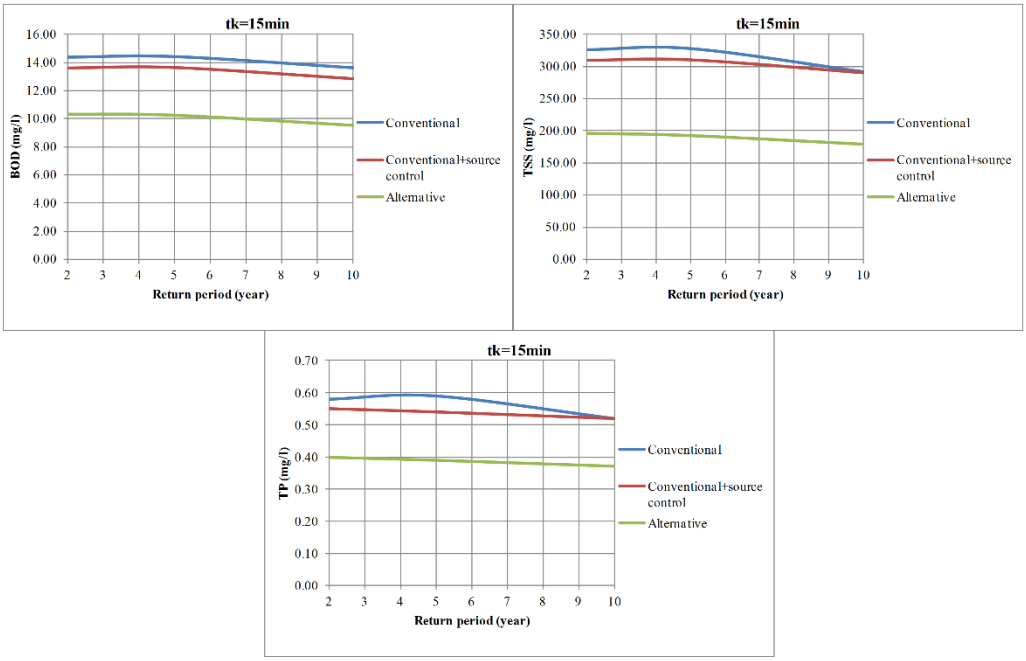

Figure 7. Mean change of BOD, TP and TSS vs. rainfall return period for different storm drainage models

Figure 8 shows the percentages of pollution reduction at the catchment outlet for BOD, TP and TSS. The best efficiency of sustainable drainage elements included in this reconstructed model is related to TSS removal, but TP and BOD concentrations decrease substantially.

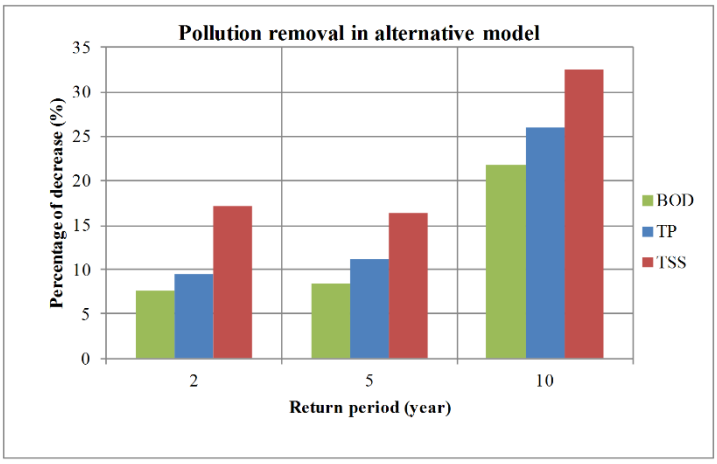

Figure 8. Percentage of decrease of pollution in the Alternative model in comparison to Conventional one

The cost analysis also provides very good results in favour of green infrastructure. If a multi-criteria analysis for technical, environmental, social and sanitary parameters was included, it is

likely the results would likely be very satisfactory [31]. A simple comparison of construction costs of conventional and alternative drainage systems are given in Table 3 and Table 4, respectively. The given prices are taken as mean market values while NBS costs are taken from [2].

As can be seen, cost savings can be expected if we choose to build in a sustainable urban drainage way. In other words, 26% less capital cost is required for the construction of an alternative system using green infrastructure compared to those using the conventional design.

Table 3. Construction costs for conventional drainage system

Construction work	Cost [€]
Construction site preparation	13.112,00
Earthworks	65.149,00
Concrete works	10.129,00
Masonry	6.685,00
Pipe purchase and installation	39.362,00
Other (additional) works	26.276,00
Σ	160.713,00

Table 4. Construction costs for alternative/reconstructed drainage system

Construction work (conventional elements)				Cost [€]
Construction site preparation				9.995,00
Earthworks				52.830,00
Concrete works				8.840,00
Masonry				4.934,00
Pipe purchase and installation				17.706,00
Other (additional) works				20.040,00
NBS element	Size	Unit	Cost [€/units]	Cost [€]
Detention pond (1+2)	166	m^3	12	1992
Swales	304	m^2	8	2432
Σ				118.769,00

6. CONCLUSIONS

From the analysis presented above, the summary of conclusions can be listed as follows:

(1) the impact of urbanisation and the design of conventional drainage systems increase natural catchment runoff by a factor of almost five times,
(2) with simple source control (in this example, the roof runoff was discharged onto pervious areas instead of being drained directly to the drainage system), both peak runoff and runoff volume are decreased by around 30%,
(3) an alternative system that includes sustainable, green infrastructure elements (e.g. detention ponds and swales) decreases both runoff and runoff volume by around 45%,

(4) pollution is decreased by 8%-30% depending on the pollution parameter, which is significant and has important repercussions for the future design of wastewater treatment plants,
(5) cost savings in the construction of a system using green elements are 26% compared to the conventional system, mainly because natural conveyance systems are cheaper than pipes, while pipe diameters are generally smaller than in a conventional system (due to the decreased peak flow),
(6) reconstruction of a conventional system is quite simple with substantial positive effects; a new storm drainage design can also represent a cheaper option.

