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Equations should be typewritten and, with the number, placed in parentheses at the right margin. References to equations should be in the form "Eq. (2)" or simply (2). For equations that cannot be entered in a single line, use the Equation Editor in MS Word. In equations and in the text, *italicize* symbols that are used to represent variables or parameters, including subscripts and superscripts. Only use characters and symbols that are available in the Equation Editor, in the *Symbol font* or in *Times New Roman*.

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EVALUATION OF THE EFFICIENCY OF UNIVERSITY CLASSROOMS WITH THE FUZZY LOGIC

UDC 727.1.054:510.64

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Abstract. *In this paper, a fuzzy logic algorithm was created in order to grade and classify the design efficiencies of classrooms selected from Süleyman Demirel University. The existing classrooms were examined on site and the orientation of the classrooms, the number of people, the classroom area and the window area of the classroom were calculated. As the input variables, the orientation of the classrooms, the number of people, the area per-capita and the ratio of window area to the classroom area were modelled. The design efficiencies of the classrooms as the output variables were obtained by the rules formed among the input variables. In the model, fuzzy model as the Mamdani type and "weighted average" method as the clarification method were used. For fuzzy logic model, 180 fuzzy rules have been formed in the type of IF, which are associated with the facade of the classroom, the number of people, the area per capita and the ratio of the window area of the classrooms to the design efficiency of the classroom. Design efficiency of the classrooms were created; the design efficiency classes and the average design efficiencies of classrooms in faculties were compared and concluded according to faculties. The efficiency of the classrooms, which is the main place of the educational buildings, depends on the decisions taken during the design phase. With the model created in this paper, more efficient designs will be provided by having knowledge about the design efficiency through making use of the decision-making process of the classrooms during the design process.*

Key words: *Fuzzy logic, Decision making, Classroom, Design efficiency.*

1. INTRODUCTİON

Education is an important instrument of social and economic development. Education is a process that begins with the birth of the individual and continues throughout his life. Most of this process takes place in educational structures. Educational structures are the places that will form the basis of the social structure, and thus that should be specially

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designed for the individuals who will give direction to the future of the country (Bal and Ekinci, 2012). In addition to increasing the quality of education and educators in order to be among the modern and information societies, it is very important to organize educational environments, which is to have educational structures with the right architectural features (Katırcı, 2016).

According to the educators, learning may occur in a suitable environment in terms of physical, social and psychological aspects. For effective education, this environment needs to be organized in a way that is appropriate to the teaching and learning activities. This necessitates organizing and directing the various interaction dimensions between the environment and the individual according to the educational objectives (Küçükoğlu and Özerbaş, 2004).

Lack of safe educational spaces suitable for learning and education can adversely affect students' achievement, motivation, learning performance and attendance to school. Therefore, the spatial quality of school buildings is an important issue to be emphasized to determine the impact of the physical conditions of the school on student achievement and school attendance (Şensoy 2018).

Education structures are the structures where the physical, mental and spiritual development of individuals occurs. When education structures provide suitable environments, an appropriate development takes place. The spaces in the educational structures enable individuals to learn, think, question, research, produce, explore and socialize. These opportunities affect education positively and contribute to social and economic development.

The education program and the philosophy of education are related to the educational environment. Therefore, architectural design is very important in educational buildings. For effective training, the design of the classrooms where education is taking place should be designed appropriately. Variations in classrooms affect education positively or negatively. A good classroom environment increases the learning rate by motivating individuals. A poor classroom area where lighting and ventilation are insufficient affects the individuals negatively.

As a result, many recent studies show that the physical quality of the building is correlated with student achievement, learning performance and motivation (Al, 2014).

The education and training process is usually carried out in classrooms, which are important components of educational structures. The realization of the educational philosophy and training program is directly related to the design of the classrooms. Designing the classrooms in accordance with the right architectural properties plays an important role in the success of individuals in the process of learning and teaching.

In this paper, classrooms in Süleyman Demirel University were examined and the design efficiencies were evaluated with fuzzy logic method.

2. Fuzzy Sets Theory And Fuzzy Logİc

In classical logic, there are “right” and “wrong” or “1” and “0”. In other words, an element is either a member of a set or not, there are no partial truths. But in real life it is not possible to define the propositions as completely true or completely wrong. In these cases, classical logic remain insufficient. Where classical logic is not sufficient, there is a need for fuzzy logic. Fuzzy logic, unlike classical logic, mimics human logic, and can perform operations in approximate and uncertain situations. Contrary to classical logic, in fuzzy logic, an element can be the element of more than one set.

2.1. Fuzzy Set Theory

Fuzzy sets are sets of inadequately defined objects without sufficient criteria for membership. Such communities have undefined boundaries. Such that, it is impossible to define whether these objects in the community belong to the community (Öz, 2007).

The Fuzzy Set Theory has been developed to express and solve problems that do not have clear boundaries. The most important feature of the fuzzy set theory is to process ambiguities by mimicking human logic. The fuzzy set theory aims to make the right decision with incomplete and indefinite information.

Fuzzy inference systems are systems formed by fuzzy If rules. The fuzzy inference system consists of the priori and posteriori parts. The priori part contains the input variables and the logical relations between them, and the posteriori part contains the result variables that arise depending on these input variables. In general, fuzzy rules are created as follows:

Rule 1: If x = a1 and y = b1 and z = c1, then t=m1

Rule 2: If x = a2 and y = b2 and z = c2, then t=m2

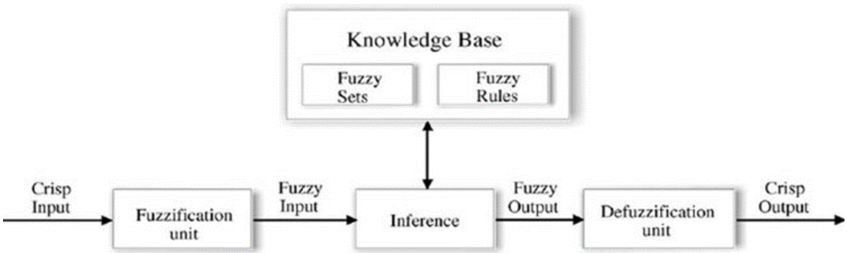


Fig. 1 The structure of a typical fuzzy logic system (Konstandinidoua et al., 2006).

Fuzzification. It is the process of decomposing a system input variables into one or more fuzzy sets, thus producing a number of fuzzy perceptions of the input.

Fuzzy Inference. After the inputs have been decomposed into fuzzy sets, a set of fuzzy if-then-else rules is used to process the inputs and produce a fuzzy output. Each rule consists of a condition and an action where the condition is interpreted from the input fuzzy set and the output is determined on the output fuzzy set. In other words fuzzy inference is a method that interprets the values in the input vector and, based on some set of rules, assigns values to the output vector.

Defuzzification. It is the process of weighting and averaging the outputs from all the individual fuzzy rules into one single output decision or signal. The output signal eventually exiting the system is a precise, defuzzified, crisp value (Konstandinidoua et al., 2006).

2.1.1. *Membership Function*

In fuzzy logic, the probability that an element belongs to the corresponding set takes values from 0 to 1. These values are expressed with a continuous membership function. The value that an element gets from the membership function is called membership degree. The membership functions determine the degree to which an element belongs to a set.

Three ways can be followed to create the membership function. These are:

1. To discuss with the people who have knowledge about the concept and to make the necessary arrangements later,
2. To utilize the data,
3. To determine with the help of the feedback from the system performance (Mayuk, 2015).

2.2. Fuzzy Logic

Fuzzy Logic was first introduced in 1965 by L.A. Zadeh. Zadeh has shown that many concepts can be better determined verbally than traditional mathematics, and that fuzzy logic and its expressions in fuzzy sets constitute a better model of real life.

On the basis of fuzzy logic, there is uncertainty. In other words, in fuzzy logic, a thinking is used that includes partial values, as well as definite values. In fuzzy logic, everything is indicated by a certain degree in the range of [0,1]. In fuzzy logic, information is in the form of verbal expressions such as very large, large, medium, small and very small. Fuzzy inference is made by the rules formed between verbal expressions. Fuzzy logic solves problems by using verbal expressions that people use in their daily life. The use of verbal expressions is a characteristic of fuzzy logic that distinguishes it from other methods.

Fuzzy Logic is one of the methods that find the most industrial application area among artificial intelligence methods and it has been used in many different fields. Some areas of application can be listed as follows: electrical appliances, auto electronics, brake systems, electronic control systems, fault monitoring, decision making, process planning, traffic signal optimization (at junction and main arteries), database inquiry, robotics, image processing and genetics algorithms.

2.3. Fuzzy Decision Making

Decision making is the process of choosing the most appropriate of all available alternatives. This process can involve very complex situations, and this situation becomes fuzzy because it cannot be expressed mathematically clearly.

In the first study on fuzzy decision making; Bellman and Zadeh (1970) proposed a fuzzy model that expresses appropriate objectives and constraints relative to fuzzy sets and determines the decision by an appropriate combination of these fuzzy sets (Özdemir Dağ, 2011).

The main objective of fuzzy logic decision-making methods can be explained as designing mechanisms that will help decision makers to make correct decisions in line with incomplete and inaccurate information (Türkbey, 2003).

It is often difficult for a decision-maker to assign a precise performance rating to an alternative for the attributes under consideration. The merit of using a fuzzy approach is to assign the relative importance of attributes using fuzzy numbers instead of precise numbers. (Yang ve Hung, 2007).

Many decision-making and problem-solving tasks are too complex to be understood quantitatively, however, people succeed by using knowledge that is imprecise rather than precise. Fuzzy set theory resembles human reasoning in its use of approximate information and uncertainty to generate decisions (Kahraman et al, 2003a)

The proposed adaptive fuzzy system with learning ability has been shown to mimic the decision-making of transport support managers and show a level of expertise comparable to their level of expertise (Pamučar et al., 2018).

Since decisions are made by man and human thought approaches more accurately with precise logic than with clear logic, Vilela et al (2019) research study has developed a methodology that integrates human logic into VoI assessment, specifically for problems in the oil and gas industry; Integration of uncertain thinking and terminology into VoI is done using FIS.

Sremac et al (2018) have developed an expert model for determining the economic order quantity. The model was developed using hybrid method-ANFIS of artificial intelligence adaptive neuro-fuzzy inference systems. The validity analysis of the model results was performed on the basis of the mean relative error and showed that the model imitated the expert work in the observed company with great accuracy.

Stojčić et al (2019) have created a model based on the principles of fuzzy logic and artificial neural networks that will fulfill the task of predicting the maximum energy of photovoltaic modules as accurately as possible. The model represents a simple solution that requires the value of the teoutput variable for the given values of the energy of the solar radiation and the average temperature of the module. Model training was performed based on the data obtained by the simulation, so as to determine whether the values obtained by estimation were compared with the actual measured values.

3. CREATİON OF THE MODEL AND RESULTS

The physical space quality of educational structures depends on the decisions taken during the design phase. In this paper, the design efficiency of the classrooms at Süleyman Demirel University was evaluated. Classrooms were examined on site and data were collected. The existing classrooms were examined on site and the orientation of the classrooms, the number of people, the classroom area and the window area of the classroom were calculated. As the input variables, the orientation of the classrooms, the number of people, the area per-capita and the ratio of window area to the classroom area were modelled. The design efficiencies of the classrooms as the output variables were obtained by the rules formed among the input variables. In the model, fuzzy model as the Mamdani type and "weighted average" method as the clarification method were used. For the fuzzy logic model, 180 fuzzy rules have been formed in the type of IF, which are associated with the facade of the classroom, the number of people, the area per capita and the ratio of the window area of the classrooms to the design efficiency of the classroom.

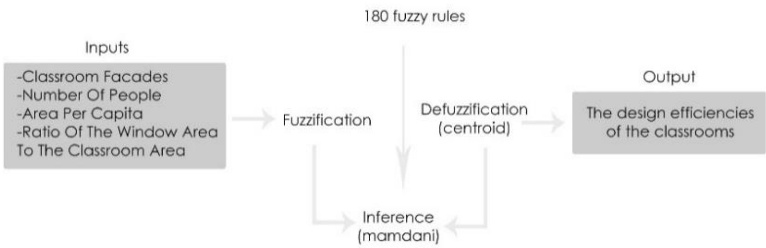


Fig. 2 The structure of fuzzy logic system

3.1.Inputs Selected In Fuzzy Logic Model

In order to evaluate the design efficiency of classrooms in Süleyman Demirel University in MATLAB2017a SDU-student- version, a mamdani-type fuzzy inference systems was used. Four inputs (parameters) were selected for this application:

3.1.1. *Classroom Facades*

The orientation of the building depends on the properties of the land it is located on. Orientation of the building according to factors such as climatic conditions, sun rays, dominant wind direction, slope, elevation, road condition and landscape provides the maximum level of performance from the building as well as the comfort of the users.

The main aim in the direction of the building is to increase the energy efficiency through optimizing climate effects in providing comfort conditions. Therefore, periodically, it is necessary:

- To protect from the heating effect of solar radiation (shading) and at the same time to benefit from the cooling effect of the wind during the hottest season (summer: during which no heating is wanted),
- To benefit from the heating effect of solar radiation and to protect from the cooling effect of the wind (wind breaker) during the least hot season (winter: during which heating is wanted) (Kısa, 2009).

When orienting the classrooms, it is useful to provide the students with a comfortable and health-friendly environment and to use the existing factors in a way to support this aim. Space design can affect students directly or indirectly in classroom and school level (Zorlu and İsmailoğlu, 2018).

It is important that the spaces in the educational structures are correctly oriented for the comfort of the users. The classrooms in which the education and training takes place in the educational buildings should be designed in the appropriate orientation according to the climate zone. According to the Educational Structures Minimum Design Standards Guide (2015), for the classrooms:

- The best advantageous orientation is the south, southeast and southwest directions.
- Middle advantageous orientation is east and west directions.
- The least advantageous orientation is north, northeast and northwest directions.

Four membership functions were created for the orientation of the classrooms. In evaluating the orientation of the classrooms; the south, southeast and southwest directions were most advantageous, the east and west directions were middle advantageous, and the north, northeast and northwest directions were considered to be the least advantageous. The orientation of the classrooms is respectively graded as 4, 3 and 2 while the dark classes without orientation are graded as 1.

Subsets (MFs) for orientation of classrooms: “dark” trimf [0 1 2], “north-northEast-northWest” trimf [1 2 3], “west-east” trimf [2 3 4] and “south-southEast-southWest” trimf [3 4 5] are given in Figure 3. The situation between this input and the output is as follows: '1' is the least advantageous, '2' is less advantageous, '3' is the middle advantage, while '4' shows the most advantageous direction.

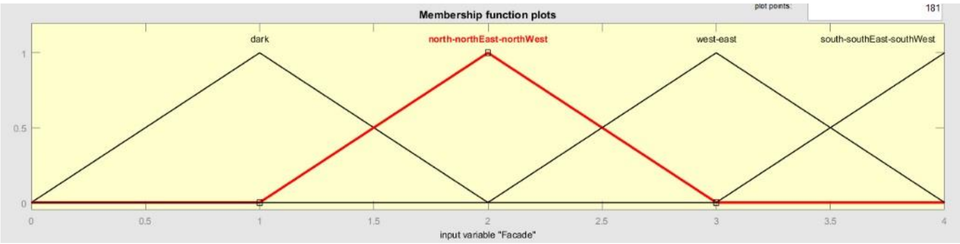


Fig. 3 Subsets and membership functions defined in the model for the orientation of classrooms.

3.1.2. *Number of People*

Educators stated that the maximum number of students acceptable in a classroom would be 36; the normal number can be 30, but the best is the acceptance of 24 students per classroom. Currently, according to the standards of the Ministry of National Education, considering the conditions of our country, 40 students per class as an optimum (Çetinkaya, 2016).

In this paper, the number of people in the classroom was calculated according to the table and chair in the classroom. Five membership functions were created for the number of people in the classrooms. The number of people in the classrooms was considered to be very low, low, middle, high and very high.

Sub-sets (MFs) for the number of people in the classrooms: “veryLow” trimf [0 24 30], “low” trimf [24 30 36], “middle” trimf [30 36 40], “high” trimf [36 40 60] and “veryHigh” trimf [40 60 200], are given in Figure 4. The situation between this input and output is as follows: the increase in the number of people has been evaluated as a disadvantage.

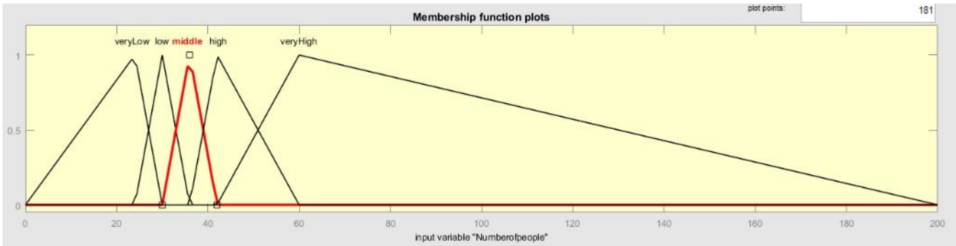


Fig. 4 The subsets and membership functions defined in the model for the number of people in the classrooms.

3.1.3. *Area per Capita*

It is thought that knowing the area per capita in the buildings is proportional to the capacity information of that structure (Erkan et al., 2017). World standards indicate that the classroom space per pupil is minimum, 1.5 m^2 for a student, normally 2 m^2, and 2.5 m^2 for best (Çetinkaya, 2016). Three membership functions were created for the area per capita in classrooms. The area per capita in the classrooms was evaluated as low, medium and high.

Sub-sets (MFs) for area per capita of classrooms: “low” trimf [0 1.5 2], “middle” trimf [1.5 2 2.5] and “high” trimf [2 2.5 6] is given in Figure 5. The situation between this input and the output is as follows: the closer is the area per capita to the best, the more advantageous it is.

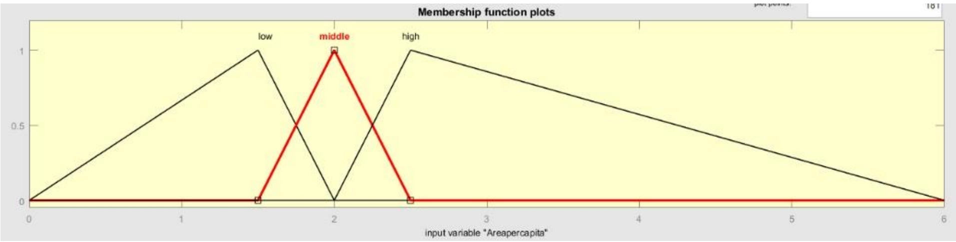


Fig. 5 Sub-sets and membership functions defined in the model for area per capita of classrooms.

3.1.4. *Ratio of the Window Area to the Classroom Area*

Windows are designed to visually link the buildings with the environment and to ventilate and illuminate the spaces. The daylight, which will be taken from the windows during the day, is important for both the physical and mental health of the users of the educational structures. Therefore, optimal illumination levels for classrooms should be determined. Due to the high share of heat loss in windows, their design and size should be well designed.

According to the Educational Structures Minimum Design Standards Guide (2015), the ratio of classroom windows to the floor area should be at least 25%. This ratio can be increased up to 50% depending on the characteristics of the climate zone. Three membership functions were created for the ratio of the window area in the classrooms to the classroom area. The area per capita in the classrooms was evaluated as low, medium and high.

The sub-sets (MF's) for the Ratio of Window Area of Classrooms to the Classroom Area: "low" trimf [0 0 25], "middle" trimf [0 25 50] and "high" trimf [25 50 50] is given in Figure 6. The situation between this input and the output is as follows: the closer is the area per capita to the best, the more advantageous it is.