Notwithstanding, it is not clear how new storm drainage design will turn out in the long-term when maintenance is included, since it has been shown through various reports and studies [3], [32], [33]. The aspect of costs during the life cycle should be considered in future research.

Obtained results are comparable with other studies with the difference that the benefits of the NBS elements are usually quantified as a single element(s) in the system, while this paper explores multiple benefits of NBS coupled with the conventional system.

Generally speaking, reconstruction of conventional storm drainage systems is very feasible. Relatively small investments can make highly positive influences on both water quantity and quality at the outlet point of the system. The full value of NBS solutions can be perceived by assessing the other benefits such as environmental [34], spatial and social [1], built environment [35], etc. Therefore, it is highly recommended for countries that have not yet adopted this type of storm drainage practice to improve it and start using sustainable and environmentally friendly solutions.

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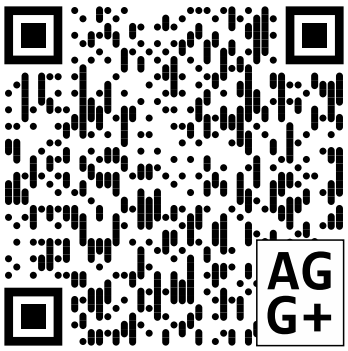
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ACCURACY ANALYSIS OF GNSS PERMANENT STATION COORDINATES USING THE LEAST SQUARE METHOD BY PROCESSING BROADCAST AND PRECISE EPHEMERIDES

ABSTRACT

This paper analyses how broadcast and precise ephemerides in alignment, using the least-squares method, affect the accuracy of coordinates of the newly included permanent stations. It has been shown that in practice, when adjusting networks whose span between points exceeds 50 km, the adjustment procedure should be carried out using the adopted precise ephemerides for a specific observation period. Precise ephemerides are recommended for 30 to 50 km baseline lengths, while adjustments with broadcast ephemerides achieves satisfactory accuracy for shorter lengths. For baseline lengths of 30 to 50 km, the use of precise ephemerides is recommended, and for shorter lengths, adjustment with broadcast ephemerides achieves satisfactory accuracy. This paper analyses statistics and presents standard deviations of horizontal and vertical positions, when broadcast and precise ephemerides are applied.

Key words: *GNSS, least squares method, broadcast ephemerides, precise ephemerides*

АНАЛИЗА ТАЧНОСТИ КООРДИНАТА GNSS ПЕРМАНЕНТНИХ СТАНИЦА ПРИМЈЕНОМ МЕТОДЕ НАЈМАЊИХ КВАДРАТА ОБРАДОМ ЕМИТОВАНИХ И ПРЕЦИЗНИХ ЕФЕМЕРИДА

Апстракт: У овом раду је анализирано на који начин емитоване и прецизне ефемериде у изравнању, примјеном методе најмањих квадрата, утичу на тачност координата новоукључених перманентних станица. Показано је да у пракси приликом изравнања мрежа чији распон између тачака прелази 50 km треба спровести процедуру изравнања примјеном преузетих прецизних ефемерида за одређени период опажања. За дужине базних линија од 30 до 50 km препорука је за примјену прецизних ефемерида, а за мање дужине изравнањем са емитованим ефемеридама постиже се задовољавајућа тачност. Кроз рад је анализирана статистика и представљена су стандардна одступања по положају и висини када се примјењују емитоване и прецизне ефемериде.

Кључне ријечи: GNSS, метод најмањих квадрата, емитоване ефемериде, прецизне ефемериде

1. INTRODUCTION

One of the leading data collection methods today, with extensive applications and possibilities, is the GNSS (Global Navigation Satellite Systems) method. GNSS consists of four main satellite technologies: GPS, GLONASS, Galileo, and BeiDou. Each consists mainly of three segments: a) space segment, b) control segment and c) user segment. Thanks to GNSS technology, end-users now collect and distribute data directly from GNSS tracking stations, known as active control stations (ACS) or real-time kinematics (RTK).

The Differential Global Positioning System (GPS) application is extensive. It is a unique system consisting of a network of fixed stations, a way of transmitting information from fixed stations, and the ability of GPS receivers to receive and process this information.

The network of SRPOS permanent stations consists of 23 evenly placed permanent stations on the Republic of Srpska territory, and it is under the jurisdiction of the Republic Administration for Geodetic and Property-Legal Affairs. Locations for the installation of new GIBL, GIDE, and GITE permanent stations were selected in accordance with the criteria that ensure a smooth operation of the equipment. Three new permanent stations are not under the jurisdiction of the Republic Administration for Geodetic and Property-Legal Affairs.

The choice of basic mathematical processing parameters depends on the source of relative GNSS positioning errors, satellite ephemerides, reference system, tropospheric and ionospheric signal delay.

2. GLOBAL POSITIONING SYSTEM (GPS)

The United States Department of Defense has developed the GPS, an all-time navigation system to meet the needs of the U.S. military and accurately determine their position, speed, and time in a common reference system in each moment anywhere on Earth or near Earth [1].