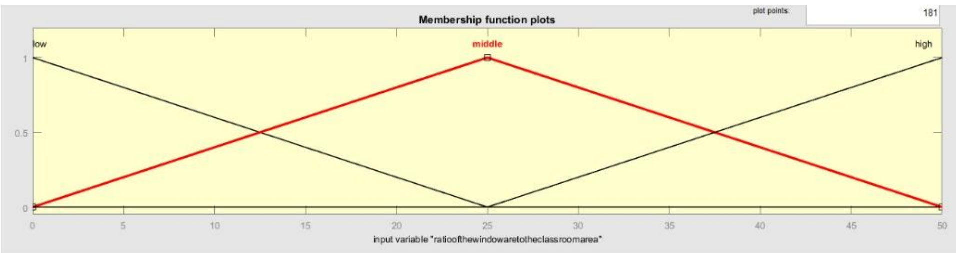


Fig. 6 The sub-sets and membership functions defined in the model for the ratio of the Window Area of Classrooms to the Classroom Area.

3.2. Output Created in the Fuzzy Logic Model

In Mamdani type Fis, five membership functions were created for efficiency values. The number of people in classrooms was evaluated as very low, low, middle, high and very high.

Sub-sets (MFs) for the design efficiency of the classrooms: "veryLow" trimf [0 0 0.25], "low" trimf [0 0.25 0.5], "middle" trimf [0.25 0.5 0.75], "high" trimf [0.5 0.75 1] and "veryHigh" trimf [0.75 1 1] is given in Figure 7.

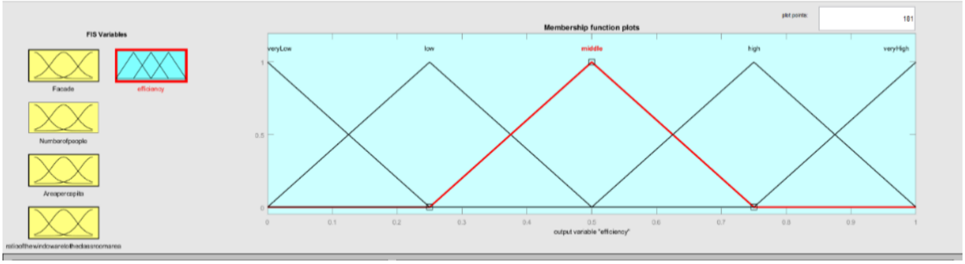
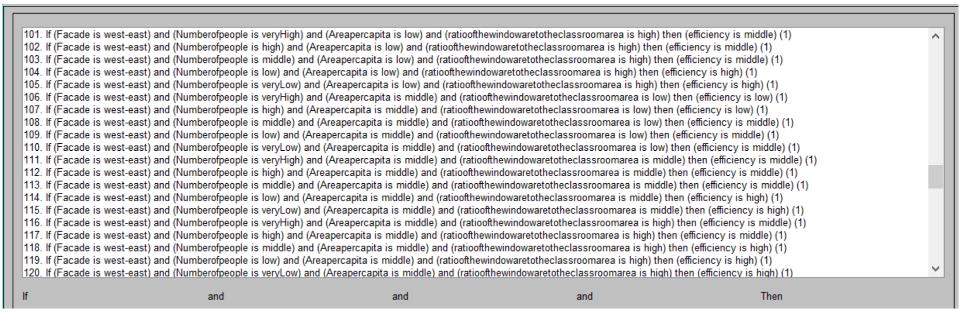


Fig. 7 Subsets and membership functions defined in the model for design efficiency of classrooms.

The fuzzy rule base includes the IF, THEN type rules written between logical input and output variables (Şen, 1999; Tayfur, 2003; Kazanasmaz, 2010). In this paper, 180 fuzzy rules have been created, which are related to the efficiency of the classroom, the number of people, the area per capita, and the ratio of the window area of the classroom to the classroom area. 20 of these Rules are shown in Figure 8.


101. If (Facade is west-east) and (Numberofpeople is veryHigh) and (Areapercapita is low) and (ratioofthewindowaretotheclassroomarea is high) then (efficiency is middle) (1)
102. If (Facade is west-east) and (Numberofpeople is high) and (Areapercapita is low) and (ratioofthewindowaretotheclassroomarea is high) then (efficiency is middle) (1)
103. If (Facade is west-east) and (Numberofpeople is middle) and (Areapercapita is low) and (ratioofthewindowaretotheclassroomarea is high) then (efficiency is middle) (1)
104. If (Facade is west-east) and (Numberofpeople is low) and (Areapercapita is low) and (ratioofthewindowaretotheclassroomarea is high) then (efficiency is high) (1)
105. If (Facade is west-east) and (Numberofpeople is veryLow) and (Areapercapita is low) and (ratioofthewindowaretotheclassroomarea is high) then (efficiency is high) (1)
106. If (Facade is west-east) and (Numberofpeople is veryHigh) and (Areapercapita is middle) and (ratioofthewindowaretotheclassroomarea is low) then (efficiency is low) (1)
107. If (Facade is west-east) and (Numberofpeople is high) and (Areapercapita is middle) and (ratioofthewindowaretotheclassroomarea is low) then (efficiency is low) (1)
108. If (Facade is west-east) and (Numberofpeople is middle) and (Areapercapita is middle) and (ratioofthewindowaretotheclassroomarea is low) then (efficiency is middle) (1)
109. If (Facade is west-east) and (Numberofpeople is low) and (Areapercapita is middle) and (ratioofthewindowaretotheclassroomarea is low) then (efficiency is middle) (1)
110. If (Facade is west-east) and (Numberofpeople is veryLow) and (Areapercapita is middle) and (ratioofthewindowaretotheclassroomarea is low) then (efficiency is middle) (1)
111. If (Facade is west-east) and (Numberofpeople is veryHigh) and (Areapercapita is middle) and (ratioofthewindowaretotheclassroomarea is middle) then (efficiency is middle) (1)
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114. If (Facade is west-east) and (Numberofpeople is low) and (Areapercapita is middle) and (ratioofthewindowaretotheclassroomarea is middle) then (efficiency is high) (1)
115. If (Facade is west-east) and (Numberofpeople is veryLow) and (Areapercapita is middle) and (ratioofthewindowaretotheclassroomarea is middle) then (efficiency is high) (1)
116. If (Facade is west-east) and (Numberofpeople is veryHigh) and (Areapercapita is middle) and (ratioofthewindowaretotheclassroomarea is high) then (efficiency is middle) (1)
117. If (Facade is west-east) and (Numberofpeople is high) and (Areapercapita is middle) and (ratioofthewindowaretotheclassroomarea is high) then (efficiency is middle) (1)
118. If (Facade is west-east) and (Numberofpeople is middle) and (Areapercapita is middle) and (ratioofthewindowaretotheclassroomarea is high) then (efficiency is high) (1)
119. If (Facade is west-east) and (Numberofpeople is low) and (Areapercapita is middle) and (ratioofthewindowaretotheclassroomarea is high) then (efficiency is high) (1)
120. If (Facade is west-east) and (Numberofpeople is veryLow) and (Areapercapita is middle) and (ratioofthewindowaretotheclassroomarea is high) then (efficiency is high) (1)

If and and and Then

Fig. 8 Rules created in the model for the design efficiency of classrooms

The part that starts with (if) and goes until (then) is based on the direction of the classroom, the number of people, the area per capita, and the ratio of the window area of the classroom to the classroom area. The part after (then) forms a situation on the efficiency value.

The fuzzy inference engine generates fuzzy output from a given input set, taking all the rules in the fuzzy rule base into account. Clarification converts the fuzzy outputs generated by the fuzzy inference engine into a single number (Şen, 1999; Tayfur, 2003; Kazanasmaz, 2010). There are clarification methods such as Centroid, bisector, mom, lom, som etc. In this paper, centroid was used as the clarification method.

The fuzzy logic algorithm was applied in order to grade and classify the design efficiencies of the selected classrooms.

The efficiency values obtained by calculating the direction, number of people, the area per capita, and the ratio of the window area of classrooms to the classroom area of 93 classrooms selected from the Süleyman Demirel University were shown in Table 1,2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, and 13.

Although the number of classrooms at the Faculty of Sport Sciences is normal, the classrooms are in a low efficiency class due to the darkness of the classrooms and the low ratio of the window area to the classrooms.

Table 1 Efficiency Values Estimated by Fuzzy Model for Faculty of Sport Sciences

Classrooms	Orientation	Number of people	Area per capita	Ratio of window area to classroom area	Efficiency
Z-201	1	20	1,47	5,31	0.25
Z-202	1	22	1,30	5,44	0.25
B-11	1	40	2,21	14,38	0.34
B-12	1	37	1,88	15,22	0.24
B-13	1	42	2,12	12,10	0.30

The classrooms at the Faculty of Technology and the Faculty of Technical Education are in a low efficiency class due to the low advantage of the facade, the high number of people and the low per capita area.

Table 2 Efficiency Values Estimated by Fuzzy Model for Faculty of Technology

Classrooms	Orientation	Number of people	Area per capita	Ratio of window area to classroom area	Efficiency
E14-Z-12	2	90	1,01	18,01	0.24
E14-Z-13	2	77	1,18	18,15	0.24
E14-Z-14	2	62	1,46	18,18	0.24

Table 3 Efficiency Values Estimated by Fuzzy Model for Faculty of Technical Education

Classrooms	Orientation	Number of people	Area per capita	Ratio of window area to classroom area	Efficiency
E12-Z-10	2	41	1,65	18,22	0.29
E12-Z-11	2	48	1,41	18,20	0.24
E12-Z-12	2	62	1,46	17,98	0.24
E12-Z-14	2	81	1,12	17,97	0.24

Although the classrooms in the Faculty of Law are most suitable as facades, they are in a low efficiency class due to the high number of people, the low per capita area and the low ratio of the window area to the classroom area.

Table 4 Efficiency Values Estimated by Fuzzy Model for Faculty of Law

Classrooms	Orientation	Number of People	Area per capita	Ratio of window area to classroom area	Efficiency
Z-11	4	150	0,99	11,56	0.25
Z-12	4	80	0,79	12,42	0.25

Classrooms at the Faculty of Architecture are in the middle efficiency class due to the fact that the area per person is suitable, the facades are less advantageous and the number of people is high.

Table 5 Efficiency Values Estimated by Fuzzy Model for Faculty of Architecture

Classrooms	Orientation	Number of people	Area per capita	Ratio of window area to classroom area	Efficiency
Z-10	2	66	2,07	17,79	0.30
Z-11	2	55	2,49	18,02	0.42
Z-12	2	53	2,58	18,23	0.42
K-10	2	43	2,71	17,79	0.42
K-11	2	40	2,87	17,38	0.41
K-12	2	54	2,16	17,77	0.34
K-13	2	38	1,81	17,90	0.39

Although some of the classrooms at the Faculty of Education and Faculty of Religious Studies and Faculty of Pharmacy are most suitable as facades, the number of people is high, the per capita area is low and the window area is in low efficiency class due to the low ratio of the classroom area.

Table 6 Efficiency Values Estimated by Fuzzy Model for Faculty of Education

Classrooms	Orientation	Number of people	Area per capita	Ratio of window area to classroom area	Efficiency
Z-5	2	88	0,86	9,48	0.20
Z-6	2	80	0,96	9,32	0.20
Z-12	4	80	0,95	9,38	0.25
Z-13	4	90	0,84	9,42	0.25
Z-14	4	81	0,93	9,52	0.25

Table 7 Efficiency Values Estimated by Fuzzy Model for Faculty of Religious Studies and Faculty of Pharmacy

Classrooms	Orientation	Number of people	Area per capita	Ratio of window area to classroom area	Efficiency
Z-38	2	64	1,18	10,47	0.21
Z-39	2	61	1,24	10,48	0.21
Z-40	2	64	1,22	10,14	0.20
Z-41	2	64	1,12	10,97	0.21
Z-42	2	72	1,09	10,05	0.20
Z-48	4	64	1,18	10,44	0.25
Z-49	4	72	1,17	9,40	0.25

Although some of the classrooms at the Faculty of Engineering and the Faculty of Economics and Administrative Sciences are most suitable as facades, they are in a low efficiency class due to the high number of people and the low per capita area.

Table 8 Efficiency Values Estimated by Fuzzy Model for Faculty of Economics and Administrative Sciences

Classrooms	Orientation	Number of people	Area per capita	Ratio of window area to classroom area	Efficiency
A/K2-47	4	70	1,20	14,12	0.25
A/K2-51	4	100	1,18	9,99	0.25
A/K2-62	2	100	1,15	10,32	0.21
A/K2-64	2	70	1,20	14,24	0.23
A/K2-65	2	70	1,23	13,79	0.22
A/K2-69	2	90	1,28	10,21	0.20
A/K2-76	4	120	1,22	15,89	0.25
A/K2-77	4	60	1,19	16,53	0.25
A/K2-74	4	60	1,26	15,78	0.25
A/K2-84	2	60	1,28	15,33	0.23
A/K2-89	2	30	1,19	16,55	0.41

Table 9 Efficiency Values Estimated by Fuzzy Model for Faculty of Engineering

Classrooms	Orientation	Number of people	Area per capita	Ratio of window area to classroom area	Efficiency
E1-Z-13	2	90	1,01	18,34	0.24
E1-K1-11	2	62	1,12	18,06	0.24
E1-K1-13	2	81	1,15	17,90	0.24
E1-K1-14	2	90	1,03	17,98	0.24
E4-K1-10	2	100	0,91	18,03	0.24
E4-K1-11	2	90	1,03	17,89	0.24
E6-Z-15	2	64	1,01	10,94	0.21
E7-K1-13	2	70	1,33	18,16	0.24
E8-Z-5	4	66	1,48	16,80	0.25
E8-Z-6	4	90	1,10	16,31	0.25
E8-Z-7	4	88	1,12	16,67	0.25
E9-Z-10	2	60	1,13	18,18	0.24
E9-Z-11	2	70	0,97	18,25	0.24
E9-Z-12	2	80	1,14	18,05	0.24
E9-Z-14	2	90	1,01	18,21	0.24
E9-K1-11	2	56	1,24	18,01	0.24
E9-K1-12	2	76	0,90	18,05	0.24
E9-K1-13	2	90	1,03	17,73	0.24
E10-K1-13/A	4	35	1,21	11,33	0.37
E10-K1-13/B	4	38	1,21	10,45	0.36
E10-K1-8	2	74	1,34	7,18	0.18
E11-Z-1/3	4	78	1,26	11,24	0.25
E11-Z-1/4	4	78	1,27	11,27	0.25
E13-Z-7	2	63	0,91	13,00	0.22
E13-Z-8	2	49	1,18	12,90	0.22

Half of the classrooms at the Faculty of Medicine and Faculty of Health Sciences are in a low efficiency class due to the fact that they are dark, the number of people is high and the area per person is low.

Table 10 Efficiency Values Estimated by Fuzzy Model for Faculty of Medicine and Faculty of Health Sciences

Classrooms	Orientation	Number of people	Area per capita	Ratio of window area to classroom area	Efficiency
A-B23	2	32	1,39	18,79	0.41
A-B24	2	110	0,87	17,60	0.24
A-B25	3	132	0,88	16,96	0.23
A-B01	3	74	1,29	17,46	0.24
A-B19	1	25	1,70	0,0	0.25
A-B20	1	65	1,70	2,0	0.13
B-119	1	182	0,92	0,0	0.11
B-120	1	182	0,91	0,0	0.11

Although the classrooms of the Faculty of Fine Arts and the Faculty of Communication show different differences, they are on average in the medium productivity class.

Table 11 Efficiency values Estimated by fuzzy model for Faculty of Fine Arts and Faculty of Communication

Classrooms	Orientation	Number of people	Area per capita	Ratio of window area to classroom area	Efficiency
Z-30	3	13	5,63	12,25	0.75
Z-38	3	14	4,35	11,42	0.75
Z-24	1	17	2,92	3,28	0.54
Z-25	1	12	4,15	3,27	0.55
Z-16	4	16	4,53	11,56	0.78
Blue Class	2	72	1,03	13,23	0.22
Z-29	2	70	1,03	20,35	0.24

The classrooms in the Faculty of Dentistry are in a low efficiency class due to the darkness of the classrooms, the high number of people, the low per capita area and the low ratio of the window area to the classroom area.

Table 12 Efficiency Values Estimated by Fuzzy Model for Faculty of Dentistry

Classrooms	Orientation	Number of people	Area per capita	Ratio of window area to classroom area	Efficiency
B-ZO2	1	100	1,78	0	0.09
B-ZO6	1	100	1,78	0	0.09

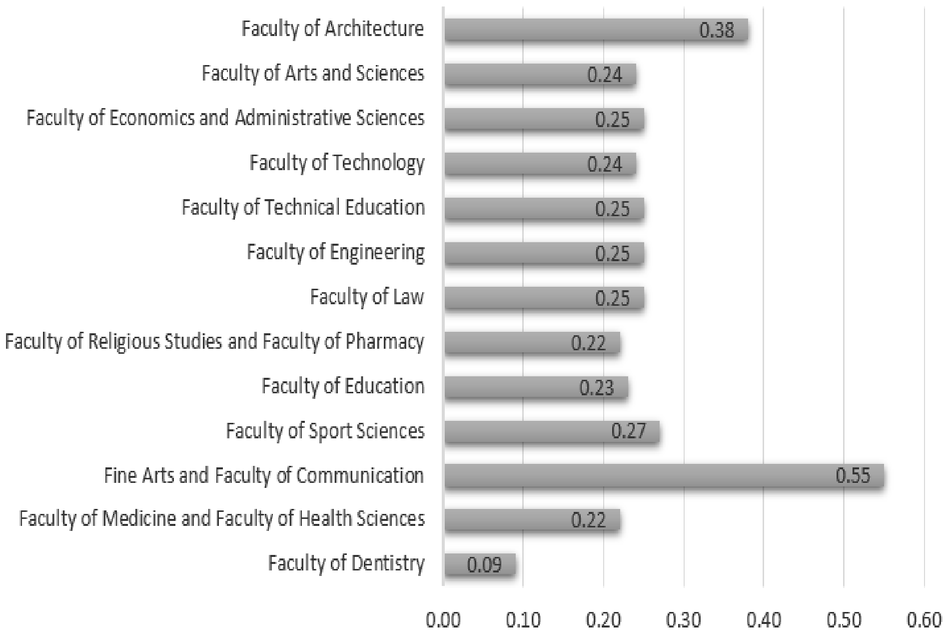
Some of the classrooms at the Faculty of Arts and Sciences are in the lower efficiency class due to the fact that some of them are on the middle and some have less advantageous fronts, the number of people is high and the area per person is low.

Table 13 Efficiency Values Estimated by Fuzzy Model for Faculty of Arts and Sciences

Classrooms	Orientation	Number of people	Area per capita	Ratio of window area to classroom area	Efficiency
Z-20	2	62	0,98	23,83	0.25
Z-44	2	40	1,05	24,99	0.25
Z-63	3	48	0,90	19,74	0.24
Z-65	3	48	0,93	19,14	0.24
Z-108	3	64	0,93	19,01	0.24
Z-109	3	85	0,90	18,52	0.24

The efficiency values obtained as a result of the model were collected in 5 main groups. Those with an efficiency value less than 0.125 forms a very low efficiency class, those between 0,125 and 0,375 forms low efficiency class, those between 0,375 and 0,625 forms middle efficiency class, those between 0,625 and 0,875 forms high efficiency class and those above 0,875 forms a very high efficiency class. The design efficiency of the classrooms is between 0,375 and 0,625.

Of the 92 samples, 4 are in the very low-efficiency class, 76 in the low-efficiency class, 9 in the middle-efficiency class and 3 in the high-efficiency class. There are no examples in the very high efficiency class.



Graphic 1 Distribution of average efficiency of classrooms in faculties.

(a) (b) (c) (d)

Fig. 9 Photos of the classrooms (a) Photos of the B-Z02 classroom of the Faculty of Dentistry. Efficiency value= 0.09 (b) Photos of the Z-16 classroom of the Fine Arts and Faculty of Communication. Efficiency value= 0.78 (c) Photos of the A/K2-51 classroom of the Faculty of Economics and Administrative Sciences. Efficiency value= 0.25 (d) Photos of the K-10 classroom of the Faculty of Architecture. Efficiency value= 0.42

When the average efficiency of the classrooms in the faculties is examined, the best efficiency is in the Fine Arts and Faculty of Communication. The worst efficiency is in the Faculty of Dentistry. The presence of dark classrooms at the Faculty of Sport Sciences, Faculty of Health Sciences led to low efficiency values. The high number of people in the classrooms and the low per capita area caused the efficiency values of the classrooms to be low.

4. Discussion and Conclusions

In this paper, a fuzzy logic algorithm was formed in order to grade and classify the design efficiencies of the classrooms which are the main spaces of the educational buildings. The model was constructed by using the parameters of the orientation of the classrooms, the number of people, the area per capita and the ratio of the window area of classrooms to the classroom area. As a result of evaluations and comparisons of existing classrooms, a design efficiency was established.

Education is an important tool in the progress and economic development of a society. The design of the educational structures can affect the users positively and negatively. Therefore, classrooms, which are the main spaces of educational buildings, should be well designed. This model enables more efficient designs to be created by using classrooms in the decision-making process during the design process and by learning about the design efficiency.

The model is open to the addition of new parameters and rules, and constitutes an analytical infrastructure for making decisions in the design process of educational structures. In addition, the development of the model allows it to be used not only in educational structures but in similar approaches for all building groups.

The paper can be used in the decision-making stage of the design of educational structures. Feedback can be obtained as a result of evaluations and comparisons of existing classrooms. This leads to the development of better designs and generations of solutions. For example, it may decide to improve the renovation, improvement of classrooms, and generate ideas about how the existing classrooms should adapt to the most current standards in terms of technological developments and change of educational curricula.

The paper was conducted with 4 input variables. However, it is open to the addition of new parameters and rules according to the course type and geographical characteristics of the classroom.

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PROCENA EFIKASNOSTI UNIVERZITETSKIH UČIONICA KORIŠĆENJEM FAZI LOGIKE

U ovom radu, stvoren je algoritam fazi logike da bi se ocenila i klasifikovala efikasnost projektovanja odabranih učionica sa Univerziteta Sulejman Demirel. Postojeće učionice ispitane su na licu mesta i izračunata je orijentacija učionica, broj ljudi, površina učionice i površina prozora učionice. Kao ulazne varijable modelirane su orijentacija učionica, broj ljudi, površina po osobi i odnos površine prozora i površine učionice. Efikasnost dizajna učionica u vidu izlaznih varijabli dobijena je pravilima formiranim među ulaznim varijablama. U modelu su korišćeni fazi model kao Mamdanijev tip i metoda "ponderisanog proseka" kao metoda razjašnjenja. Za model fazi logike formirano je 180 fazi pravila IF tipa, koja su u vezi s fasadom učionice, brojem ljudi, površinom po osobi i odnosom površine prozora učionica i efikasnošću projektovanja učionice. Kreirane su efikasnost dizajna učionica; klase efikasnosti dizajna i prosečne efikasnosti projektovanja učionica na fakultetima su upoređene i izvedeni su zaključci prema fakultetima. Efikasnost učionica, koje su glavno mesto obrazovnih zgrada, zavisi od odluka donesenih u fazi projektovanja. Sa modelom stvorenim u ovom radu, obezbediće se efikasniji dizajn poznavanjem efikasnosti dizajna i korišćenjem procesa odlučivanja o učionicama tokom procesa projektovanja.

Ključne reči: *Fazi logika, donošenje odluka, učionica, efikasnost dizajna*.

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OPTIMIZATION OF SINGLE-SPAN SINGLE-STOREY PORTAL FRAME BUILDINGS

UDC 72.012.26
624.072.336
004.43Visual Basic

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Abstract. *Many structural designs are done without comprehensive consideration for achieving optimum design. To achieve minimum mass optimization, a mathematical model was developed in this study and subjected to British Standard (BS 5950) code requirements for structural integrity as constraints. Visual basic application (VBA) codes were written into a spreadsheet environment to implement the model. The developed optimization model was validated using different sample shed structures of same volume (729m³) but of different height to span to length (H: b: L) ratios which were obtained using the Ratio method and the Step size method. The best parameter ratio of height to length to breadth obtained was 1:1:1 which is similar to what was obtained by other authors. Parametric design case study analysis was also performed for three different design situations with a given span b, heights H and h and frame spacing S. The minimum masses of steel for a fixed plan area of the buildings were obtained for each of the three scenarios. It is recommended that design engineers should consider varying major frame parameters such as frame spacing and heights at pre-design stages in order to obtain optimal values of parameters which will ensure economical structures.*

Key words: *optimization, steel structures, portal frames, Visual basic, single-story*

1. INTRODUCTION

Single storey buildings form the largest sector of the steel construction market in the United Kingdom. These buildings are used mainly for workshops, factories, warehouses, stores and recreation. Traditionally they are called ‘sheds’. The size of the sheds varies from small workshops with a few thousand square meters to warehouses with more than one million square meters. The increasing specialization of steel workers and other

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members of the supply chain has led to significant improvements in the quality, cost and delivery of single-story steel buildings. These improvements have been made possible by the increasingly effective use of the portal frame structures. Portal frames for industrial buildings have been extensively studied because of their wide spread use [1-6].

Earlier, before the advent of computer, an important goal of the structural design process was to find a calculation method that was elegant, simple and reasonably accurate. Once the efficacy of the design process is established, it was recorded as a convenient method to solve repetitive structural design problems. The approach which is referred to as the quick 'Rule of Thumb' became an essential resource for structural engineers. However, as computer software evolved and advanced the 'Rule of Thumb' and approximate method became less important. Quick computational speed and ease of application of computer methods made the initial 'Rule of Thumb' approach less relevant. The computer-based approaches allow for quicker computation of design alternatives with great ability to improve structural integrity and reduce cost. The need to reduce cost of construction and shorten the implementation period necessitated a new design trend [7-9]. This new design approach uses analysis and design software to evaluate possible design options replacing the conventional design methods. Optimization is the process of modifying a system to make the system work more efficiently or use fewer resources. It involves studying the problems in which one seeks to minimize resources and maximize the benefits or profit by systematically choosing the values of real or integer variables from within an allowed set [10, 11].

To obtain efficient frame designs, researchers have introduced various optimization techniques ranging from mathematic programming to stochastic search technique [12]. The complexity of these techniques made many researchers reluctant to use them in common practice [13]. The mathematical gradient based programming method requires formulating a set of equations and obtaining derivatives to handle different design situation. This was argued to be a cumbersome task [11]. On the other hand, Stochastic search technique required overcoming obstacles such as pre-convergence, computation costs and processing time issues to reach an optimal solution. The limitations became more complicated when the assessed problems had a complex search space [13].

Researchers have also experimented with evolutionary computing methods, including genetic algorithms [14-20] and simulated annealing [21] and Generalized Reduced Gradient (GRG) algorithm [22]. Grierson and Khajehpour [23] developed methods involving multi-objective genetic algorithms (MOGAs) and Pareto optimization to investigate trade-offs for high-rise structures

2. Objectives of Investigation

In the face of increase in price of materials, economic recession and increase in competition, civil engineers and manufacturers are forced to reduce cost of construction and shorten the implementation period [22]. As a result, removal of excesses is a priority. Optimization is a sure means of achieving removal of excesses. This research work aimed at optimizing frame parameters of single span single storey steel open frame utility building. The specific objectives of the research work are to:

i. develop a minimum mass optimization model for fixed and pinned feet single span single storey portal steel frame utility building, and
ii. establish the relationships between frame parameters and the mass of frame work steel.

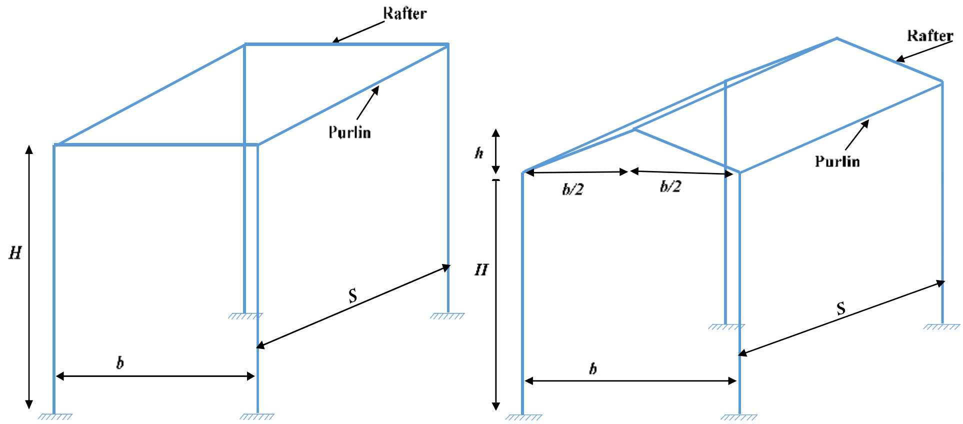
The developed optimization model will be verified using twenty-five sample shed structures of the same volume (729m³) but of different height to span to length *(H: b: L)* ratios. Visual Basic Application (VBA) codes will be written in Microsoft Excel 2010 environment to implement the model for three case studies. The usefulness of this work derives from the fact that optimization helps in the production of minimum mass designs and promotes reduction of construction weight with attendant improvement in the ease of construction of portal steel frames. The study is unique in the flexible ability of the program written and combination of tables and charts to present optimization process results.

3. Research Methodology

3.1. Development of minimum mass optimization model

The following were considered in order to obtain the overall mass of the portal frame structure:

i. The structure was divided into frames whose number was determined based on its length
ii. The frames are far apart at a constant distance (or frame spacing)
iii. The structure consists of a minimum of two portal frames
iv. Each frame consists of two stanchions, two rafters for pitched roof (Fig. 1a) and one rafter for flat roof (Fig. 1b)



(a) Pitch frame structure (b) Non-pitch steel frame structure

Fig. 1 Typical sections of pitch and non-pitch fixed feet open frame

i. Open steel frame pitched single span single storey building [Fig. 1(a)]

Two stanchions are required for each frame in a typical pitched portal frame building (Fig. 1(a)). Therefore, for n number of portal frame in a building, the mass of stanchion for the entire structure (M_T) is expressed in Equation 1.

$$M_T = 2nM_s \tag{1}$$

Similarly, two rafters whose lengths on plan are 1/2 of the breadth of the building are required in a typical pitched portal frame (Fig. 1). Therefore, for *n* number of portal frames in a building, the total mass of rafter M_R is expressed in Equation 2.

$$M_R = \frac{1}{2} \cdot 2nM_r = nM_r \tag{2}$$

Purlins are usually spaced at 1.2m for long span corrugated aluminum roofing sheets ideal for shed structures. Hence, purlin is assumed to be spaced at 1.2*m*. Hence, the total mass of purlin, M_{Pt} is expressed in Equation 3.

$$M_{Pt} = \frac{b}{1.2} M_p \cdot S \cdot (n-1) \tag{3}$$

The total mass of steel for the building frame is expressed in Equation 4.

$$Z = M_T + M_R + M_{Pt} = n(2M_s + M_r) + \frac{b}{1.2} \cdot M_p \cdot S \cdot (n-1) \tag{4}$$

where M_s is the mass of stanchion
M_r is the mass of rafter
M_R is the total mass of rafter
M_p is the mass of purlin per unit length
M_{Pt} is the total mass of purlin
M_s is the mass of one stanchion
M_t is the mass of two stanchions of a portal
M_T is the total mass of stanchion for the entire building structure
L_p is the length of purlin
N_p is the number of purlins
S is the frame spacing
b is the breadth of building (or frame span); and
Z is the total mass of steel for the building frame.

ii. Open steel frame of non-pitch portal frame [Fig. 1(b)]

Two stanchions are also required per each frame in a typical non-pitch portal frame. However, just one rafter is required. The total mass of steel mathematical model is similar for both pitch and flat roofed portal frame considered.

iii. Design Objective

The objective is to obtain the minimum mass of the structural steel that adequately satisfy the design constraints.

Therefore, the Objective function is expressed in Equation 5.

$$Z = n(2M_s + M_r) + \frac{b}{1.2} \cdot M_p \cdot S \cdot (n-1) \tag{5}$$

Minimize Z subject to the following constraints (BS 5950-1:2000)

a. Moment resistance M
b. Design steel stress P_y
c. Overall Buckling P_b
d. Section Classification
e. Serviceability, using the criterion of minimum web thickness, t_w
f. Shear Strength check.
g. Compression Resistance P_c
h. Equivalent Slenderness λ_{LT}
i. Minimum web thickness t

Accordingly, the constraints are expressed below

Minimize Equation 5 subject to Equation 6 to 14

a. **Moment resistance *M***

$$C_1 = M \leq Mb / m_{LT} \tag{6}$$

b. **Design steel stress P_y**

$$C_2 = P_y (275 N / mmA?) \tag{7}$$

c. **Overall buckling P_b**

$$C_3 = V / P_c + M_x / M_b + M_y / P_y Z_y \leq 1.0 \tag{8}$$

d. **Section classification**

$$C_4 = IF \frac{b}{T} < 9 \in \text{ and } \frac{d}{s} < 80 \in \text{ then the section is plastic} \tag{9}$$

e. **Serviceability, using the criterion of minimum web thickness, t_w**

$$C_5 = T \text{ and } C_{web} < P_{bw} = (b_1 + n_1 k) \cdot t_w \cdot P_{yw} \tag{10}$$

f. **Shear strength check**

$$C_6 = F_V \leq P_V \text{ where } P_V = 0.6 P_y A_V \tag{11}$$

g. **Compression resistance P_c**

$$C_7 = P_c = A_g P_c,\ p_c = \frac{P_E P_y}{\Phi + \sqrt{(\Phi^2 + P_E P_y)}} \text{ where } P_E = \pi^2 E / \lambda^2 \tag{12}$$

h. **Equivalent slenderness λ_{LT}**

$$C_8 = \lambda_{LT} = UV\lambda \ \sqrt{\beta w} \quad \lambda = L_E / \gamma_y \tag{13}$$

i. **Minimum web thickness *t***

$$C_9 = t \geq d / 250 \tag{14}$$

where M_b is the buckling resistance moment
m_{LT} is the equivalent uniform moment factor for lateral torsional buckling
V is the compressive force due to axial force
P_c is the compression resistance
M_x is the nominal moment about the major axis
M_y is the nominal moment about the minor axis
P_y is the steel design strength
Z_y is the section modulus about the minor axis;
b is the flange length

T is the flange thickness
d is the web length
s is the web thickness
C_{web} is the web compressive force
r is the root radius
P_{bw} is the web bearing capacity
b_1 is the stiff bearing length
P_{yw} is web design strength
λ is the slenderness
p_c is the compressive strength
A_g is the gross sectional area

iv. Variables

The design variables of the research work are

- Height to eaves: Ranging from 2.5m to 11.5m at a step size of 0.5m
- Height from eaves to apex: Ranging 0 to 17.3m (slope 0 to 60^0) at a step size of 3^0
- Frame Spacing: Ranging from 2m to 8m at a step size of 0.1m

3.2. Optimization Procedure

The optimization procedure is illustrated in Fig 2

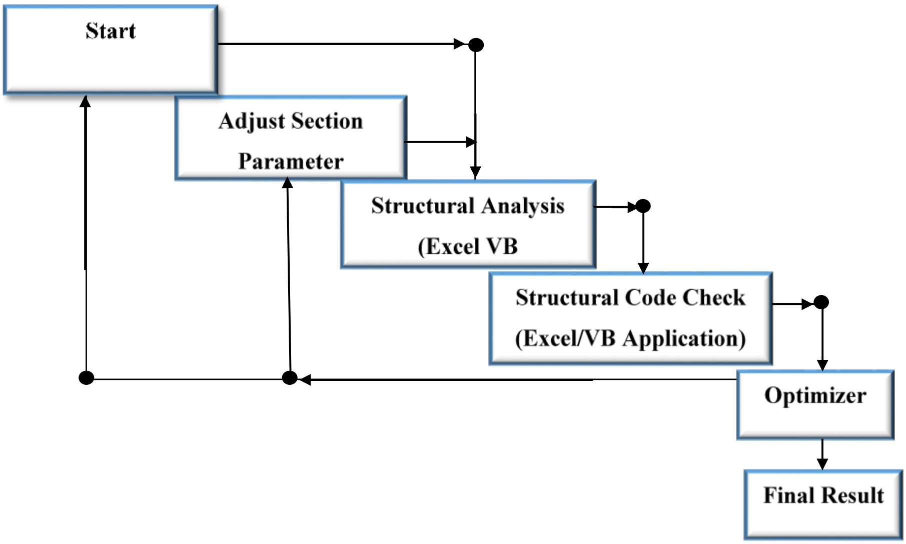


Fig. 2 Structural design, analysis and optimization process

3.3. Validation of model

Sample test of the already established parametric relationships of single span single storey open framed buildings were run on the program and similar results were obtained.

3.3.1. *Ratio method*

Using the ratio method, the ratio between the length, breadth and height of the structure was made in a modulus of 3. This was computed by the use of the tree diagram illustrated in Fig. 3. The re-occurring ratios which are 2:2:2 and 3:3:3 were removed and the 25 possible ratios of length, breadth and height are used to model 25 different portal frames of same volume (729m³). Each of the models was designed for structural integrity using the Excel program produced by using basic Excel functions to implement design formula and satisfy design requirements. The masses of steel sections adequate for the purlins, rafters and stanchions of each of the 25 ratios of the same volume were optimized using the objective functions.

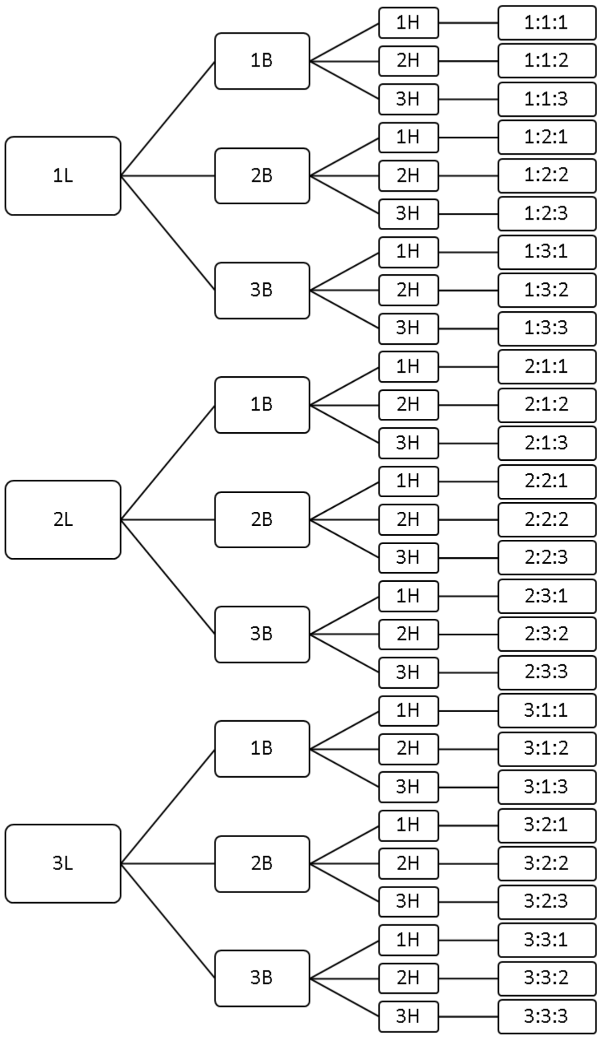


Fig. 3 A tree diagram for computation of possible combinations of the dimensions in mod3

3.3.2. *Step size method*

For same volume (729 m^3) of shed structure, the breadth (or span, *b*) and height (*H*) were kept at same ratio while the length (*L*) was varied at step size of 10cm to obtain optimum length for this volume (729 m^3). Similarly, the span and length were kept at same ratio and the height was varied at step size of 10cm to obtain optimum height for the same volume (729 m^3). Also, the length and height were kept at same ratio while the span was varied at step size of 10cm to obtain optimum span of the volume (729 m^3).