GNSS signals have very little power, so they are subject to several sources of noise and errors. The range measured by the GNSS receiver is contaminated with errors, which is why it is called a pseudo-range. GNSS errors in a general sense can be classified into errors of satellite origin, receiver errors, errors originating from the middle of the signal movement, and other measurement errors [2].

2.1. SATELLITE EPHEMERIDES

The errors of satellite ephemerides belong to the group of errors of satellite origin. The receivers calculate the satellite position based on the information contained in the navigation message known as satellite ephemerides. These ephemeride parameters are estimated in the control segment and then transmitted to satellites. The satellites broadcast updated ephemerides data every 2 hours. These parameters are estimated using a curve corresponding to the satellite orbit prediction (Figure 1), which leaves residual errors relative to the actual orbit [3].

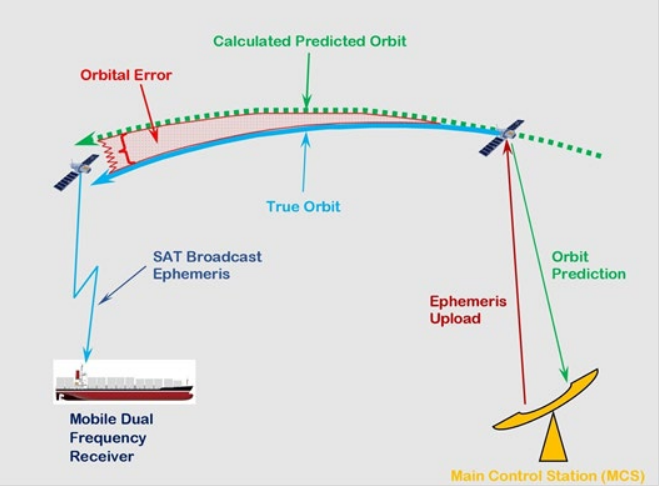

Figure 1. *Simplified representation of a satellite orbit error [4]*

This error source introduces a mean square error LMS (Root Mean Square) of about 2 m [5]. The error can be reduced if global or local area network corrections are available for the satellite position. These corrections are used to improve the correction of broadcast ephemerides and thus to improve the accuracy. More precise ephemerides, available from the International GNSS Service [6], can be used for post-processing if centimetre-level precision is required and when a two-frequency receiver is used.

Highly accurate orbit information is extremely important for determining the position derived from GPS. Broadcast ephemerides generated by the GPS Operational Control Segment (OCS) are available free of charge in real time to users who decode the GPS navigation message and contain data on Kepler elements and their time changes. Although the broadcast ephemerides are accurate enough for most navigation users, high-precision applications need improved orbit information. There are numerous sources of ephemerides that are available online for post-processing.

One of the services that generate ephemerides is the International GNSS Service - IGS [7]. IGS is a key element of the Global Geodetic Surveillance System - GGOS [8] and it fulfils three key roles. The first role is to establish links between SLR observation techniques, VLBI techniques, and DORIS ground beacons. These links are key to the creation of the ITRF International Terrestrial Reference Framework [9]. Another role is to condense and improve the geometric distribution of the global geodetic network, enabling accurate modelling of satellite orbits and clocks, atmospheric behaviour, and terrestrial processes such as neotectonics. The ultimate role is to enable the user segment to access the ITRF, which is increasingly important as the accuracy of publicly available GNSS positioning is improved. From this arises the need for a better understanding of the relationship between the ITRF and national data [10].

For the user to achieve precise positioning, it is necessary to know the orbits and clocks of GNSS satellites. Positioning accuracy is directly affected by errors in satellite paths and clocks. Orbit and clock information, with relatively low accuracy is transmitted via GNSS navigation messages, and other information is provided by IGS. The display of GPS satellite ephemerides, satellite clocks, and stations, as well as their accuracy, latency, continuity, and availability, are shown in Table 1 [11].

Table 1. *Accuracy, latency, continuity, availability, and sampling intervals for IGS orbit and clock products relating to GPS satellite orbits and satellite (sat) and station (stn) clocks as of 2013 [6]*

GPS satellites ephemerides Satellite and station clocks		Sample interval	Accuracy	Latency	Continuity	Availability (%)
Broadcast (for comparison)	Orbits Sat. clocks	-	≈ 100 cm ≈ 5 ns RMS, 2.5 ns σ	Real time	Continuous	99.99
Ultra-rapid (predicted half)	Orbits Sat. clocks	15 min	≈ 5 cm ≈ 3 ns RMS, ≈ 1.5 ns σ	Predicted	4 x daily, at 3 h, 9 h, 15 h, 21 h UTC	95
Ultra-rapid (observed half)	Orbits Sat. clocks	15 min	≈ 3 cm ≈ 150 ps RMS, ≈ 50 ps σ	3 - 9 h	4 x daily, at 3 h, 9 h, 15 h, 21 h UTC	
Rapid	Orbits, Sat. and stn. clocks	15 min 5 min	≈ 2.5 cm ≈ 75 ps RMS, ≈ 25 ps σ	17 - 41 h	daily, at 17 h UTC	95
Final	Orbits, Sat. and stn. clocks	15 min 30 s (Sat.) 5 min (Stn.)	≈ 2 cm 75 ps RMS, 20 ps σ	12 - 18 d	Weekly, Thursday	99
Real-time	Orbits Sat. clocks	5-60 s	≈ 2 cm 300 ps RMS, 120 ps σ	25 s 5 s	Continuous	95

IGS determines several categories of so-called precise ephemerides, some of which are predicted and are available in real time. Final IGS ephemerides, whose accuracy is as much as 2.5 cm, can be freely downloaded from the Internet, unlike broadcast ephemerides, which are only available in a couple of weeks [2].

Since the accuracy of broadcast ephemerides within a navigation message is of the order of 1 m [11], the scale effect will be 0.05 ppm. This paper focuses on the difference between the basic mathematical processing based on adjustment with broadcast and precise ephemerides. The formal accuracy of precise ephemerides of 2 cm does not affect the accuracy of the resulting vector components [11].

2.2. TROPOSPHERIC AND IONOSPHERIC SIGNAL DELAY

The tropospheric delay has two components, wet and dry. The wet component is difficult to model, but fortunately, it represents only a 10% delay. The dry component, responsible for the rest of the delay, can be modelled more easily. The tropospheric delay is frequency independent so, unlike the ionospheric delay, it cannot be removed by combining measurements from the L1 and L2 GPS signals. Depending on the satellite altitude, the tropospheric delay is about 2.5 m to 25 m from the range measurement [5].

The tropospheric signal delay in the zenith direction is eliminated by corrections calculated according to some of the many tropospheric models. For the needs of the basic mathematical processing of GNSS measurements in the network of permanent stations, the most frequently used HOPFIELD model was chosen. During GNSS measurements, the values of atmospheric parameters (temperature, atmospheric pressure, and partial pressure of water vapour) were not measured but calculated from the standard model of the atmosphere.

The ionosphere acts as a dispersive medium, which means that the ionospheric delay depends on the frequency. This delay represents one of the significant errors in the GNSS positioning

range and, in some situations, can reach a value of 300 ns (100 m) [12]. The ionospheric delay of the first-order signal is fully captured by the formation of linear frequency combinations IONO FREE from the performed two-frequency GNSS measurements [13]. Second-order ionospheric delay is not treated because it is completely negligible for vector lengths in the GPS permanent stations network.

2.3. EUROPEAN TERRESTRIAL REFERENCE SYSTEM 89

The choice of precise ephemerides for the basic mathematical processing also raised the question of the reference system. Precise satellite ephemerides refer to the ITRS reference system in the measurement epoch, while the SRPOS permanent station coordinates refer to the ETRS89 reference system. The two systems diverge from each other by definition because the ETRS89 reference system is connected to the Eurasian lithosphere plate and moves together with it at a speed of about 2.5 cm/year. In the past 30 years, this distance has reached 70 cm, corresponding to a scale effect of 0.03 ppm, or 1.5 mm in the length of the GITE - GIBL vector. Due to the error below the level of measurement noise during the basic mathematical processing, the transformation of precise ephemerides from the reference system ITRS into the reference system ETRS89 was not performed.

In 1991, the IAG Subcommittee on the European Reference Framework EUREF recommended that the state reference system for Europe coincides with the ITRS in the epoch t_0 = 1989.0 and is connected with the stable part of the Eurasian plate. It is called the European Terrestrial Reference System 89 (ETRS89). Currently, ETRS89 is a regional European system derived from ITRS and is used as a coordinate system throughout Europe [14].

The practical implementation of ETRS89 was initially provided by 93 stations covering Western European countries (European Economic Community, Scandinavian countries, and Austria and Switzerland). Base stations provided laser observations towards satellite targets (SLR / LLR) as well as VLBI quasar readings. A GPS campaign was launched in May 1989, and GPS observations were also used to establish EUREF [15]. Since 1997, the ETRS89 system has been applied by the permanent EUREF network.

3. THE REPUBLIC OF SRPSKA POSITIONING SYSTEM – SRPOS NETWORK

Implementing a network of permanent GNSS stations is a precondition for accurate recording and setting of boundaries, which provides new opportunities in establishing an up-to-date register of landowners, as well as eliminating errors in land registers and cadastral records. The service was supposed to provide GNSS measurements for positioning on the entire Republic of Srpska territory in real time with different accuracy levels by applying one of its RTK and DGPS operating modes and PP mode for subsequent data processing.

The service of permanent GNSS stations of the Republic of Srpska SRPOS was formally launched on September 27, 2011. The Network of Permanent Stations of the Republic of Srpska (SRPOS) currently includes 44 GPS permanent stations, 23 on the territory of the Republic of Srpska, 12 on the territory of the Federation of BiH, four on the territory of Serbia, two on the territory of Croatia and three on the territory of Montenegro.

ETRF2000 was chosen for the epoch 2011.307 as the final reference frame in which the coordinates of the permanent stations of the SRPOS network were calculated. These coordinates represent the position of permanent stations in the ETRS89 reference system.

3.1. INCLUSION OF NEW STATIONS IN THE SRPOS NETWORK

Locations for the installation of new GIBL, GIDE, and GITE permanent stations were selected under the following conditions:

- the location of the permanent station provides a space without physical obstacles above the vertical boundary angle of 10˚,
- the location of the permanent station provides power supply and has other necessary infrastructure for broadcasting corrections,
- the location of the permanent station is protected from lightning strikes,
- there are no sources of strong radio radiation near the location of the permanent station (high voltage lines, transformer stations, radar systems, etc.).

Due to the need to determine the exact coordinates of the permanent stations, the choice of locations for their placement was defined by the relative proximity of the permanent stations of the SRPOS network. The GIBL permanent station is located 2.6 km northwest of the SRPOS permanent station Banja Luka, the GIDE permanent station is located 0.2 km west of the SRPOS permanent station Derventa, and the GITE permanent station is located 0.3 km east of the SRPOS permanent station Teslić (Figure 2).