3.3.3. *Case study analysis*

Parametric design case study analysis was also performed for three different design situations with a given span b, heights H and h and frame spacing S. The design cases include:

A. Given a span *b*, frame spacing *S* and height from eaves to apex *h*, the height from ground to eaves *H* was varied and corresponding masses of steel for purlin, rafter and stanchion were estimated.
B. Given a span *b*, heights *H* and *h*, the frame spacing *S* was varied, and corresponding masses of purlin, rafter and stanchion were determined and
C. Given height to eaves *H*, height from eaves to apex *h* and optimal spacing *S* of 6.1m, span *b* was varied, and corresponding masses of purlin, rafter and stanchion were determined

3.4. Data analysis using VBA enabled spreadsheet

To obtain the mass of structure of each combination of dimensions, a VBA enabled spreadsheet is developed to calculate the number of frames, the mass of purlin, mass of rafter and the mass of stanchion. The conventional method of programming the spreadsheet to select the section of steel was used according to the British Standard codes (BS5950) for the stipulated dimensions. Relevant functions were defined using Visual Basic for Applications in the supplied Visual Basic editor, and such functions were automatically accessible on the worksheet. Programs were written that pull information from the worksheet, perform required calculations, and report the results back to the worksheet.

4. Results and Discussions

4.1. Results and discussion of the Ratio method

Masses of steel sections which satisfy design requirements were optimized by the use of the objective functions. The results displayed in Table 1 serves as guide for validity of the objective functions. The objective of the structural optimization process was to minimize the cost of steel frame while satisfying structural safety criteria for strength design. From Table 1 and Fig. 4, the minimum resultant steel mass of 1,755.80kg was obtained when the length: breath: height was ratio at 1:1:1. The result is in agreement with the results from other researchers [14, 16, 20]. The most expensive parametric combination was l: b: 3h with a huge resultant mass of 13,288.29kg. The results revealed the possibility of wasting (or saving) more mass of steel by simple parameter adjustment. Huge savings can be made when parameters are adequately combined while careless combination of shed dimensions can cause significant increase in cost.

Table 1 The resultant mass of steel involved in the computation of the data generated by the ratio method

Ratio	Length(m)	n=l/4	mr(kg)	ms(kg)	Ms(kg)	Mr(kg)	Mp(kg)	Z (kg)
l.b.h	**9.00**	**2**	**32.80**	**23.10**	**207.90**	**417.48**	**11.90**	**1755.80**
l.b.2h	7.14	2	25.20	45.00	642.90	254.57	11.90	3151.58
l.b.3h	**5.83**	**2**	**23.10**	**149.20**	**3197.34**	**190.54**	**11.90**	**13228.29**
l.2b.h	7.14	2	60.10	19.00	135.72	1214.28	11.90	3113.13
l.2b.2h	5.67	2	45.00	40.30	456.97	721.63	11.90	3383.60
l.3b.h	6.24	2	89.30	16.00	99.84	2364.23	11.90	5313.48
2l.b.h	14.29	4	25.20	19.00	135.72	254.57	11.90	2316.59
2l.b.2h	11.34	3	23.10	37.00	419.55	185.22	11.90	3185.42
2l.b.3h	10.43	3	19.00	45.00	651.67	129.71	11.90	4394.91
2l.2b.h	11.34	3	45.00	16.00	90.71	721.63	11.90	2934.07
2l.2b.3h	7.86	2	31.10	40.30	475.27	345.80	11.90	2670.65
2l.3b.h	10.43	3	59.80	13.00	62.75	1224.71	11.90	4337.88
2l.3b.2h	7.86	2	46.00	19.00	149.38	767.20	11.90	2248.88
2l.3b.3h	6.87	2	39.10	31.10	320.41	569.68	11.90	2523.15
3l.b.h	18.72	5	23.10	16.00	99.84	203.86	11.90	2265.26
3l.b.2h	14.48	4	19.00	25.20	262.79	129.71	11.90	2764.78
3l.b.3h	12.98	3	16.00	40.30	523.10	97.90	11.90	3518.15
3l.2b.h	14.48	4	39.10	13.00	62.75	576.64	11.90	3118.83
3l.2b.2h	11.79	3	31.10	19.00	149.38	345.80	11.90	2089.62
3l.2b.3h	10.30	3	25.10	31.10	320.41	243.80	11.90	2790.06
3l.3b.h	12.98	3	54.10	13.00	56.25	993.11	11.90	3574.24
3l.3b.2h	10.30	3	39.10	19.00	130.50	569.68	11.90	2696.36

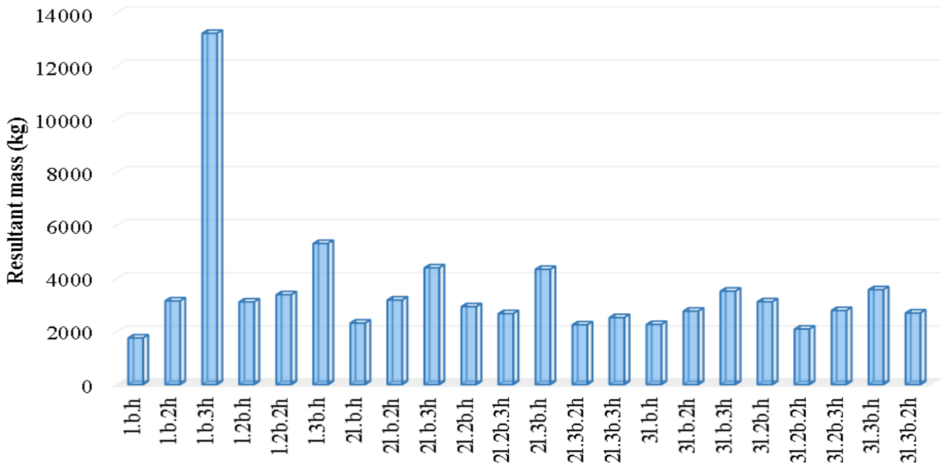


Fig. 4 Chart of the resultant mass of steel versus the ratio of dimension

4.2. Results and discussion of the Step size method

Masses of sections of purlin, rafter and stanchion obtained by the step size adjustment of the frames parameters were computed for the optimum masses of steel using the objective function. The results are displayed in Table 2 to Table 4.

The step size method results in Table 2 show the optimum parameters of length 9.1m, breadth 8.95m and height 8.95m (1.017l: b:h) with resultant steel mass of 1,746.13kg. In Table 3 minimum resultant mass of steel of 1739.21kg is achieved at 9.15m length, 8.7m breadth and 9.15m height (1.05l: b: 1.05h). Table 4 revealed the minimum resultant mass of 1,755.80kg at 9m length, 9m breadth and 9m height (l: b: h). From table 4.5, optimum resultant steel mass of 1,743.84kg is obtained at 9.1m length, 8.6m breadth and 9.21m height (1.06l: b : 1.07h).These results are equivalent and similar to the result obtained by ratio method in table 4.1 and complement previous works [24] on parametric optimization of single span single storey structures.

Table 2 The resultant mass of steel of fixed portal frame for a varying length (Length >7.0m) keeping height and breadth the same on a fixed volume

Length(m)	Breadth(m)	Height(m)	n=l/4	mr(kg)	ms(kg)	Ms(kg)	Mr(kg)	Mp(kg)	Z(kg)
7.8	9.67	9.67	2	37	25.1	242.66	505.86	11.90	2078.22
7.9	9.61	9.61	2	37	25.1	241.11	502.65	11.90	2065.02
8	9.55	9.55	2	37	25.1	239.60	499.50	11.90	2052.08
8.1	9.49	9.49	2	37	25.1	238.12	496.41	11.90	2039.37
8.2	9.43	9.43	2	37	25.1	236.66	493.37	11.90	2026.90
8.3	9.37	9.37	2	37	25.1	235.23	490.39	11.90	2014.65
8.4	9.32	9.32	2	37	23.1	215.20	487.46	11.90	1928.09
8.5	9.26	9.26	2	37	23.1	213.93	484.59	11.90	1916.72
8.6	9.21	9.21	2	37	23.1	212.68	481.76	11.90	1905.54
8.7	9.15	9.15	2	37	23.1	211.45	478.98	11.90	1894.56
8.8	9.10	9.10	2	37	23.1	210.25	476.25	11.90	1883.76
8.9	9.05	9.05	2	37	23.1	209.06	473.57	11.90	1873.15
9	9.00	9.00	2	32.8	23.1	207.90	417.48	11.90	1755.80
9.1	**8.95**	**8.95**	**2**	**32.8**	**23.1**	**206.75**	**415.18**	**11.90**	**1746.13**
9.2	8.90	8.90	3	32.8	23.1	205.63	412.91	11.90	2649.06
9.3	8.85	8.85	3	32.8	23.1	204.52	410.69	11.90	2634.77
9.4	8.81	8.81	3	32.8	23.1	203.43	408.50	11.90	2620.72
9.5	8.76	8.76	3	32.8	23.1	202.36	406.34	11.90	2606.89
9.6	8.71	8.71	3	32.8	23.1	201.30	404.22	11.90	2593.28
9.7	8.67	8.67	3	32.8	23.1	200.26	402.13	11.90	2579.88
9.8	8.62	8.62	3	32.8	23.1	199.23	400.07	11.90	2566.68
9.9	8.58	8.58	3	32.8	23.1	198.22	398.05	11.90	2553.69
10	8.54	8.54	3	32.8	23.1	197.23	396.05	11.90	2540.88

Table 3 The resultant mass of steel of portal frame for a varying breadth (breadth >9.0m) keeping height and length the same on a fixed volume

Length(m)	Height(m)	Breadth(m)	n=l/4	mr(kg)	ms(kg)	Ms(kg)	Mr(kg)	Mp(kg)	Z (kg)
9.55	9.55	8.00	3.00	28.20	25.10	239.60	319.05	11.90	2553.43
9.49	9.49	8.10	3.00	28.20	25.10	238.12	323.03	11.90	2558.47
9.43	9.43	8.20	3.00	32.80	25.10	236.66	380.37	11.90	2723.71
9.37	9.37	8.30	3.00	32.80	25.10	235.23	385.01	11.90	2731.03
9.32	9.32	8.40	3.00	32.80	23.10	215.20	389.64	11.90	2626.71
9.26	9.26	8.50	3.00	32.80	23.10	213.93	394.28	11.90	2635.00
9.21	9.21	8.60	3.00	32.80	23.10	212.68	398.92	11.90	2643.41
9.15	**9.15**	**8.70**	**2.00**	**32.80**	**23.10**	**211.45**	**403.56**	**11.90**	**1739.21**
9.10	9.10	8.80	2.00	32.80	23.10	210.25	408.20	11.90	1744.66
9.05	9.05	8.90	2.00	32.80	23.10	209.06	412.84	11.90	1750.19
9.00	9.00	9.00	2.00	32.80	23.10	207.90	417.48	11.90	1755.80
8.95	8.95	9.10	2.00	37.00	23.10	206.75	476.17	11.90	1869.59
8.90	8.90	9.20	2.00	37.00	23.10	205.63	481.40	11.90	1876.54
8.85	8.85	9.30	2.00	37.00	23.10	204.52	486.63	11.90	1883.56
8.81	8.81	9.40	2.00	37.00	23.10	203.43	491.86	11.90	1890.66
8.76	8.76	9.50	2.00	37.00	23.10	202.36	497.10	11.90	1897.82
8.71	8.71	9.60	2.00	37.00	23.10	201.30	502.33	11.90	1905.05
8.67	8.67	9.70	2.00	37.00	23.10	200.26	507.56	11.90	1912.35
8.62	8.62	9.80	2.00	37.00	23.10	199.23	512.79	11.90	1919.71
8.58	8.58	9.90	2.00	37.00	23.10	198.22	518.03	11.90	1927.13
8.54	8.54	10.00	2.00	37.00	23.10	197.23	523.26	11.90	1934.61

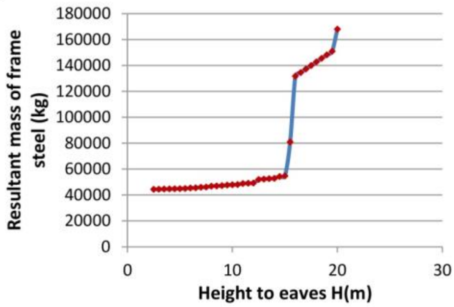
Table 4 The resultant mass of steel of portal frame for a varying height (height>8.0) keeping length and breadth the same on a fixed volume

Length(m)	Breadth(m)	Height(m)	n=l/4	mr(kg)	ms(kg)	Ms(kg)	Mr(kg)	Mp(kg)	Z (kg)
9.49	9.49	8.10	3	37	23.10	187.11	496.41	11.90	2800.04
9.43	9.43	8.20	3	37	23.10	189.42	493.37	11.90	2803.64
9.37	9.37	8.30	3	37	23.10	191.73	490.39	11.90	2807.42
9.32	9.32	8.40	3	37	23.10	194.04	487.46	11.90	2811.39
9.26	9.26	8.50	3	37	23.10	196.35	484.59	11.90	2815.53
9.21	9.21	8.60	3	37	23.10	198.66	481.76	11.90	2819.85
9.15	9.15	8.70	2	37	23.10	200.97	478.98	11.90	1852.62
9.10	9.10	8.80	2	37	23.10	203.28	476.25	11.90	1855.89
9.05	9.05	8.90	2	37	23.10	205.59	473.57	11.90	1859.25
9.00	**9.00**	**9.00**	**2**	**33**	**23.10**	**207.90**	**417.48**	**11.90**	**1755.80**
8.95	8.95	9.10	2	33	23.10	210.21	415.18	11.90	1759.95
8.90	8.90	9.20	2	33	23.10	212.52	412.91	11.90	1764.18
8.85	8.85	9.30	2	33	23.10	214.83	410.69	11.90	1768.49
8.81	8.81	9.40	2	33	25.10	235.94	408.50	11.90	1848.08
8.76	8.76	9.50	2	33	25.10	238.45	406.34	11.90	1853.35
8.71	8.71	9.60	2	33	25.10	240.96	404.22	11.90	1858.69
8.67	8.67	9.70	2	33	25.10	243.47	402.13	11.90	1864.11
8.62	8.62	9.80	2	33	25.10	245.98	400.07	11.90	1869.60
8.58	8.58	9.90	2	33	31.10	307.89	398.05	11.90	2112.75
8.54	8.54	10.00	2	33	31.10	311.00	396.05	11.90	2120.77

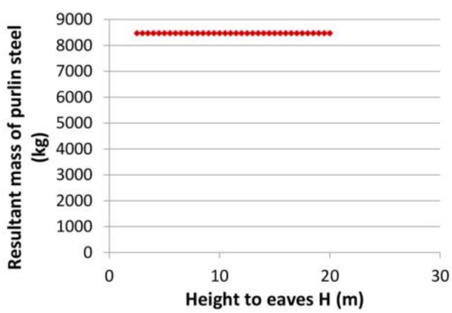
4.3. Results and discussion of Case study analysis

4.3.1. *Case A*

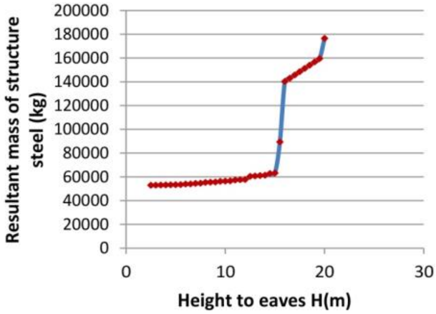
For a given length (20m), frame spacing (6.1m) and height from eave to apex (3.47m), the height to eave was varied from 2.5m to 22.5m at step size of 0.5m. Figures 5(a-f) present the



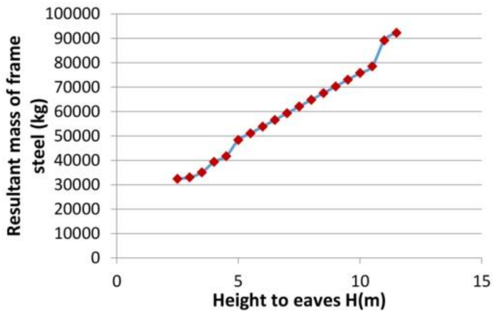
(a) Mass of frame steel versus the Height to eaves of fixed feet portal frame



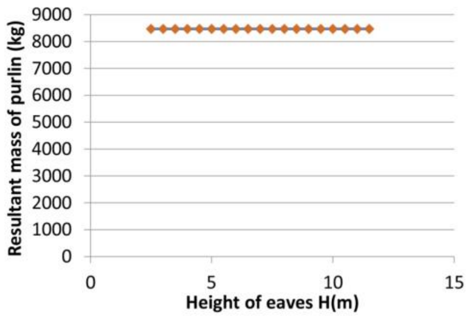
(b) Mass of purlin steel versus the Height to eaves of fixed feet portal frame



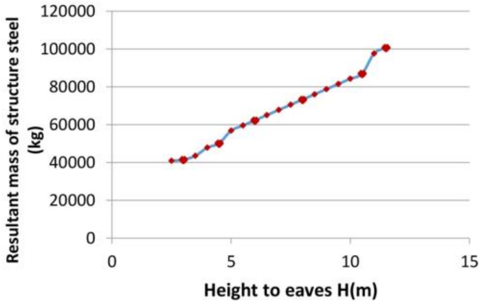
(c) Resultant mass of structured steel versus the Height of fixed feet portal frame



(d) Mass of frame steel versus the Height to eaves of pinned feet portal frame



(e) Mass of purlin steel versus the Height to eaves of pinned feet portal frame



(f) Resultant mass of structure steel versus the Height to eaves of pinned feet portal frame.

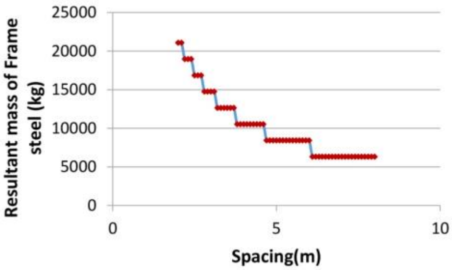
Fig. 5 Mass of steel for Case B design results of section optimization of stanchion in the structure for fix feet and pin feet. The figures graphically illustrate the relationship between change in respective masses of purlins, frames and structures for fixed or pin feet portal frames. The design with minimum resultant steel mass (cheapest design) that satisfied the constraints is considered the best. The best designs are highlighted. The minimum mass of 52,840.8kg and 40,881.7kg are obtained for fix feet and pin feet frames respectively when the stanchions were 2.5m high. Significant increase in masses of structures is noticed when height of stanchions was increased from14m to 14.5m and from 17.5m to 18m. The significant increase in mass of structure is due to stanchions slenderness requirement.