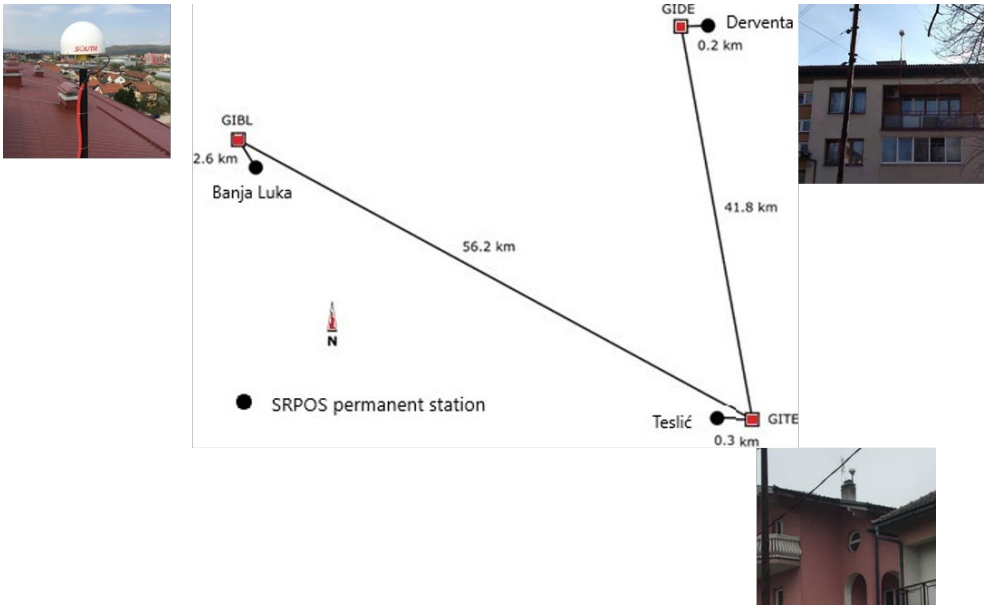

Figure 2. *Representation of GNSS vectors selected for basic mathematical processing and the immediate location of the GIBL, GIDE, and GITE permanent stations*

3.2. MEASUREMENTS IN THE NETWORK OF PERMANENT STATIONS

In the network of permanent stations, NetS8 + and NetS9T GNSS receivers and CHOKE RING GNSS antennas manufactured by SOUTH SURVEYING & MAPPING TECHNOLOGY CO., LTD were used. The NetS8 + and NetS9T GNSS receivers are specifically designed to work on permanent stations. CHOKE RING antennas are widely represented on permanently operating stations due to the excellent performance of multiple reflection filtering and the accuracy of the position of phase centres.

Measurements in the network were performed for five days, from August 8, 2020, to August 12, 2020. The length of the measured session was 24 hours, while the vertical boundary angle was 10˚, and the data registration interval was 15 seconds.

3.3. DOWNLOADED DATA

Daily observation files for SRPOS permanent stations Banja Luka, Derventa, and Teslić, in the industrial standard format RINEX, were taken from the Republic Administration for Geodetic and Property-Legal Affairs in Banja Luka and are shown below (Table 2), as well as the coordinates for these permanent stations (Table 3).

***Table 2**. Downloaded daily RINEX observation files*

Measuring day	BANJA LUKA	DERVENTA	TESLIĆ
08/08/2020	balu221w00.rnx	derv221w00.rnx	tesl221w00.rnx
09/08/2020	balu222w00.rnx	derv222w00.rnx	tesl222w00.rnx
10/08/2020	balu223w00.rnx	derv223w00.rnx	tesl223w00.rnx
11/08/2020	balu224w00.rnx	derv224w00.rnx	tesl224w00.rnx
12/08/2020	balu225w00.rnx	derv225w00.rnx	tesl225w00.rnx

***Table 3**. List of coordinates of permanent stations*

Station	X [m] Y [m] Z [m]	φ [dms] λ [dms] h [m]
Banja Luka	4332148.9575	44° 46' 23.53323"
	1342950.2204	17° 13' 23.67717"
	4469642.6240	214.6830
Derventa	4300617.8700	44° 58' 36.64918"
	1389651.9080	17° 54' 25.63116"
	4485681.2370	215.8995
Teslić	4329889.2046	44° 58' 36.64918"
	1394955.9788	17° 51' 26.38906"
	4456055.2474	270.9276

Navigation files with precise satellite ephemerides in a standard SP3 format (Table 4) were downloaded from the official website of the International GNSS Service (IGS) for a total of 9 days (5 measurement days and two days before and after the measurement campaign).

***Table 4.** Downloaded daily SP3 navigation files (https://www.igs.org/)*

Date	Precise ephemerides
06/08/2020	igs21174.sp3
07/08/2020/	igs21175.sp3
08/08/2020/	igs21176.sp3
09/08/2020	igs21181.sp3
10/08/2020/	igs21182.sp3
11/08/2020/	igs21183.sp3
12/08/2020/	igs21184.sp3
13/08/2020/	igs21185.sp3
14/08/2020/	igs21186.sp3

4. RESULTS

In the first step of this paper, the downloaded RINEX data were imported, and all data were checked. In the first case, broadcast ephemerides were used, and in the second case, published precise ephemerides were imported. Based on a predefined observation plan, baselines (vectors) were processed. During the processing, it was checked whether the phase uncertainties were solved for all vectors, that is, whether fixed solutions were obtained for all vectors. Published precise ephemerides were included to obtain the highest quality and most accurate adjustment results.

Using the least-squares method, the results of aligned base vectors were obtained, i.e. their aligned components as well as variance and covariance. The adjustment results represent the most probable values of point coordinates.