4.3.2. *Case B*

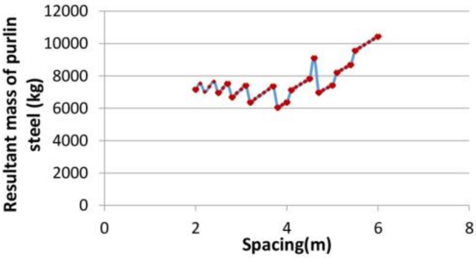
For a given span (20m), Height to eaves (10m), height from eaves to apex (3.5m), the spacing was varied from 2m to 8m at step size of 0.1m. Figures 6(a-f) present the optimization results of the fixed and pin feet frames. The figures portray the relationship between masses with respect to frame spacing. Mass of structure decrease as the frame spacing increase till the optimum mass was obtained at frame spacing 6.1m. Farther spacing resulted in increase in mass of the structure. All the three parts of the structure, the purlin, rafter and stanchion contributed to change in mass of the structure. Mass of purlin was highly nonlinear. Higher number of frames due to small frame spacing resulted in the initial very high mass of structure. As the spacing increased, the number of frames reduced hence mass of frame reduced. Huge reductions in mass of structural steel frame were noticed between frame spacing 3.7m and 3.8m; 4.6m and 4.7m; 6m and 6.1m. Also, significant increase in the masses of frame was observed when spacing was varied from 7.6m to 7.7m. Though 0.1m (100mm) can be considered to be insignificant in practice, but the effect in terms of mass reduction or increment is very significant. The effect of increasing mass of purlin became more significant as the frames get wider more due to the need for thicker steel section to compensate wider spacing. Initially, the increase in mass of purlin could not result to increase in mass of structure because of decrease in mass of frame. However, as the frames get wider, bigger sections are required for the purlin. The mass of purlin became more significant to the increase in mass of structure when the frames were 6.2m or more apart.

4.3.3. *Case C*

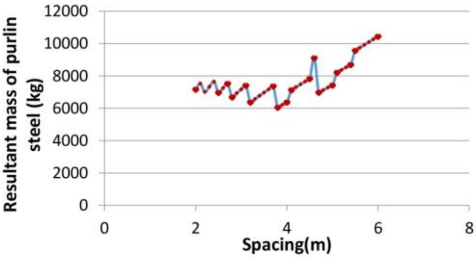
For a given Height to eaves (H=10m), height from eaves to apex (h=2m), frame spacing (s=6.1m), the span was varied from 4m to 29.5m at step size of 0.5m. Figures 7(a-f) show the result of change in span of fixed and pin feet portal frames. From the figures, the mass of structure steel of the fixed feet portal frame increased as the span increased. Expectedly, the increase in mass of the structure steel was due to increase in masses of purlin and rafter steel for the mass of stanchion steel remained constant as the span increased. Figures 7(d-f) however, showed initial reduction in mass of structure steel of pin feet portal frame when span was increased from 4.5m to 10.5m and afterward increased. The initial decrease in mass of structure steel was because of initial decrease in mass of stanchion steel. Contrary to the fixed feet portal frame, the mass of stanchion steel has a huge effect not only on the mass of structure steel but also on the graphical shape of pin feet portal frame.



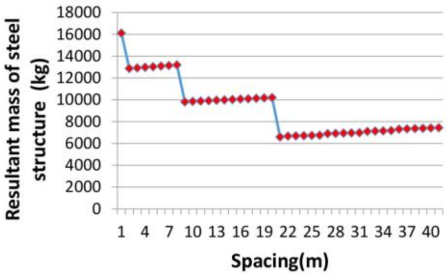
(a) Mass of frame steel versus the spacing for fixed feet portal frame



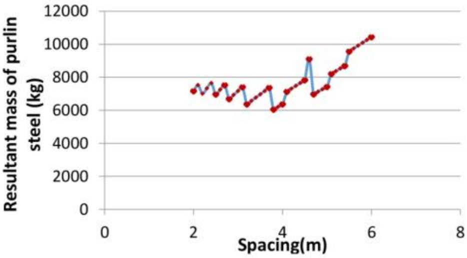
(b) Mass of purlin steel versus the spacing for fixed feet portal frame



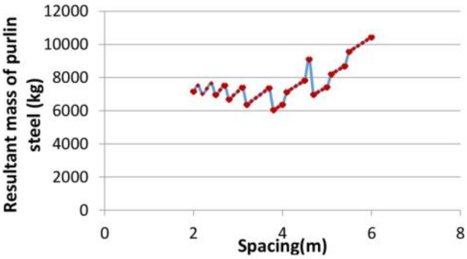
(c) Resultant mass of structured steel versus the spacing for fixed feet portal frame



(d) Mass of frame steel versus the spacing for pinned feet portal frame

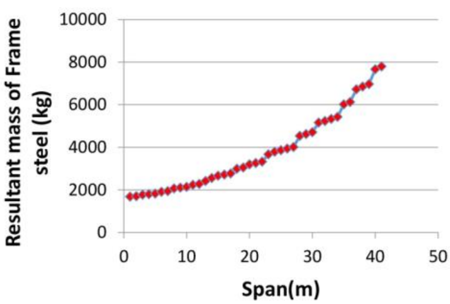


(e) Mass of purlin steel versus the spacing for pinned feet portal frame

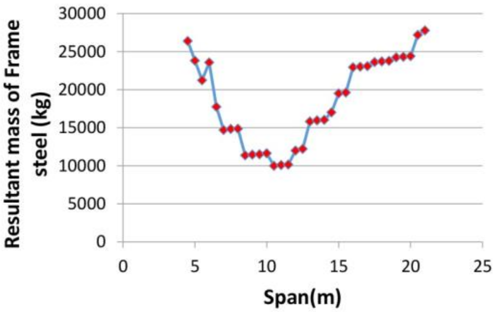


(f) Resultant mass of structure steel versus the spacing for pinned feet portal frame.

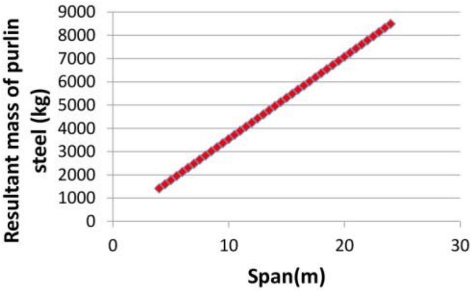
Fig. 6 Mass of steel for Case B design



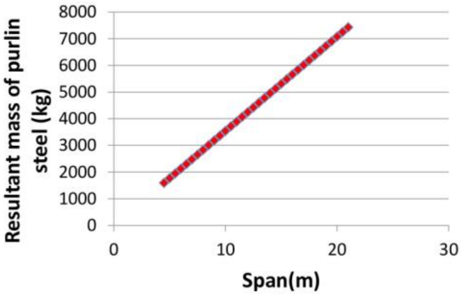
(a) Mass of frame steel versus the Span for fixed feet portal frame



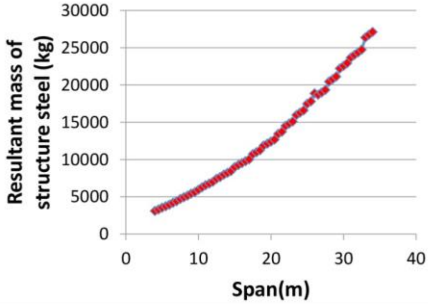
(d) Mass of frame steel versus the Span for pinned feet portal frame



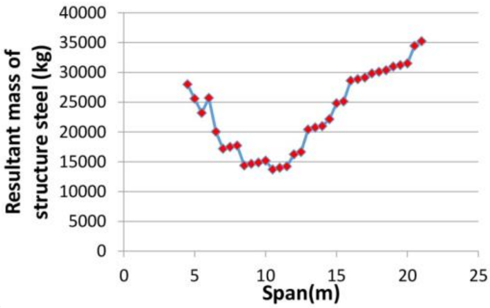
(b) Mass of purlin steel versus the Span for fixed feet portal frame



(e) Mass of purlin steel versus the Span for pinned feet portal frame



(c) Resultant mass of structure steel versus the Span for fixed feet portal frame



(f) Resultant mass of structure steel versus the Span for pinned feet portal frame.

Fig. 7 Mass of steel for Case C design

4.3.4. *Boundary Conditions*

As shown in Figures 5 to 7, the mass of purlin remained the same despite similar increase in the height from ground to eaves and feet condition was changed from fixed to pin. This indicates that the change in the portal frame feet boundary conditions from fixed feet portal frame to pin feet has no effect on masses of purlin. However, significant change was experienced in mass of structure. For instance (Figure 5), mass of structure which was 59,000kg for fixed feet frame was increased to 80,000 kg for pinned feet frame at the same frame dimensions. The results suggest that fixed feet portal frames are more capable of achieving minimum weight at most variations of frame parameters.

5. CONCLUSIONS

The optimum and efficient structural design of a steel portal frame building involves considering various design alternatives. In this study, a mathematical model was developed (subjected to British Standard (BS 5950) code requirements for structural integrity as constraints) to achieve minimum mass optimization. Visual basic application (VBA) codes were written into a spreadsheet environment to implement the model.

The developed optimization model was validated using different sample shed structures of same volume (729m³) but of different height to span to length *(H: b: L)* ratios which were obtained using the Ratio method and the Step size method. The best parameter ratio of height to length to breadth obtained was 1:1:1 which is similar to what was obtained by other authors.

Parametric design case study analysis was also performed for three different design situations with a given span b, heights H and h and frame spacing S. The design cases include: 1) Given a span b, frame spacing S and height from eaves to apex h, the height from ground to eaves H was varied and corresponding masses of steel for purlin, rafter and stanchion were estimated. 2) Given a span *b*, heights *H* and *h*, the frame spacing *S* was varied, and corresponding masses of purlin, rafter and stanchion were determined and 3) Given height to eaves *H*, height from eaves to apex *h* and optimal spacing *S* of 6.1m, span *b* was varied, and corresponding masses of purlin, rafter and stanchion were determined. The minimum masses of steel for a fixed plan area of the buildings were obtained for each of the three scenarios. The minimum masses of steel for a fixed plan area of the buildings were obtained for each of the three scenarios.

From the results obtained, for a 20m span fixed feet frame at 6.1m frame spacing, 52,840.8 kg optimum mass was obtained at 2.5m height to eaves while maximum mass was 176,840.8kg at 22.5m heights. Also, optimum mass of 6206.5kg was obtained for horizontal rafter as against maximum mass of 71,664.3kg obtained at eaves to apex height 27.99m for a 15m span frame, with 9m height to eaves and 4m frame spacing. Similarly, optimum mass of 13,397.6kg was obtained at 6.1m frame spacing while the maximum mass of 28,242kg was obtained at 2m frame spacing for 20m span frame, 20m long structure, 10m height to eaves and 3.5m height from eaves to apex. Also, this research work as demonstrated how optimum parameters of steel formwork of fixed and pin feet single span single storey open frame building are obtained by minimum mass of structure steel.

The research work has established relationship between heights (H or h), steel frame spacing and mass of framework steel of fixed feet and pin feet single span single storey open frame buildings. Pinned feet frames were found to have larger masses of steel than fixed feet frames at most variations of frame parameters. It is recommended that design engineers should consider varying major frame parameters such as frame spacing and heights at pre-design stages in order to obtain optimal values of parameters which will ensure economical structures.

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OPTIMIZACIJA ZGRADA SA PORTALNIM RAMOVIMA SA JEDNIM POLJEM

Mnogi konstruktivni projekti se rade bez sveobuhvatne analize postizanja optimalnog dizajna. Da bi se postigla optimizacija minimalne mase, u ovoj studiji je razvijen matematički model podvrgnut zahtevima Britanskog standarda (BS 5950) gde konstruktivni integritet predstavlja ograničenje. Kodovi aplikacije Visual Basic (VBA) su pisani u okruženju proračunske tabele kako bi se model primenio. Razvijeni model optimizacije potvrđen je korišćenjem različitih primera konstrukcija hala iste zapremine (729m³), ali različitih odnosa visine prema rasponu (H: b: L), koji su dobijeni metodom Razmere i metodom veličine Koraka. Najbolji dobijeni odnos parametara visina - dužina i širina bio je 1: 1: 1, što je slično onome što su dobili drugi autori. Parametarska analiza slučaja projektovanja takođe je izvršena u slučaju tri različite konstrukcijske situacije sa datim rasponom b, visinama H i h i razmakom okvira S. Minimalne mase čelika za utvrđenu površinu zgrada su dobijene za svaki od tri scenarija. Preporučuje se da projektanti razmotre variranje parametara okvira kao što su razmak okvira i visina u fazi projektovanja kako bi dobili optimalne vrednosti parametara koji će osigurati ekonomičnu konstrukciju.

Ključne reči: *optimizacija, čelične konstrukcije, portalni ramovi, Visual basic, jedno polje*

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CONSERVATION APPROACH TO THE INDUSTRIAL HERITAGE OF VOJVODINA

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Abstract. *This article presents new research, which has the objective of defining theoretical and methodological approaches to valorisation and conservation of the industrial heritage. It studies the present condition of industrial heritage in Vojvodina and the evolution of the conservation approach during the period under study (1945–today) through legislation and the documentation of the Institutes for Cultural Heritage Preservation. It indicates the previous inadequate partial evaluation, which has resulted in a loss of many important evidences of the industrial past. A mental schema, based on the Nara document of authenticity, is set as a tool for an interdisciplinary research and evaluation of industrial heritage authenticity. The proposed evaluation method, tested on the example of the brewery in Zrenjanin, results in a conservation project that offers a potential framework for future conservation approach to the industrial heritage of Vojvodina.*

Key words: *industrial heritage, valorisation, criteria, conservation approach, Vojvodina*

1. INTRODUCTION

1.1. Research framework

In 2013, the *Society of Conservators of Serbia* (*Društvo konzervatora Srbije*, http://www.dks.org.rs) declared industrial heritage as the most vulnerable category of historical material remains at the national level, explaining this condition as a consequence of an obsolete legal framework, which did not define industrial heritage as a specific type of cultural heritage.

Although conservationists consider industrial heritage as part of the total corpus of cultural heritage, the current level of exploration and implemented conservation works indicate an inadequate approach to industrial remains. Thus, the importance of forming a

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common strategy is emphasized, which would include all relevant governance structures and institutions at national and local levels, as well as the private and civil sectors.

In 2015, the *National Team for the Industrial Heritage Protection* (*Nacionalni tim za zaštitu industrijskog nasleđa*) was created, whose task is to define a working methodology in the field of industrial heritage and implement it in conservation practice. *National Team* conducted a systematic research of the former conservation approach and the current condition of industrial heritage in Vojvodina.

In this article will be discussed the differences in interpreting conservation paradigms in legislation, theory and practice, which have led to a number of failures in the process of preserving Serbian industrial heritage.

The primary goal of this research is to define theoretical and methodological approaches to valorisation and allocation of specific tangible and intangible values of the industrial heritage.

The previously defined goal and subject of research determine the following tasks:

1. Analysing the evolution of the conservation approach during the period under study (1945–today) through legislation and the documentation of the *Institutes for Cultural Heritage Preservation* (*Zavodi za zaštitu spomenika kulture*).
2. Obtaining a mental schema that provides an interdisciplinary approach to the future research and assessment of industrial heritage authenticity.

In line with the fundamental problem of this research, the paper is based on the initial hypothesis that establishing criteria, goals and indicators in evaluating industrial heritage will determine the framework for standardizing and developing the model of conserving and presenting industrial heritage.

In the research process, several scientific methods have been applied to verify the conception of the scientific hypothesis. The initial phase of work consists of identification and determination of subjects and problems of research, as well as interpretation of basic scientific knowledge relevant to the research. Systematic study of the legal framework and theoretical principles of the industrial heritage preservation implies the application of synthetic research, as a process of generating knowledge from the special to the general, but also a deductive method of research, using analysis, synthesis, generalization and specialization. In the research and analysis of archival material, relevant sources and documentation a historiographic method was also used.

1.2. Industrial past of Vojvodina

Until the mid-nineteenth century, Vojvodina was a poorly developed peripheral area of the Habsburg monarchy, its economy based on manual processing of cereals and manufacturing of bricks, leather, cloth, soap, saltpetre, oil, beer and spirits. Former holders of production were inhabitants of German origin, settled in this area under mercantilist policy measures.

In the Austro-Hungarian Empire, the industrial revolution took place during the 80s of the 19th century. At the time, the economic position of Vojvodina was primarily determined by its agricultural resources. The industry, based on processing of local raw materials, achieved prestigious results compared to other parts of the Monarchy.

With the development of the railway, peripheral areas of the Monarchy were integrated in the state economic system. The vicinal railway had special importance for the economic development of southern Hungary, connecting a number of villages in order to achieve more efficient transport of raw materials (Szilágyi, Tufegdžić, 2015). Major branches of industry were: brewing, milling, silk production, sugar production, brick making (Draganić, Silađi, 2018). Beer production, which in this region dates from the mid-18th century, was the first activity with characteristics of industrial production. The brewery in Pančevo, for instance, was the first steam-powered brewery in southern Hungary. Furthermore, by the beginning of World War I, milling industry became the most developed, as evidenced by more than 200 mills dating from the pre-war period. Also, Vojvodina, with its annual production of silkworms in 1894 reaching one-third of the total state production, had a leading role in silk production in Hungary. In the period 1882-1908 three state silk factories were built. The largest one was in Novi Sad. In the early 20th century cultivation of sugar beet became one of the state agricultural policy priorities. Systematic investment in industrial sugar production resulted in the construction of three sugar factories (1910-1912). Given the quality of the soil, with a high percentage of clay in it, ceramic materials produced in Vojvodina were very popular across the Empire. According to the official Hungarian statistics, at the beginning of the 20th century, there were 177 industrial enterprises in Vojvodina with more than 20 employees each (Borovszky, 1909, 1911).

Even many of those factories did not survive the great economic crisis between the two world wars or the socialist socio-economic transformations, according to recent preliminary reconnaissance of the terrain, over 150 industrial buildings and remains have been recorded.

1.3. Conservation approach

Modern service for the protection of cultural properties was constituted after World War II, when Vojvodina became a part of The Socialist Federal Republic of Yugoslavia. Following the liberation, *The Law on the Protection of Cultural Monuments and Natural Rarities* (*Zakon o zaštiti spomenika kulture i prirodnih retkosti*) from 1946 was passed, initiating exploration and documentation of destroyed properties with cultural and historical significance for the new state. Industrial buildings confiscated from the capitalists, who were of mostly German and Hungarian origin, did not have cultural or historical significance in the new political context. Valorised only from an economic point of view as generators of further economic development, old factories were an ideal platform for the implementation of the new state ideology - self-managed socialism. In the process of liquidating technological backwardness as the post-war priority, many machines, which were the pioneering examples of industrialization, disappeared.

Legal protection of cultural heritage was further supported by *The Law on the Protection of Cultural Monuments* (*Zakon o zaštiti spomenika kulture*) of 1977. A systematic approach to the study of immovable cultural properties was marked by dividing them into four types: cultural monuments, spatial cultural and historic sites, archaeological sites and significant places. Industrial buildings, complexes or sites were not allocated to any of those four categories. For the first time in the system of legal protection, cultural properties were categorized depending on their significance as: cultural property, cultural property of great importance and cultural heritage of exceptional importance. Since evaluation criteria were not specified in the *Law*, some theorists have questioned the evaluation system as such. The *Law* does define the procedure for determining cultural properties. Hence, the *Decision on proclaiming property* (*Odluka o proglašenju kulturnog dobra*) contains description of property, boundaries of protected surroundings, as well as basic preservation, maintenance and use requirements. However, it does not include any elements relating to the valorisation.

Nevertheless, in a proposal, which serves as a base for decision making, the specific character of property must be indicated. If some *cultural property is a property of general public interest*, it should be socially valorised, either by local or wider community. Unfortunately, in the period of socialism, evaluation was an expression of personal, subjective assumptions. Conservators offered their opinion and attitude, either subordinate to the current and variable social imperative or, in the full sense of the word, personal and questionable.

Cultural heritage has an ideological function, which may be legitimizing the existing forms of a political system or form of government, the affirmation of state power or justification of certain historical dogmas. In practice, this function is achieved by favouring the protection and presentation of a certain type of cultural properties. It is known that during the period of communism values of sacred structures were negated, as well as the heritage of the German community, once the majority in Vojvodina. Today, due to the general negative attitude towards the achievements of socialism, there is no awareness of the values and potentials of industrial complexes dating from the second half of the 20th century.

2. MATERIAL

2.1. Current condition of industrial heritage in Vojvodina

In the *Central Registry of Immovable Cultural Properties* (*Centralni registar nepokretnih kulturnih dobara*) only 39 properties are identified which have technical or industrial characteristics (http://www.heritage.gov.rs). They are legally protected and categorized as: cultural property (CP III), cultural property of great importance (CP II), and cultural property of exceptional importance (CP I). Since the data in the *Central Registry* are incomplete and out of date, it was necessary to conduct a field survey to determine the condition of the buildings and degree of machines preservation.

An overview of the listed industrial heritage was made according to the categories adopted by *The International Committee for Conservation of Industrial Heritage* (http://ticcih.org/) (Table 1).

Analysing the current situation of listed industrial buildings, the following conclusions were drawn.

Despite legal protection, six monuments were demolished, two of which were of great importance. There is no information about the reasons for their destruction. Water mills, roller mills and thermal power plants were the last remaining examples of their kind in Vojvodina. Three monuments, including the first steam brewery south of Budapest, are very vulnerable, almost completely destroyed. Most of the monuments with dilapidated architecture do not have preserved equipment. However, there are two examples, a silk damask weaving workshop and a Czech warehouse, with completely preserved equipment, that require proper presentation. Both cultural properties of exceptional importance are empty, even though, according to documentation, they were partially restored in recent years. Without an integrative approach, including the implementation of modern functions in abandoned buildings, monuments continue to decline. Only seven industrial monuments are in good condition, most of them can be described as well restored architectural membranes that have lost functional integrity. A blacksmith's workshop is the only example where all aspects of industrial heritage are successfully preserved and presented. A comprehensive and authentic picture of the old workshop is achieved in an interactive museum by unifying immovable/movable tangible heritage and craft skills.

Table 1 Current condition of industrial heritage in Vojvodina

	Property, location	Year of inscription	Status	Buildings condition	Machines Condition
	Agricultural & food production				
1.	Water mill, Donji Petrovci	1997	CP III	demolished	not preserved
2.	Water mill, Neštin	1971	CP II	demolished	not preserved
3.	Water mill, Rivica	1965	CP III	extremely endangered	not preserved
4.	Water mill,Kusić	1875	CP III	demolished	not preserved
5.	Dry mill, Kikinda	1951	CP I	medium	partially
6.	Windmill, Čurug	1962	CP II	medium	partially
7.	Windmill, Melenci	1965	CP II	medium	partially
8.	Windmill, Orom	1969	CP III	medium	partially
9.	Windmill, Obornjača	1983	CP III	medium	partially
10.	Steam mill, Subotica	1993	CP III	medium	completely
11.	Roller mill, Beška	1980	CP III	demolished	not preserved
12.	Brewery, Pančevo	1948	CP II	extremely endangered	partially
13.	Brewery, Apatin	1994	CP III	good	not preserved
14.	Grain store, Sremska Mitrovica	1966	CP II	bad	not preserved
15.	Czech warehouse, Novi Sad	1998	CP III	bad	completely
16.	Red warehouse, Pančevo	1997	CP III	good	not preserved
17.	Supplies warehouse, Pančevo	1997	CP III	bad	not preserved
18.	Grain store, Mali Horgoš	2001	CP III	bad	partially
19.	Grain store, Novo Miloševo	2003	CP III	medium	partially
20.	Grain store, Novi Bečej	1999	CP III	bad	not preserved
	Canals				
21.	Lock Slajz, Apatin	1983	CP I	medium	partially
	Energy & power				
22.	Thermal power plant, Vrdnik	1976	CP II	demolished	not preserved
	iron & steel				
23.	Blacksmith workshop, Bač. Topola	1991	CP III	good	completely
	Papers				
24.	Printing house, Pančevo	2001	CP III	demolished	not preserved
25.	Printing house, Šid	1976	CP III	good	not preserved
	Railways				
26.	Railway station Tamiš, Pančevo	1997	CP III	very good	partially
27.	Railway station, Jasenovo	1980	CP III	good	partially
28.	Railway station, Horgoš-Kamaraš	1986	CP III	extremely endangered	not preserved
29.	Railway station, Naumovićevo	1987	CP III	good	partially
30.	Railway station, Palić	1997	CP III	very good	partially
31.	Railway station, Sr. Mitrovica	1978	CP III	good	not preserved
	Textiles				
32.	Hemp factory, Bački Petorvac	1998	CP III	bad	partially
33.	Weaving silk damask, Bezdan	2005	CP III	bad	completely
34.	Socks factory, Apatin	1994	CP III	medium	partially
	Water				
35.	Pumping station Kučka, Apatin	1994	CP III	bad	partially
36.	Water tower, Palić	1997	CP III	good	not preserved
37.	Water tower, Ečka	2001	CP III	bad	not preserved
38.	Lighthouses, Pančevo, river Tamiš	1972	CP II	medium	partially
39.	Wells, Vladimirovac	1990	CP II	bad	partially

The general conclusion is that the current condition of protected industrial properties is extremely poor due to a partial evaluation. Documentation shows that many properties have not been researched and valorised prior to legal protection. Consequently, the subsequent conservation works were implemented partially, often without a prior analysis and expert opinions. Considering the insufficient awareness of the importance of certain monuments', later generations of conservationists and local communities have allowed dilapidation and destruction of unique examples of technical heritage.

According to the comparative analysis of data in *Decisions on proclaiming*, documentation and current condition of listed industrial heritage, deficiencies in the process of evaluation have been identified. It means that new methodological framework should be based on a theoretically verified valorisation.

3. Methodologies of Valorisation and Conservation Industrial Heritage

3.1. The issue on monuments values

In the 80s of the 20th century, Jukka Jokilehto unified earlier thinking on the process of analysing authenticity and offered tangible references for the future authenticity document (UNESCO, 1994). According to Jokilehto, the complexity of concept is hidden in recognizing and connecting the following aspects of authenticity: creativity, truth and cultural tradition (Jokilehto, 1985). Creativity primarily refers to the form and artistic approach, truth to historical materials, while cultural tradition refers to functions. However, it is almost impossible to obtain a valid critical judgement of a monument without connecting different aspects of authenticity. Individual characteristics attribute certain peculiarity to the subject, but it is only through their organic connection and inter-dependency that a meaningful unity is constituted, which establishes the quality of the monument.

At the same time, Tomić classifies monument characteristics into three categories which actually correspond to different aspects of authenticity concept (Tomić, 1983). Characteristics of uniqueness, documentation and qualification are in accordance with the current understanding of authenticity concept, articulated in keeping with the three different aspects. The first refers to the subject originality (as a product of mental and creative work), the second to its material veracity (as a historical document) and the third to its continuity within the framework of the given cultural context. Hence, a monument's uniqueness is manifested through a meaningful unity of visible and hidden, physical and mental characteristics, their understanding depending on the source of information.

It is possible to get closer to the real essence of an industrial monument only by attempting to understand it integrally, in its authenticity, taking all its characteristics, material and conceptual, into account. Further, these characteristics need to be critically analyzed and interpreted without any preconceptions. Nevertheless, the greatest challenge is preserving the authenticity of an industrial heritage that has irretrievably lost its original purpose. Authenticity of a place, or rather material components of an industrial heritage, are the main factors in determining the vitality of its value presentation. Industrial localities rest on a fundamental assumption that traces of industrial past they carry, the authenticity of their form and material, present the key potential for their future. However, without the third dimension of the authenticity concept, referred to as cultural tradition by Jokilehto and as qualificativity? by Tomić, industrial heritage does not have the ability to transfer its importance to future generations.

3.2. Evaluation method

The Nara document on authenticity, based on previously considered theoretical attitudes, has been recognized as a tool for understanding different aspects of authenticity of industrial heritage.

"Depending on the nature of the cultural heritage, its cultural context, and its evolution through time, authenticity judgements may be linked to the worth of a great variety of sources of information. Aspects of the sources may include form and design, materials and substance, use and function, traditions and techniques, location and setting, and spirit and feeling, and other internal and external factors. The use of these sources permits elaboration of the specific artistic, historic, social, and scientific dimensions of the cultural heritage being examined." (UNESCO, 1994)

With the aim of better understanding the stratification of the authenticity concept, it is possible to develop *Article 13* into a grid, where the vertical axis is presented by the *aspects* and the horizontal by *dimensions*. This way the defined mental schema enables an interdisciplinary approach to research and evaluation of authenticity of industrial heritage tangible and intangible dimensions, but not the quantitative measure of their level.

Social revaluation is a method of quantitative evaluation of identified monumental values. Social community (Scheffler, 2017) involvement in industrial heritage valorisation should ensure community benefit through social, cultural or economical connection with heritage. Such ‘connected community’ shows a strong commitment and responsibility for evaluation, preservation and promotion actions.

4. RESULTS

The proposed evaluation method was tested on the example of the brewery in Zrenjanin, which was previously researched as part of a comprehensive study of brewing context and continuity in Vojvodina (Tufegdžić, 2014).

Founded in 1745 in Great Bečkerek by the Habsburg Commerce, this small beer workshop expanded into a medium scale steam brewery in the following centuries, and later into a modern industrial factory. After unsuccessful privatization in 2003, one of the most modern breweries in the region is now in bankruptcy proceedings. Beer production has been stopped, while buildings and equipment, including machines over a century old, slowly decay.

Research of spatial concept, architecture and technology has pointed to direct influence of Czech engineers. The oldest preserved buildings in the complex, built in 1910 by Lazar Dundjerski, a wealthy landowner and industrialist, were a prototype of the Czech *lager* brewery.

The tradition of beer consumption was nurtured in the brewery complex since its establishment. Until recently, one could taste the *cellar beer* or *liquid bread* made by old recipes in the beer hall, the oldest restaurant of its kind in the country. Also, the festival *Days of Beer* is a continuation of public beer consumption, which began in 1769, as part of the fairs. Thanks to this strong beer tradition, the festival continues despite the fact that beer production in Zrenjanin has been suspended since 2003.

Although already quite devastated, the brewery continues to define the identity of the place - in social terms, based on activities and functions, and in terms of space, physical and aesthetic. Unfortunately, without an adequate conservation approach the brewery could soon permanently lose its significance and place in the social consciousness. Therefore, an analysis was conducted at two levels: individual and expert, according to the authenticity grid (Table 2) and collective and socially responsible, according to questionnaire (Table 3).

Table 2 Expert valorisation of the brewery in Zrenjanin

Aspects	Dimensions			
	Artistic	Historic	Social	Scientific
Form and design	facades: compositional unity artistic expression coloristic accents	unique integral industrial complexes from the early 20th century	project by renowned Czech Bureau Novak and Jahn	original form of characteristic buildings - study of typology
Materials and substance	red brick steel wood	large format bricks, traditionally manufactured in Austro-Hungary, no longer produced	projects of the historic buildings reconstruction	Prussian vault barrel vault
Use and function	line type complex: integrated malt and brewery distinctive chimney kiln	functional schemes provide information on the method of brewing in the 19th and 20th century	new functions in the complex palace Dundjerski once the centre of social life	original equipment evidence of technological development
Traditions and techniques	characteristic way of brick use – facades and vault	nurtured and preserved the traditional way of producing liquid bread, until recently consumed in the beer hall	testimony of the changed relation man - machine from craft to industrial production	possibility of studying old techniques and methods of craft brewing
Location and setting	urban landmark	generated development of the first industrial zone along river bank	once a strategic position in the urban matrix	evidences of the raw materials use and transportation development
Spirit and feeling	ambient values	Dundjerski palace expression of owners power in the early 20th century	place identity – the cult of beer consumption and Dundjerski family	

Results of the evaluation were the main parameters in the preparation of the conservation project (Tufegdžić, 2013), based on: renewal of small scale traditional beer production, use of original equipment, tasting *cellar beer*, promotion of beer festival, presentation of Dundjerski family, preservation of original architecture, and implementation of brewery museum with an interactive tour.

Table 3 Social valorisation of the brewery in Zrenjanin (100 respondents)

Past		Present		Future	
significance	recognition	significance	recognition	significance	recognition
economical 54%	generator of industrialization	historical 46%	oldest factory	tradition 34%	continuation of production
social 36%	social centre palace/beer hall	location 27%	real estate	cultural 32%	beer museum
technological 10%	transformation craft - industry	architectural 20%	urban landmark	tourist 21%	beer museum, beer festival
		non 7%	ruins	economic 13%	new workplaces

Highly rated by the *Committee of the Republic Institute for Cultural Heritage Preservation* (*Komisija Republičkog zavoda za zaštitu spomenika kulture*), the conservation project was also verified by the local community. Thanks to the involvement of the *Association of Citizens "Urban Forum"* (*Udruženje građana "Urbani forum"*) and support of local government, in 2017 part of the complex was renovated and converted into a *Beer museum*. *The Zrenjanin Tourism Organization* (*Turistička organizacija Zrenjanina*) intends to further develop the tourism potential of the ambient unit that the museum makes with the Dundjerski palace and the river Begej.

5. Conclusions

In accordance with the primary goal of the research, this paper presents a new methodological framework for valorisation and preservation of industrial heritage values. Research has shown that the conservation approach to industrial heritage is a complex process that should be theoretically based and practically verified, on the following premises:

1. Criteria for the industrial heritage authenticity valorisation must include both, tangible and intangible, characteristics of the monument.
2. Goal of the industrial heritage conservation must be preservation of its specific, socially recognised, values in a way which will allow its contemporary use.
3. Indicator of success of the industrial heritage conservation and presentation will be the level of project sustainability and the degree of community development.

New methodological approach, determined by above mentioned criteria, goals and indicators in evaluating industrial heritage, has already been accepted by the *Institute for Cultural Heritage Preservation in Zrenjanin* (*Zavod za zaštitu spomenika kulture Zrenjanin*), which has prepared the documentation required for legal protection of this valuable testimony of industrialization, not only in Vojvodina, but also in the wider Central European context. (http://www.zrenjaninheritage.com/kulturna-dobra/grad-zrenjanin/k%D0%BE%D0%BCpl%D0%B5ks-piv%D0%B0r%D0%B5-lazara-dund%D0%B5rskog)

In the future, it is expected that the defined valorisation matrix will be incorporated into the cultural heritage preservation practice, as well as urban planning strategies, in order to advance inadequate segments of the existing conservation and planning approach to industrial heritage conservation.

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KONZERVATORSKI PRISTUP INDUSTRIJSKOJ BAŠTINI VOJVODINE

Ovaj rad predstavlja novo istraživanje, koje ima za cilj definisanje teorijskih i metodoloških pristupa valorizaciji i očuvanju industrijskog nasleđa. Proučava sadašnje stanje industrijske baštine u Vojvodini i evoluciju konzervatorskog pristupa u posmatranom periodu (1945 - danas) kroz zakonodavstvo i dokumentaciju Zavoda za zaštitu spomenika kulture. U radu se ukazuje na prethodnu neadekvatnu delimičnu evaluaciju, koja je rezultirala gubitkom mnogih važnih dokaza industrijske prošlosti. Mentalna shema, zasnovana na Nara dokumentu o autentičnosti, postavljena je kao sredstvo za interdisciplinarno istraživanje i procenu autentičnosti industrijskog nasleđa. Predložena metoda evaluacije, testirana na primeru pivare u Zrenjaninu, rezultira konzervatorskim projektom koji nudi potencijalni okvir za budući konzervatorski pristup industrijskom nasleđu Vojvodine.

Ključne reči: *industrijsko nasleđe, valorizacija, kriterijumi, konzervatorski pristup, Vojvodina*

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RECOMMENDATIONS FOR URBAN REVITALIZATION OF THEATER LOCATIONS: A CASE STUDY – REPUBLIC OF SERBIA

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Abstract. *Theater location quality is researched according to a pre-formed model with the aim to improve quality in the functioning of theaters in settlements of the Republic of Serbia. An omnipresent process of globalization has led to significant changes in the field of culture, and thus a reduction in interest for classic theater performances has occurred. The poor condition of theater buildings in architectural and structural terms as well as their immediate environment, in urbanistic sense, is the result of neglecting the field of culture on a national level for many years. By summing up the total scores for specific urban aspects obtained on the basis of the conducted research and previously collected data, it was found that the average score of the location quality of theaters is 6 of maximum 10, based on the established scoring and evaluation of the determined aspects within the research. Since the active functioning of the theaters at the local level is important for the development of the traditional culture of the population, it is justified to propose specific measures transformation of the theater immediate environment and to implement them as soon as possible for 30 existing theaters in the Republic of Serbia.*

Key words: *theater location evaluation, urban revitalization, theaters of Serbia*

1. Introduction

The main objective of this study is to determine the quality of existing theater locations from urban aspects and point to the possibility of remodelling their immediate surroundings, in order to improve their functioning, and therefore increase the attendance at theater performances. "The global economy and technology condition the typification of lifestyles, behavioural culture and formal norms". [1] The impact of globalization on the theater culture can be viewed as increase in competition, physical deterioration of theater buildings, weakening of operation and closure of certain cultural establishments. "It has been observed

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that the theaters in Serbia, despite the unenviable conditions around them throughout their existence are in fact institutions that will not disappear, because they are places that nurture and preserve the profound tradition, symbolism and culture of the society throughout the centuries." [2] As Dinulović [3] said "the quality of performance of a theater play is a crucial, but not the only functional and technological process of a theater either as a building or as an institution" it is necessary to carry out specified interventions on their surrounding in order to rise their functioning to a higher level. [4] Considering the phases of urban transformation of Barcelona, Degen and Carcia [5] mentioned, among the other things, the provision of new public spaces and renovating theaters. "Exactly this architectural domain of the theater is of importance here, even more so than the formal characteristics of the medium of the theater." [6] Due to the social inertness, the immediate environments of the theaters have gradually deteriorated. Since it is known that the significance of the urban area for the functioning of a facility is very high [7], refurbishment of a theater's environment must represent a priority task for society and city administration. "Theater presents one of the most distinct spatial formations embedding the collective organizations of social practice. It instates a spatial form of utterly legible and powerful identity and proposes straightforward resources of order and identification." [8] As cultural structures represent an integral part of every settlement "social instrument" within its urban context [8] and its most representative element, it is important to preserve their quality, as well as alter the space around them in a manner that elevates them to a level worthy of the culture of every society. Theaters transform the culture and thus influence the development of entire regions and each individual member of the society has a guaranteed right to culture. [9]

2. Analysis of the Quality of Theater Locations

2.1. Model of research

In order to determine the quality of the theaters' locations, the following urban aspects have been analyzed:

- the existence of other theaters or facilities of a similar purpose,
- distance between adjacent theater facilities,
- gravitational area of the theater,
- number of residents in the gravitational area of the theater,
- transportation accessibility of the theater,
- ecological conditions around the theater,
- artificial conditions around the theater,
- belonging to structural elements,
- accessibility to separate theater entrances,
- representation of stationary traffic and
- important numerical indicators.