4.1. MATHEMATICAL PROCESSING OF GPS VECTOR

After entering the points and checking all the entered data, baselines (vectors) are processed. In data processing in order to obtain the components of the base vector between two points, mathematical models of relative positioning are used. The processing of baselines is done based on the observation plane and network sketch, so it is predetermined which baselines will enter the adjustment of the network. Manual processing of baselines was used when adjusting the subject network.

Simultaneous GNSS measurements on six permanent stations allow the formation of a total of five independent GNSS vectors. Such a choice is not unequivocal. The adopted approach coincides with the approach applied in EUREF thickening measurement campaigns and consists of a selection of independent vectors that meet two criteria. The first criterion is that the vectors are interconnected, and the second is that they collectively have the smallest length.

Following the adopted approach, the basic mathematical processing of the performed GNSS measurements was performed for the vectors: Banja Luka - GIBL, Derventa - GIDE, Teslić - GITE, GITE - GIBL, and GITE - GIDE. The total length of the selected vectors is 101.1 km (Figure 2).

4.2. CALCULATION OF DAILY SOLUTIONS

The coordinates of permanent stations were determined individually for each day within the adjustment by the method of least squares. The daily adjustment of the permanent station network was performed using a mathematical model that included the following wholes: the functional model, stochastic model, and date defect.

The functional model of adjustment consists of measured and unknown quantities. The measured quantities are components of the GNSS vector obtained within the basic mathematical processing of the initial measurement results, and the unknown quantities are the three-dimensional coordinates of permanent stations. The stochastic model is represented by a quasi-diagonal matrix whose diagonal members of the covariance matrix are represented by the covariences of the individual vector components and are obtained in the basic mathematical processing of the initial measurement results. The date defect is three, and it is eliminated in the adjustment process by fixing the SRPOS coordinates of the permanent station Banja Luka.

The adjustment parameters that were common to each daily solution are presented in Table 5.

***Table 5**. Common parameters of daily adjustments*

Parameter	Value
Total number of vectors	5
Total number of measurements	15
Total number of points	6
Total number of unknowns	18
Date defect	3
Significance level of one-dimensional test	5.0 %
Significance level of multidimensional test	1.0 %
The power of the test	80 %
A priori standard unit of weight	10

The quality of the coordinates of permanent stations obtained by daily solutions was assessed from the point of view of their consistency from day to day. Quality indicators are determined in two ways. The first method involved the calculation of standard deviations of daily solutions from their deviations from the arithmetic mean, and the second method involved the calculation of a unified estimate of standard deviation from standard deviations of daily solutions.

The standard deviations of the horizontal and vertical positions of permanent stations along the axes of the geocentric coordinate system, when broadcast ephemerides were used, are respectively:

$\sigma_{HP} = 428.8 \text{ mm}$

$\sigma_{VP} = 104.0 \text{ mm}.$

Standard deviations of the position of permanent stations, when precise ephemerides are included in the adjustments, are:

$\sigma_{HP} = 2.9 \text{ mm}$

$\sigma_{VP} = 4.9 \text{ mm}.$

The standard deviations of the horizontal and vertical positions of the permanent station along the axes of the local geodetic system are:

- With broadcast ephemerides:

$\sigma_{HP} = 71.1\ mm$

$\sigma_{VP} = 54.2\ mm$

- With precise ephemerides:

$\sigma_{HP} = 2.6\ mm$

$\sigma_{VP} = 4.4\ mm$

The equality of dispersions of horizontal and vertical positions obtained in the two presented ways was tested by Fisher's test with a significance level of 5% and a confidence level of 95%, respectively:

- With broadcast ephemerides:

$$F_{HP} = \frac{428.8^2}{71.1^2} = 36.37 > 2.37 = F_{(0.95,4,\infty)}$$

$$F_{VP} = \frac{104.0^2}{54.2^2} = 3.68 > 2.37 = F_{(0.95,4,\infty)}$$

- With precise ephemerides:

$$F_{HP} = \frac{2.9^2}{2.6^2} = 1.24 < 2.37 = F_{(0.95,4,\infty)}$$

$$F_{VP} = \frac{4.9^2}{4.4^2} = 1.24 < 2.37 = F_{(0.95,4,\infty)}$$

When we look at the testing of the equality of dispersions of horizontal and vertical positions obtained in two ways, it can be concluded that the coordinate accuracy is not consistent with the daily variations of the coordinates of permanent cells when broadcast ephemerides were used in the adjustment.

According to the results of Fisher's test, the estimates of standard deviations obtained from the deviation from the arithmetic mean fully correspond to the estimates of standard deviations of daily solutions obtained by adjustment if precise ephemerides are included in the adjustment. It can be concluded that the accuracy of the coordinates is consistent with daily variations of the coordinates of the permanent stations.

4.3. CALCULATION OF THE DEFINITIVE SOLUTION

To control the concurrence of the coordinates of the network of permanent stations with the official SRPOS coordinates of the permanent stations Banja Luka, Derventa, and Teslić, the network of permanent stations was adjusted as free by the method of least squares.

The date defect of the network was eliminated in the adjustment process by fixing the values of SRPOS coordinates of the permanent station Banja Luka.

During the adjustment of the subject network, before the processing of the vector between the measured points, the merging of the measurement intervals (their joining) was performed for each point individually. Free adjustment of the network was performed with the parameters shown in Table 6.

Table 6. *Free adjustment parameters*

Parameter	Value
Total number of vectors	25
Total number of measurements	75
Total number of points	6
Total number of unknowns	18
Date defect	3
Significance level of one-dimensional test	5.0 %
Significance level of multidimensional test	0.5 %
The power of the test	80 %
A priori standard unit of weight	10

A sketch of the grid after adjustment, with error ellipses, is shown in Figure 3 and Figure 4.