A research model which can easily determine the quality position of each theater has been developed. The evaluation criteria and parameters as well as the scoring system are listed in the table. (Table 1) [10]

Table 1 Model of evaluation of the location quality of theaters

The basic numerical indicators of the theaters		Value
Numerical indicators	Capacity of the auditorium (number of seats)	No.
	Size of the plateau	m^2
	Number of parking spaces for automobiles	No.
	Number of parking spaces for bicycles	No.
Evaluation of the location quality of theaters		
Criterion	Parameter	Point
Facilities in the surrounding area	There are several similar facilities.	1
	There is one similar facility.	2
	There are no similar facilities.	3
Mutual distance between theater facilities in the surrounding area	In the immediate vicinity (< 1 km).	1
	At a smaller distance (1 km to 10 km).	2
	At a greater distance (10 km to 50 km).	3
	At a great distance (> 50 km).	4
Gravitational area of the theater facility	r < 0,5 km	1
	0,5 km < r < 5 km	2
	5 km < r < 25 km	3
	r > 25 km	4
Population in the gravitational area of the theater facility	Up to 20.000 residents.	1
	Between 20.000 and 50.000 residents.	2
	Between 50.000 and 100.000 residents.	3
	Between 100.000 and 250.000 residents.	4
	Over 250.000 residents.	5
Theater’s location in relation to traffic elements	Presence of 1 or 2 modes of transport.	1
	Presence of 3 or 4 modes of transport.	2
	Farther away from transportation facilities.	1
	Close to transportation facilities.	2
	Farther away from a major street.	1
	Close to a major street.	2
	Presence of public city transp. lines.	1
	A bus line in the vicinity.	1
	Bus and other stops in the vicinity.	1
	Presence of a taxi service.	1
Ecological conditions	The facility is near a body of water.	1
	The facility is on flat terrain.	1
	The facility is protected from the wind.	1
	The facility is shaded.	1
	The facility is isolated from noise.	1
	The facility is protected from air pollution.	1
	The facility is safe.	1
Historical ambience of the settlement	Located farther away from the historical part.	1
	Located in the historical part or in its vicinity.	2
Significant landmarks and areas	In the vicinity of landmarks.	1
	In the vicinity of gathering places.	1
	In the vicinity of residential areas.	1
Part of structural elements	The facility is part of a street or block.	1
	The facility is part of a square.	2
Accessibility of the facility (separation of entrance)	A separate economic entrance.	1
	A separate entrance for staff.	1
	A separate entrance for the participants.	1
	A separate entrance for visitors.	1

Evaluation of the location quality of theaters		
Criterion	Parameter	Point
Stationary traffic	For automobiles	1
	For bicycles	1
	For commercial vehicles	1
Numerical indicators	Area of plateau per visitor > 0,5 m^2/v.	1
	Parking spaces (automobile) per visitor > 0,03/v.	1
	Parking spaces (bicycle) per visitor > 0,02/v.	1
Total number of points	0 - 50	
Location's quality (%)	(0% - 100%) - 2 x total number of points	
Location quality score	(0 - 10) - 0,1 x % of the location's quality	
Score of location quality	(0 - 10) - whole number	

2.2. Research of theaters in Serbia

According to the formed model location quality from an urban aspect was investigated and verified for 30 theaters[1] in 12 cities from the Republic of Serbia (see Fig. 1):

- in Belgrade – 1. National Theater, 2. Yugoslav Drama Theater, 3. Belgrade Drama Theater, 4. Terazije Theater, 5. Zvezdara Theater, 6. Atelier 212, 7. Bitef Theater, 8. "Boško Buha" Theater, 9. Theater "Duško Radović", 10. Little Theater "Puž", 11. "Slavija" Theater, 12. "Dah Theater" and 13. "Pan Theater";
- in Novi Sad – 14. Youth Theater, 15. Serbian National Theater and 16. The Novi Sad Theater;
- in Kikinda – 17. National Theater;
- in Sremska Mitrovica – 18. Theater "Dobrica Milutinović";
- in Sombor – 19. Sombor National Theater;
- in Vršac – 20. National Theater "Sterija";
- in Zemun – 21. Madlenianum Opera and Theater and 22. Puppet Theater "Pinocchio";
- in Šabac – 23. Šabac Theater;
- in Niš – 24. National Theater and 25. Puppet Theater Niš;
- in Subotica – 26. National Theater, 27. Children's Theater of Subotica and 28. "Kosztolányi Dezső" Theater;
- in Užice – 29. National Theater and
- in Zrenjanin – 30. National Theater "Toša Jovanović".

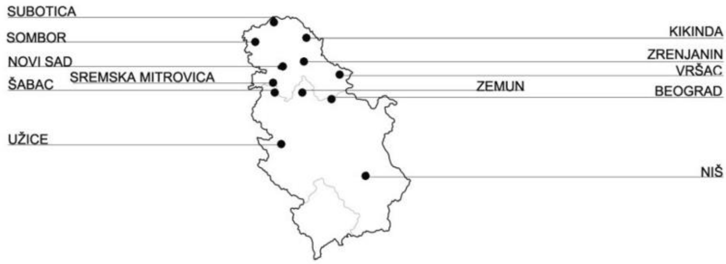

Fig. 1 Settlements location in the Republic of Serbia where the studied theatres are situated (Source: authors' drawing)

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[1] The paper emerged from a research conducted within the project entitled "Technical and technological condition and potentials of architectural buildings for theatrical events in the Republic of Serbia" (project's register number - 16010), approved and funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia in the period from 2010 until 2014 at the Faculty of Technical Sciences in Novi Sad, Serbia.

The choice of theater was based on the availability of data and the ability to record the current situation. A detailed survey of 30 theaters in the Republic of Serbia according to the aforementioned model of research is given in Supplemental Data (Table I, II, III, IV and V). Supplemental Data is accessible through the following link:

3 Comparative Analysis of the Quality of Theater Locations in the Republic of Serbia

In this research, a comparative analysis and valuation of theater location from numerous urban aspects was carried out, which was used to determine the overall values and disadvantages of theaters in the Republic of Serbia, as well as the specific potentials and negativities of individual buildings.

3.1. Facilities of a similar purpose

It has been observed that in the presence of several similar facilities in the region or in the settlement, among the other things, there is a functional specialization. Thus, e.g. in Belgrade, there are theaters that differ in size, repertoire (musicals, avant-garde performances, international festival "Slavija", children's performance) and audience. Subotica, Novi Sad, Niš and Zemun have much fewer theaters than Belgrade, but they are different from one another. In contrast, in cities in which there is only one theater, it has the function of organizing all kinds of performance for all categories of visitors. These theaters have regional significance and because of their monumental expression, these facilities have become "the primary visual association of the city" [11].

3.2. Mutual distance between theater facilities in the surrounding area

It has been observed that smaller distance between the theaters, has bigger influence on the development of competition between them, as well as on the reduction in the number of visitors to each of the facilities, due to a decrease in their gravitational areas. People are oriented towards the theater that is closest to them and they visit it more frequently. A much greater distance between theater facilities influences a more even distribution of visitors, but sometimes leads to lower attendance, due to the necessity to use transportation when visiting a theater play. In some cases, the distance between theaters in the same settlement is not as important as the distance between theaters with the same characteristics in the two different settlements. Thus, for example, performances that take place in Subotica, in "Kosztolányi Dezső" Theater and in The Novi Sad Theater in Novi Sad are in Hungarian language, while in other theaters plays are usually performed in Serbian language.

3.3. Gravitational area of a theater facilities

Theaters are destinations with a gravitational force that invites, receives and assimilates people [8]. The approximate[2] sizes of the gravitational areas of theater facilities were established.

[2] The assessment of the size of the gravitational areas is based on an assessment of employees in the theater facilities as well as the researchers themselves, since such official data do not exist, which is why they must be

The National Theater in Belgrade has more than one radius of inhabitants' gravitation. One is the radius ranging from 0.5 km to 5 km, which is within the walking distance. The second radius ranges from 5 km to 25 km, if we observe the availability to the theater through a public and private motorized traffic, i.e. the gravitational field of the territory of the entire city and its immediate surroundings. The third radius of gravity is conditioned by a large variety of the repertoire and alluring power of the theater. This way, the radius of gravity is greater than 500 km, or more precisely, the gravitational area covers the entire Republic of Serbia. The situation is similar for the other theaters in Belgrade as well. Unlike the National Theater in Belgrade, theaters in Kikinda, Sremska Mitrovica, Sombor, Vršac, Šabac, Užice and Zrenjanin are the only ones in their surroundings, and their gravitational areas are larger than the territory of the cities themselves.

This can be considered as basic, but not the only data. Namely, some theaters occasionally have a much larger area of gravity, which depends on the level of quality of the play, the premiere or the language of the performance. In addition, it is important to point out that many theaters have visiting performances in other settlements, thus completely changing the gravitational areas.

3.4. Population in the gravitational area of the theater facility

To determine the number of residents in the gravitational field of theaters it is important to know the total number of inhabitants in the municipalities: Belgrade 1.639.121, Novi Sad 335.701, Kikinda 59.329, Sremska Mitrovica 79.773, Sombor 85.569, Vršac 51.217, Zemun 166.292, Šabac 115.347, Niš 257.867, Subotica 140.358, Užice 78.018 and Zrenjanin 122.714.[3]

Based on the number of theaters in the region, as well as on the gravitational areas of the individual theaters, the approximate number of residents in the gravitational area has been determined for all representative theaters. National Theater in Belgrade and SNP in Novi Sad have a greater gravitational area (territory of the Republic of Serbia), and therefore the higher number of visitors, thus they developed into theaters with national significance. The number of residents who visit theaters varies. In cities which have gravitational areas that cover several smaller settlements in their surroundings, the number of visitors in the gravitational area is greater than the population of these cities. In smaller towns, which have only one theater, the gravitational area is the surface area of this settlement, and the population in the gravitational area is the total population of this town. Residents who gravitate towards The Novi Sad Theater and "Kosztolányi Dezső" Theater in Subotica are a specific population group, part of the Hungarian population, so they make up a slightly smaller number.

3.5. Theater's location in relation to traffic elements

Each type of transport enables arrival to the city and availability to the theater, so it is extremely important for the quality of the theaters' location, and their functioning. In all of the 12 settlements whose theaters have been studied in this paper, road (pedestrian,

considered with some reserve. During the survey of the gravitational areas, the largest estimated area for a given facility was taken into account.

[3] Statistics on the number of inhabitants in the settlements of Serbia for 2011, source: www document, available at http://media.popis2011.stat.rs/2011/prvi_rezultati.pdf (07/02/2015)

bicycle and motor) and rail (train and tram) transport modes are represented. Water (river) traffic exists in 7, and air traffic is present in 3 settlements.[4] Most of the theaters are away from traffic facilities and near the main road and bus stops. Organized public transport exists in 7, and does not exist in 5 cities.

3.6. Ecological conditions

Based on the research it was concluded that all theaters studied are located away from a water surface or that it neither exists in the settlement nor in its vicinity. Most of the theaters are on the flat ground. Most of the theaters have a favorable location in relation to the effect of the wind. Wind does not interfere with the functioning of theater facilities, but its impact can be very unfavorable for people who spend time on the plateaus in front of the theaters. The nearness of a park or avenue in front of certain theaters contributes to the quality of environmental conditions representing means of protection for visitors from the influence of the wind. Greatly built environment of a few theaters reduces the adverse effect of the wind. Vegetation is the most commonly used element of protection against too strong insolation of theaters. Certain theaters are shaded by tall buildings located nearby. Insolation is not essential for the functioning of theaters, but it is very important for people who spend time on the plateaus in front of them. The most important requirement for visitors staying at the entrance plateau in front of the theater is security. It is estimated that 43% theaters are safe, isolated from noise and protected from air pollution. The hazard for visitors mainly originates from traffic. People visiting theaters that are located next to the pedestrian area are completely protected from motor vehicle traffic.

3.7. Historical ambience

Most of the theaters are located either in the historical centre or in its immediate vicinity. It is necessary to point out that certain buildings in the historical parts of the settlement are themselves presenters of historical and ambient values of both the region and the city.

3.8. Significant landmarks and areas of the settlement

Most of the facilities are located in the vicinity of significant buildings and places of gathering. The most important areas, parks and squares, increase the attractiveness of theaters and enable their better perception.

3.9. Part of structural elements of the settlement

Facilities were also analyzed as parts of structural elements: streets, blocks, paths, banks and squares. A problem of access to a theater may occur when the theater buildings are embedded in a block, especially if they are part of the old city core or lie alongside narrow streets or frequented pedestrian areas. Thus, e.g. difficulty in an economic access to the SNP in Novi Sad is observed, since the facility is located in a well built downtown in the pedestrian zone. Theaters that are parts of squares (e.g. "Boško Buha" Theater) have the problem of the economic access, because it has to be done across attractive and constantly

[4] Data on the represented forms of transport in residential areas, available at http://www.mojgrad.rs/Beograd/Transport-i-saobracaj (04/02/2015)

visited areas. Here we must emphasize the importance of the overlapping of urban factors, which are in collision when it comes to a good location, attractive, accessible and visited, on one side, and an adequate and easy operation as well as the preparation of theatrical performances (access to all entrances to the building), on the other.

3.10. Accessibility of the facility

In most theaters there are separate accesses to entrances: economic, employee, actors and visitors. Ten (33%) facilities have all four accesses to entrances, 6 (20%) theaters have three, 7 (23%) theaters have two and also 7 (23%) theaters have only one access to entrance.

3.11. Stationary traffic

Most theaters have parking for cars. It is unfavorable that only two theaters have a sufficient number of parking spaces. Some of the theaters do not have a single provided parking space. The problem of individual theaters that do not have their own parking lots for visitors' needs is mitigated by the existence of easily available and relatively close organized public parking with a large number of parking spaces, as well as the proximity of stations for public transport and the existence of a taxi service in the city.

3.12. Numerical indicators

Numerical indicators such as seating capacity, size of the plateau in front of the entrance of the building, the already mentioned number of parking spaces express the quality of the functionality of theater facilities in mathematical terms. The information on the capacity of the auditorium is important from the aspect of theater development and achieving local, metropolitan, regional, national or global significance. A larger seating capacity exists in SNP in Novi Sad (1400 seats), National Theater in Belgrade (900 seats), National Theater in Subotica (900 seats), Šabac Theater in Šabac (700 seats) and National Theater in Niš (700 seats). They already have a high reputation at the national level. For good functioning of theater facilities, it is necessary to harmonize the number of seats for visitors and the size of the plateau in front of the building. Based on the criteria that one person who is standing requires 0.5 m^2, it was found that the most of theaters have plateau for gathering of the visitors but they are not of sufficient size or do not have the one at all. National Theater in Belgrade has a plateau of only 30 m^2, but the Republic Square can be used for the purpose of gathering people prior to the show. The disadvantage is that the plateau of the theater and the area of the square are separated by a busy street. Square is the only area for gathering visitors of the "Boško Buha" Theater in Belgrade and the the Theater "Dobrica Milutinović" in Sremska Mitrovica. The National Theater in Subotica has large free areas in its immediate surroundings that can be used as a plateau to assemble 900 visitors. The specific form of the basics of The Zvezdara Theater in Belgrade, which is shaped like the letter "L", allows the formation of a smaller plateau for gathering of visitors before the show.

4. Evaluation of the Location Quality of Theaters

By summing up the scores for the individual aspects of urban development and according to a defined model of research of theater's location quality, it was found that the location of:

- 1 theater has a rating of 8;
- 11 theaters have a rating of 7;
- 13 theaters have a rating of 6 and
- theaters have a rating of 5.

The Terazije Theater in Belgrade is located on a site that has the best conditions for the functioning, and the "Pan Theater" and "Dah Theater" in Belgrade, The National Theater in Sombor, The Novi Sad Theater in Novi Sad and the "Kosztolányi Dezső" Theater in Subotica are in locations that have very poor conditions. By summing up the total scores for specific urban aspects, it was found that the average score of theater locations is 6. (Table 2) This indicates a justification to propose specific measures transformation of the theater immediate environment and to implement them as soon as possible.

Table 2 Summary score of the quality of theater locations

Criterion	Parameter	No.	%
Facilities in the surrounding area	There are several similar facilities.	24	80
	There is one similar facility.	3	10
	There are no similar facilities.	3	10
Mutual distance between theater facilities in the surrounding area	In the immediate vicinity (< 1 km).	18	60
	At a smaller distance (1 km to 10 km).	6	20
	At a greater distance (10 km to 50 km).	1	3
	At a great distance (> 50 km).	5	17
Gravitational area of the theater facility	r < 0,5 km	0	0
	0,5 km < r < 5 km	6	20
	5 km < r < 25 km	5	17
	r > 25 km	19	63
Population in the Gravitational area of the theater facility	Up to 20.000 residents.	2	7
	Between 20.000 and 50.000 residents.	4	13
	Between 50.000 and 100.000 residents.	2	7
	Between 100.000 and 250.000 residents.	5	16
	Over 250.000 residents.	17	57
Theater's location in relation to traffic elements	Presence of 1 or 2 modes of transport.	6	20
	Presence of 3 of 4 modes of transport.	24	80
	Farther away from transportation facilities.	24	80
	Close to transportation facilities.	6	20
	Farther away from a major street.	6	20
	Close to a major street.	24	80
	Presence of public city transportation lines.	25	83
	A bus line in the vicinity.	22	73
	Bus and other stops in the vicinity.	22	73
	Presence of a taxi service.	30	100

Criterion	Parameter	No.	%
Ecological conditions	The facility is near a body of water.	0	0
	The facility is on flat terrain.	22	73
	The facility is protected from the wind.	24	80
	The facility is shaded.	18	60
	The facility is isolated from noise.	12	40
	The facility is protected from air pollution.	11	37
	The facility is safe.	13	43
Historical ambien-ce of the settlement	Located farther away from the historical part.	9	30
	Located in the historical part or in its vicinity.	21	70
Significant land-marks and areas of the settlement	In the vicinity of landmarks of the settlement.	26	87
	In the vicinity of gathering places.	26	87
	In the vicinity of residential areas.	19	63
Part of structural elements	The facility is part of a street, block or shore.	19	63
	The facility is part of a square.	11	37
Accessibility of the facility	There is a separate economic entrance.	22	73
	There is a separate entrance for staff.	18	60
	There is a separate entrance for the participants.	14	47
	There is a separate entrance for visitors.	25	83
Stationary traffic	for automobiles	21	70
	for bicycles	0	0
	for commercial vehicles	5	17
Numerical indicators	area of plateau per visitor > 0.5 m^2/v.	11	37
	parking spaces for automobiles per visitor > 0.03/v.	2	7
	parking spaces for bicycles per visitor > 0.02/v.	0	0
Total number of points	0 - 50	-	31,4
Location's quality (%)	(0% - 100%) - 2 x total number of points	-	62,8
Location quality score	(0 - 10) - 0,1 x % of the location's quality	6,3	-
Score of location quality	(0 - 10) - whole number	**6**	**63%**

(Source: Author's survey in 2014)

5. Conclusions

The most favourable situation for the operation of each theater is when it is the only one in the region, thus obtaining regional importance. However, from the user's perspective, this is not convenient, because there is no possibility of choice. More theater facilities on a smaller territory encourage competition and affect the formation of a specific repertoire, and provide users with a choice. A larger number of theaters at a small distance creates a network of facilities that provides excellent accessibility to culture for residents. The gravitational area of every theater and the number of inhabitants in it depends on a theater facilities' network, the territorial division of the population according to this network, as well as the repertoire and languages in which the plays are performed.

The theater's location quality depends on the traffic elements, because they provide access to the theater. Especially significant are: the representation of multiple types of traffic, proximity of intercity bus stations, railway stations, ports and airports and the proximity of major roads. Traffic has adverse effects, because it disrupts the ecological and functional conditions of the theater. Intensified traffic noise interferes with the work of the theater, and an increased amount of exhaust gases reduces the pleasure of stay on the plateau before the play. High frequency of traffic affects the safety of visitors, and can also lead to traffic congestion, thus preventing efficient access to the theaters. The existence of multiple forms of transport, organized public city bus, tram and trolleybus transport, taxi services, nearness of bus, tram and taxi stations as well as transport facilities (bus station, railway station, airport, port, public parking lots and garages) are a great convenience for visitors, because they enable arriving at the theater, and give them the opportunity to choose modes of transport.

Theaters on flat ground have favourable conditions for ensuring easy access for all categories of visitors. The favourable effect of wind contributes to the ventilation of space and the pleasantness of stay in open areas in front of theaters. Existing plateaus in front of theaters are generally too exposed to intense insolation and there is no protection in the summer. Theaters that are further away from traffic areas have favorable environmental conditions; they do not have pollution by noise and exhaust fumes and are safe for visitors.

Theaters that are part of the street are very easy to reach, but their visitors may be endangered by frequency of traffic and pollution. If a theater is surrounded by the historical core buildings in its immediate proximity or if it is itself a building of ambient value, then it is even more attractive to visitors. The proximity of the place of residence, the visitor's starting point, is of great importance for the easiness of arriving to the theater without the use of any means of transport. A theater which is a part of the street is less noticeable, while a theater which was built as a free-standing building or in a square is visible from various sighting points.