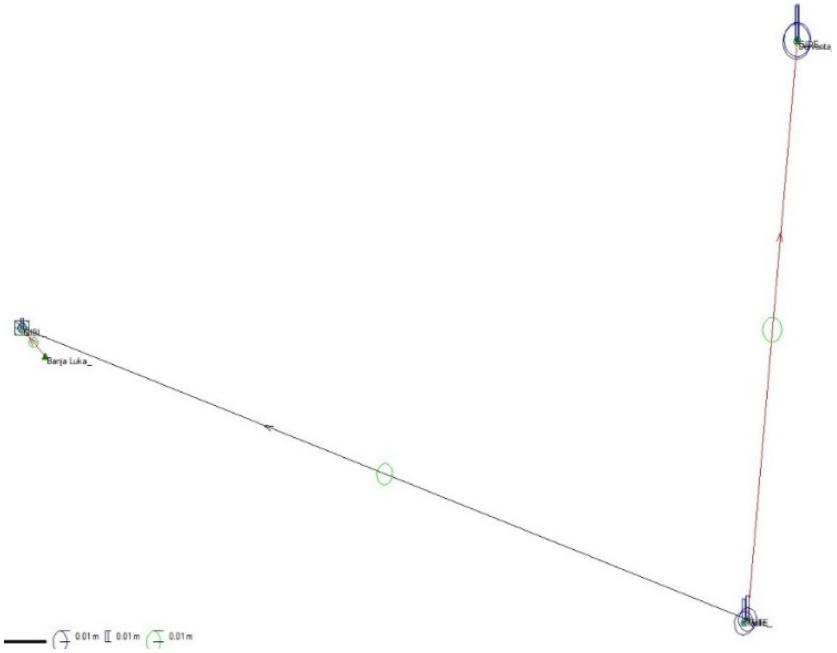

Figure 3. *Sketch of the grid after the adjustment with broadcast ephemerides*

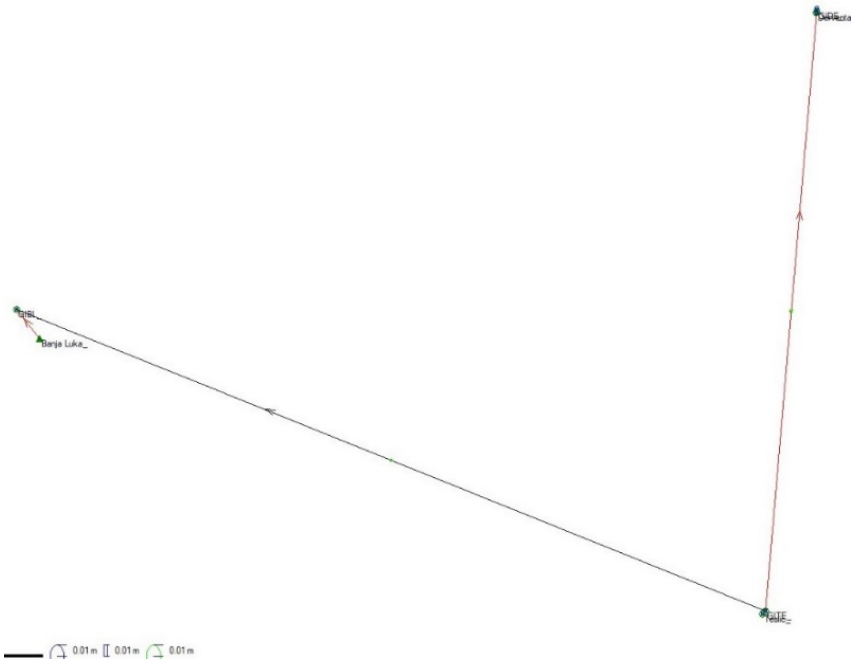

Figure 4. *Sketch of the grid after the adjustment with precise ephemerides*

Table 7 shows the coordinates for permanent stations after the free adjustment in the WGS84 and ETRS89 coordinate system when broadcast and precise ephemerides were used. Table 8 shows standard deviations by coordinate axes and standard position deviations.

Table 7. *Coordinates of stations after free adjustment*

With broadcast ephemerides			With precise ephemerides		
Station	X, Y, Z [m]	E, N, H [m]	Station	X, Y, Z [m]	E, N, H [m]
Banja_Luka	4332148.9575	201159.9311	Banja_Luka	4332148.9575	201159.9311
	1342950.2205	4964698.6641		1342950.2205	4964698.6641
	4469642.6241	214.6830		4469642.6241	214.6830
Derventa	4300617.8555	256135.3335	Derventa	4300617.8599	256135.3361
	1389651.9066	4985032.9840		1389651.9110	4985032.9800
	4485681.2197	215.8773		4485681.2197	215.8811
Teslić	4329889.2047	250593.4652	Teslić	4329889.2064	250593.4679
	1394955.9755	4943403.3392		1394955.9791	4943403.3354
	4456055.2397	270.9216		4456055.2372	270.9218
GIBL	4331278.3938	199615.8870	GIBL	4331278.3978	199615.8848
	1340964.7502	4966795.2555		1340964.7494	4966795.2500
	4471081.6382	221.0718		4471081.6340	221.0714
GITE	4329640.8058	250829.0047	GITE	4329640.8076	250829.0072
	1395112.9350	4943655.7281		1395112.9384	4943655.7246
	4456236.3784	264.0464		4456236.3764	264.0470
GIDE	4300517.3739	256172.4910	GIDE	4300517.3778	256172.4928
	1389653.6563	4985152.4731		1389653.6596	4985152.4699
	4485756.9660	202.1616		4485756.9663	202.1652

Table 8. *Standard deviations obtained by free adjustment and standard position estimates*

With broadcast ephemerides				With precise ephemerides			
Station	σ_X [mm] σ_Y [mm] σ_Z [mm]	σ_E [mm] σ_N [mm] σ_H [mm]	σ_{HP} [mm]	Station	σ_X [mm] σ_Y [mm] σ_Z [mm]	σ_E [mm] σ_N [mm] σ_H [mm]	σ_{HP} [mm]
Banja_Luka	0.0	0.0	0.0	Banja_Luka	0.0	0.0	0.0
	0.0	0.0			0.0	0.0	
	0.0	0.0			0.0	0.0	
Derventa	25.3	12.1	19.9	Derventa	3.3	1.6	2.6
	13.9	15.7			1.8	2.1	
	24.5	32.2			3.2	4.2	
GIBL	6.7	4.0	5.9	Teslić	0.7	0.3	0.5
	4.3	4.4			0.4	0.4	
	7.0	8.8			0.7	0.9	
GIDE	24.6	11.8	19.3	GIBL	3.2	1.5	2.5
	13.5	15.3			1.8	2.0	
	23.8	31.3			3.1	4.1	
GITE	16.6	8.1	13.2	GITE	1.8	0.8	1.4
	9.3	10.4			1.0	1.1	
	16.2	21.2			1.7	2.3	
Teslić	17.1	8.4	13.6	GIDE	1.9	0.9	1.4
	9.5	10.7			1.0	1.2	
	16.6	21.8			1.8	2.3	

5. CONCLUSION

This paper aims to analyse the accuracy of the coordinates of permanent stations using the least-squares method by processing broadcast and precise ephemerides. It is important to note that the figures were not closed during the network formation.

All used permanent stations are located in the area of Banja Luka, Teslić, and Derventa and are located at a spatial distance of approximately 50 km. Static relative positioning is known to be a very precise positioning method that achieves the accuracy of up to 0.1 ppm (0.1 mm / km) in the vertical view and up to 0.4 ppm (0.4 mm / km) in the horizontal view [16]. Due to these baseline lengths, it makes sense to analyse further and quantify the impact of broadcast and precise ephemerides on the newly determined coordinates.

The vertical component accuracy is worse than for the horizontal component, which is the expected situation and fact, which arises from the general design of the GNSS system. In both cases, using broadcast and precise ephemerides, it can be said that the observation time for the three components (north, east, and up) affects the accuracy; as the observation time increases, so does the accuracy. Components such as satellite availability and visibility, ambiguity, and ambiguous GNSS signal paths in short observation times affect the accuracy from time to time.

In the first part of the research, adjustments were conducted by days, in the first case using broadcast and in the second case using precise ephemerides. The value of Fisher's test statistics for 95% confidence is 2.37. When we look at the testing of the equality of dispersions of horizontal and vertical positions obtained in two ways, it can be concluded that the coordinate accuracy is not consistent with the daily variations of coordinates of permanent stations when broadcast ephemerides were used in the adjustment, because their ratio at the horizontal position is 36.37 mm and at the vertical position 3.68 mm, which is greater than the test statistic. The estimates of standard deviations obtained from the deviation from the arithmetic mean fully correspond to the estimates of standard deviations of daily solutions obtained by the adjustment if precise ephemerides are included in the adjustment because their ratio in both horizontal and vertical positions is 1.24 mm. This value is less than the test statistic value of 2.37 mm, so it can be concluded that the coordinate accuracy is consistent with the daily variations of the coordinates of the permanent stations.

We obtained the coordinates of the newly determined permanent stations in the WGS84 system and the ETRS89 system by free adjustment. Standard deviations of the horizontal and vertical position showed much larger deviations when broadcast ephemerides were used in the adjustment. The largest deviation was $\sigma_{HP} = 19.9\ \mathrm{mm}$ and $\sigma_{VP} = 28.35\ \mathrm{mm}$for the permanent station Derventa. When precise ephemerides for the same station were used in the adjustment deviations were $\sigma_{HP} = 2.6\ \mathrm{mm}$ and $\sigma_{VP} = 3.7\ \mathrm{mm}$. The smallest standard deviations of the horizontal and vertical position were obtained for the GIBL permanent station, with broadcast ephemerides $\sigma_{HP} = 5.9\ \mathrm{mm}$ and $\sigma_{VP} = 7.9\ \mathrm{mm}$, and with precise ephemerides $\sigma_{HP} = 0.5\ \mathrm{mm}$ and $\sigma_{VP} = 0.8\ \mathrm{mm}$.

Finally, it can be concluded that the use of precise ephemerides impacts the accuracy of determining the coordinates of newly included stations for baseline lengths exceeding 50 km. Therefore, in practice, when adjustment networks whose span between points exceeds 50 km,

the adjustment procedure should be carried out using the adopted precise ephemerides for a certain observation period. For baseline lengths of 30 to 50 km, precise ephemerides are recommended, and for shorter lengths, adjustment with broadcast ephemerides achieves a satisfactory accuracy.

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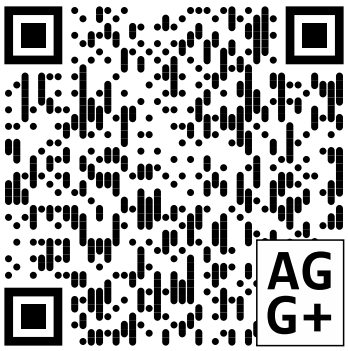
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