For good functioning of theater facilities, it is necessary to provide access to the separate entrances intended for different users. A larger number of required entrances are difficult to achieve in facilities that are part of the building row, then in facilities that are located at an attractive square or within close edge built block. Theaters that are located in the historic core of the settlement or in pedestrian areas generally do not have predicted surfaces for stationary traffic. Most of the theaters do not have a sufficient number of parking spaces. The appropriate size of the plateau in front of the building is a precondition for an unobstructed course of the main activities taking place in theaters. Facilities that have higher capacities are potentially the buildings that can be developed and can reach the level of world significance. Theaters that are part of a square have an advantage over facilities that are only part of the street, because the surface of the square can be used to assemble the visitors. Theaters whose quality of location was estimated with a score of 5 should be either dislocated from the current position or reconstructed to a greater extent. Most of the locations of the studied theaters have unsatisfactory urban conditions. For most of the perceived deficiencies there are possible solutions.

It has been observed that the biggest problem with most theaters is the lack of parking spaces and plateaus for gathering visitors. Less favourable natural influences can be seen as a consequence of locating the theaters in heavily built central areas of the settlements. Although the position of the theater in the city centre is the most favourable in terms of accessibility, priority is given to those theaters that are further away from the centre, because they have the ability to organize their work more adequately.

6. RECOMMENDATIONS

Based on the conducted research and the observed interdependence between the buildings and their immediate environment, the following interventions are proposed:

- It is essential for the theaters to function not as isolated individual institutions, but to include the state in the organization of their work. Networking of theaters should be ensured on an international scale as well.[5]
- Since the number of visitors depends on the represented forms of transport, as well as the level of development of traffic communication means at the city and intercity scale, it is essential to intervene in this area too.
- In settlements that have no organized public transport, at least one line should be introduced, if it does not already exist, which would link transportation facilities and residential areas with theaters.
- There are several ways of resolving the issue of stationary traffic: prohibition of the movement of motor vehicles in the center of the settlement, introduction of a traffic regime or the use of taxis, public city transportation and bicycle traffic. Another solution would be the construction of garages in the vicinity of the theaters.
- Fountains should be built on all plateaus in front of theaters in order to refresh the air in the warm summer months. Such an intervention would also improve the aesthetic quality of the area in the settlement where the theater is located.
- In places where there are leveling differences, it is required to set up a ramp with a slope of 5% for independent movement of persons with disabilities as accessibility standards may only be met by comprehensive shaping of a space according to universal design principles. [12] [13]
- When possible, it is necessary to set up vegetation on the plateaus as a protection in order to provide "the inhabitants with nature, meet their atavistic needs and soften the hard and definite surfaces of urban structures, provide shelter in its shadow and introduce a lively green colour of its leaves to the ever-gray palette of an urban ambiance.“ [14]
- Subsequent providing of parking space could be solved by building a garage in the area of the wider city centre.
- The exclusiveness of the theatrical event and the invitation for citizens to participate in the spectacle can be provided by a temporary change in traffic regime, banning motorized traffic.
- It is necessary to organize a plateau in front of each theater building, and the existing ones need to be extended and rearranged.
- Since the theater is a facility whose functioning should not be dependent on climate conditions, it is necessary to provide a functional, healthy and interesting plateau which enables a simple, easy and safe access and entry to the building.

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[5] Since 2011, there have been attempts to revive theaters by organizing international manifestations such as the "Theater Night". This is an event organized by an international network "European Theater Night". European Theater Night is an international project launched in 2008 in Croatia in order to directly stimulate creativity in drama and acting on the territory of the entire Europe and bring culture closer to the general public. From its beginning until today, this event takes place each year, besides Croatian and Serbian, also in Belgium, the Czech Republic, Slovakia, Austria, Slovenia, Bosnia and Herzegovina, Bulgaria, Montenegro, Slovenia and Hungary. (Blic Online 11/11/2014) Available at http://www.blic.rs/Kultura/Vesti/510273/Noc-pozorista-u-subotu-u-24-grada-Srbije (02/02/2015)

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APPENDIX

Avalilable on: http://casopisi.junis.ni.ac.rs/index.php/FUArchCivEng/article/view/5364/3320

PREPORUKE ZA URBANISTIČKU REVITALIZACIJU LOKACIJA POZORIŠTA, STUDIJA SLUČAJA – REPUBLIKA SRBIJA

Sa ciljem da se poboljša kvalitet funkcionisanja pozorišta u naseljima Republike Srbije, istražili smo kvalitet lokacije pozorišta prema prethodno formiranom modelu. Opšte prisutan proces globalizacije doveo je do značajnih promena u oblasti kulture, a samim tim se smanjilo i interesovanje za klasične pozorišne predstave. Loše stanje pozorišnih objekata u arhitektonsko-građevinskom smislu i njihovog neposrednog okruženja, u urbanističkom, posledica je dugogodišnjeg zanemarivanja oblasti kulture na nacionalnom nivou. Sumiranjem ukupnih bodova za specifične urbane aspekte dobijenih na osnovu sprovedenog istraživanja i prethodno prikupljenih podataka, utvrđeno je da je prosečna ocena lokacija pozorišta 6 od maksimalnih 10, na osnovu formiranog bodovanja i vrednovanja utvrđenih aspekata u okviru istaživanja. Pošto je aktivno funkcionisanje pozorišta na lokalnom nivou značajno za razvijanje tradicionalne kulture stanovnika, opravdano je da se predlože konkretne mere transformacije neposrednog okruženja pozorišta i da se one što pre implementiraju za 30 postojećih pozorišta u Republici Srbiji.

Ključne reči: *model vrednovanja lokacije pozorišta, urbanističke intervencije, pozorišta Srbije*

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FUNCTIONAL AND AESTHETIC TRANSFORMATION OF INDUSTRIAL INTO HOUSING SPACES

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Abstract. *Buildings preservation by the conversion of their function has become a domain of interest in the field of industrial heritage. Due to the need to expand existing housing capacities in urban areas, a large number of industrial buildings are nowadays converted into multi-family and single-family housing. The paper deals with the analysis of the functional and aesthetic internal transformation of industrial into housing spaces. The research goal is to determine the principles of conceptualization of housing functional plan within the framework of the original physical structure of the industrial building, at the architectonic composition level and housing unit (dwelling) level. Besides, the paper aims to check the existence of common patterns of the aesthetic transformation of converted spaces, examined through three epochs of the development of industrial architecture: the second half of the XIX century, the first half of the XX century and the post-WWII period.*

Key words: *interior, conversion, industrial space, housing space, functional transformation, aesthetic transformation*

1. INTRODUCTION

In the process of forming new or adapting existing physical structures, architectural design is the basic instrument of (re)shaping a spatial environment following human needs, cultural, urban and economic requirements. The architecture of internal spaces represents an integral part of the design process, while the users' behavior and their comfort depend largely on the quality of the interior designs (Petermans & Pohlmeyer, 2014; De Botton, 2006). Internal architecture implies an appropriate choice of design elements whose mutual relation, rhythm, and position, a contrast in terms of colors, materials, textures, and lighting, form the specific aesthetic experience of the space, functionally and constructively justified. The functionality, as the primary determinant and the usable dimension of the interior

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spaces, is determined by the activities of the users. The constructive component defines volume and form of the interior space, resulting in a compositionally harmonic entity (Kojić Đ., 2001).

The contemporary concept of sustainable development has brought the field of actions in terms of urban recycling, as well as the revitalization and conversion of the buildings that are no longer in use, often recognized as a significant part of built heritage. In the process of conversion of abandoned buildings into new purposes, the interior spaces of the existing structures suffer the highest degree of transformations. Changes can be recognized by the functional and aesthetic transformation, originally already defined spatial forms, followed by an appropriate contemporary interpretation of tradition, all to create new sustainable values and solutions. Generally, there is a tendency for partial or complete preservation of the identity of the building and its cultural values, adding a layer of functionality while respecting human needs and current trends. Such spatial permeation creates new interior designs combining historical and contemporary styles (Tappe, 2017).

Due to the restructuring of the industrial sector, many production facilities have been closed, while nowadays abandoned areas and buildings occupy locations in the city centers (Stangel & Witeczek, 2015; Špirić, 2015). To preserve recognized values of industrial architecture and physical structure of the buildings, the issue of conversion of industrial buildings has become more important. Industrial buildings can be successfully converted into different types of purpose, depending on their morphological characteristics, site conditions, economic and social factors. Due to the continuous urbanization processes as well as growing demand for the construction of housing environments (Živković et al., 2016), local communities often choose to convert abandoned industrial facilities into single-family and multi-family housing.

The paper examines the conversion of the former industrial facilities into contemporary housing spaces. Research provides an overview of the functional and aesthetic transformation of the interior spaces, valorizing the determining parameters. The research goals are:

1. Determining the principles of a functional layout within the framework of existing physical structures, at the architectonic composition level and the level of the housing unit (dwelling) of a newly designed housing facility;
2. Analysis of the aesthetic transformation from the aspect of the preservation degree of the original internal form, construction, materials, and their correlations with the newly introduced design elements and equipment, as well as the determination of common principles of aesthetic transformation recognized through the epochs of the development of industrial architecture.

2. Adaptive Reuse of Industrial into Housing Spaces

2.1. Historical development and features of industrial buildings

Industrial architecture evolved alongside the emergence of the industrial revolution in the second half of the XVIII century, triggering social and technological development around the world. The first buildings were built to set up appropriate constructive elements to protect the production process from external conditions, while visualization was neglected (Kojić B., 1962). Economics and rationality of the production process were key motives in designing industrial buildings. At the beginning of the XX century, architectural design principles started to change due to the increased need for a comfortable working space. Nowadays, the aesthetic of form, facade articulation, used materials and construction systems, which is closely related to the historical epoch as well as their morphological characteristics, makes them authentic in the term of built heritage.

Industrial buildings from the late XVIII and XIX centuries were mostly built in the form of *mills factories* that included different manufacturing plants and warehouses in urban areas (Tyrrell, 1911). The physical characteristics of their interiors had resulted from the need to provide adequate spatial capacities for equipment and machines of large dimensions, without the existence of many internal obstacles, developing an open functional plan. These multi-story facilities were often built in a masonry system, made of brick or stone, or with timber structural frames with flat roofs, and isolated staircases for fire protection (Douglas, 2006). Constructive elements and materials were visible from the outside and in the interior of the buildings. The elongated rectangular forms enabled optimal natural transverse lighting and ventilation of the interior spaces, through the openings positioned in a uniform rhythm on the longitudinal facades (Table 1).

Industrial buildings from the beginning of the XX century were made of concrete and steel, in a frame construction system. The use of these materials soon enabled the construction of significantly bigger structures, housing all stages of the production process in one building. Industrial zones moved from urban to peripheral areas of the cities. Firstly, facilities were built in the form of multi-story daylight factories, with a visible construction and large openings that spread from floor to ceiling, providing a high degree of penetration of natural light into the interior (Cantell, 2005). In the following years, steel took the lead in the construction of single-story large-span industrial buildings (Table 1). High flexibility characterized their interior spaces, while the lighting was enabled also through roof lanterns (Jevremović et al., 2012). In the first half of the XX century, industrial architecture also developed under the influence of Modern movement (Le Courbisier, 1973).

Table 1 Overview of the characteristics of industrial buildings by epochs

Historical epoch	2nd half of XIX century	1st half of XX century	post-WWII period
Location	urban areas	urban/peripheral areas	peripheral areas
Number of floors	mostly multi-story	multi-story/single-story	mostly single-story
Building composition	elongated, rectangular	elongated, compact	various
Form of the roof	flat/slope	flat/slope	flat/slope/jagged
Openings character	uniform rhythm, often arched upper part	uniform rhythm, square and rectangular shape	various rhythm and forms
Openings dimension	medium	"from pillar to pillar"	various
Construction system	masonry/frame	frame	frame
Construction span	medium	large	various
Structural elements	brick/stone walls	concrete/steel pillars	concrete/steel pillars
Material - walls	brick/stone	concrete/brick	concrete/metal panels/asbestos
Material - celling	brick/stone/timber	concrete/steel	concrete, steel

Industrialization in the post-WWII period reaches its peak with the expansion of the cities. Industrial buildings were massively constructed in the 1950s and 1960s in the peripheral areas of the cities. They were built in the form of single-story and multi-story facilities, characterized by the minimal thermal standard, and the variety of forms and structures (Douglas, 2006). The post-WWII buildings were under the strong influence of

Modernism, using prefabricated concrete for structural elements (Milojković et al., 2017). They were often in a steel frame construction with large roof surfaces and the use of materials as concrete, lightweight metal panels and asbestos for façade construction.

2.2. Protecting industrial heritage using the principles of adaptive reuse

Deindustrialization swept Western capitalist countries in the 1970s while at the end of the XX century brought the decline of manufacturing in the socialist countries, causing many urban changes. Due to the shift of the industry-based economy to the service sector many industrial complexes were closed, so nowadays these brownfield areas occupy the attractive urban cores. Abandoned industrial buildings are no longer needed for former purposes, while new production facilities are intensively built-in peripheral free zones (Stas, 2007). In some cases, facilities are being demolished to release previously occupied areas for new urban activities, while in others they are recognized as suitable for the reuse (Stanojević et al., 2019).

The idea of preserving industrial heritage was developed primarily to use the social, cultural and economic benefits of brownfield areas while promoting the identity of the city to attract domestic and foreign investment, tourists and the population (Hussein, 2017; Mengusoglu & Boyacioglu, 2013). At the end of the XX century, the adaptive reuse of abandoned facilities is recognized as the concept that supports the sustainable change of the built heritage. Adaptive reuse not only prolongs the lifespan of industrial buildings but also preserves and cultivates valuable elements of industrial architecture of different epochs (Turnšek, 2013). It involves a set of measures of transforming the existing architectural structure following the functional, technical, constructive, and aesthetic requirements set by the new purpose. Further, it requires the legally prescribed permission to change the purpose of a facility, reconfiguration of the functional plan (implementing a new functional matrix into an existing construction pattern), as well as recycling materials and components of the envelope of the building. New requirements must be met within the physical boundaries of existing facilities, resulting in transformations of space relative to the original structure (Eyuce O. & Eyuce A., 2010).

Designed to accommodate large machines and other equipment, industrial facilities provide significant opportunities in terms of conversion into different purposes. Their adaptability depends on their morphological characteristics, resulted from the typology of industrial facilities (mills factories, daylight factories, single-story halls, etc.) characterized by the different number of floors, span dimension, type of construction, used materials, etc. (Straton, 2005). The conversion process primarily reflects on internal architecture. Designed program of contents determines the extent and type of interventions within the facility. In this regard, internal architecture, design, and conversion are closely related to the different degrees of the transformation of a given space. New interventions within already-built structures require the establishment of an appropriate relationship with the existing spatial composition, whereby we distinguish three models of interventions (Keković, 2014):

- full respect for inherited spatial structure;
- creating a new spatial structure with respect to the existing one;
- built-in the new structure into the existing space.

The choice of an intervention model in the conversion process depends primarily on whether the building is under a certain regime of built heritage protection, or whether there are legal constraints in terms of the level and scope of interventions. In case of cultural monuments, there is no change in the external form and envelope of the buildings, while interventions are concentrated only on the interior, using the existing structural pattern and materials, with additional contemporary materials and equipment. The approach is related to the personal affinity of the designer and his/her developed sense of preserving the industrial heritage. Redesigning the interior can be conservative, completely contrasting with the original, or a compromise between contemporary and inherited.

2.3. Possibilities and constraints in the conversion of industrial into housing spaces

Progressive urbanization processes have caused an increase in the number of inhabitants in urban areas, raising the question of the need to expand the capacity for housing within existing urban structures. Strengthening of the real estate market across the world has a huge impact on converting abandoned buildings and areas into residential purpose (Turnšek et al., 2018). Thus, the costs of constructing buildings, the price of renting apartments and land acquisition are reduced, while protecting the resources of local communities (Živković et al., 2011). Also, given the attractiveness and position of abandoned buildings within the urban areas, former industrial facilities are often converted into residential ones. In the process of transformation, it is necessary to respond to the needs of future users and to fulfill the requirements of the housing purpose, related to the dimensional characteristics of the space, views, orientation, access, natural lighting, etc. In this regard, different types of industries, depending on their morphological characteristics, are more or less adaptable and suitable for converting to multi-family or single-family housing.

Physical parameters (criteria) to be taken into account in the process of conversion into housing spaces imply (Petković-Grozdanović et al., 2016):

- the spatial capacity of the building (size, number of floors, cross width/depth);
- the possibility of natural lighting of the interior of the building;
- qualitative functional organization and flexibility of the new housing space;
- the possibility of forming open areas (terraces);
- the ability to form and/or to implement horizontal and vertical communications.

The spatial capacity of the building depends on dimensions of the existing structure, its volume and the number of floors. Multi-story industrial buildings, such as XIX-century mills factories are suitable for conversion to multi-family housing. In the process of their reuse, the dwellings are positioned on higher floors, while lower floors are intended for commercial and business contents. Single-story industrial facilities can be successfully converted into single-family dwellings. If the spatial capacity does not meet the requirements, there is a need for vertical extension or division of the existing form and volume. The cross depth of the building determines the degree of natural light penetration into the interior as well as the functional layout of the architectonic composition. The cross depth up to 16m provides high-quality natural lighting with the possibility of forming a central corridor, supporting the sub-division of the plan (Llewelyn, 2000). Mills factories have an optimum depth for conversion into multi-family housing, while single-story one-span facilities are suitable for single-family housing. Additional interventions in the form of introducing atriums are needed for other types of industrial buildings.

The quality of the layout of a newly-designed residential building depends on the degree of flexibility of the existing structure. Optimal spans, applied construction systems as well as the open functional plan, that characterize industrial buildings, make them suitable for conversion. Outdoor spaces are formed by the introduction of terraces in multi-family housing. Roof gardens are characteristic for lofts within former multi-story industrial buildings and single-family dwelling of former production facilities. Respecting fire protection demands, if the functional plan allows, the existing staircases are used, while otherwise, it is necessary to introduce an additional staircase within or outside the existing facility structure.

3. Conceptualization of the Functional Plan in the Conversion Process

The conceptualization of the functional plan of the adapted industrial structures will be examined through two different levels: the architectonic composition level of the new residential building and the level of the individual housing unit (dwelling).

3.1. Architectonic composition level of converted industrial building

The architectonic composition of a residential building includes dwellings, as its building elements, vertical staircases, and elevators that connect floors, corridors to access to each housing unit, common premises, and open outdoor spaces. In the process of conversion of former industrial facilities, spatial modifications are recognized by adapting the disposition of new contents in already defined spatial forms and constructive scheme. Given that industrial facilities, both single and multi-story, are most often characterized by an open plan, with the absence of internal walls or a limited partition of different phases of the technological process, the conversion implies a certain degree of vertical and horizontal division into smaller functional units. The following functional parameters for future residential building should be considered, at the level of the architectonic composition:

- clustering the housing units concerning the position of staircases and corridors as well as the existing constructive scheme;
- the position and number of staircases and corridors on each floor;
- qualitative functional layout and flexibility of the newly-designed space;
- the access to housing units and their degree of individualization (privacy);
- the implementation of outdoor spaces.

Multi-story industrial facilities suitable for conversion into multi-family housing are of elongated rectangular forms. They have an envelope consisting of supporting masonry walls or/and frame construction with a limited number of internal pillars. In the conversion process, the existing plan is divided into smaller functional units transversally. The housing units are positioned along longitudinal facade fronts, following the existing pillars disposition in the formation of partition walls (Figure 1,2,3). Thus, the pillars are not visible within the dwelling or as "dotted" elements do not burden the functional plan. The depth of the building enables the formation of a central corridor, in relation to which the housing units rely on its both sides. Their orientation is one-sided or double-sided with those occupying the angular parts of the building (Figure 1). Ground floors are often conceived with private external entrances to each of the dwelling, contributing the degree of individualization and living quality. Staircases, usually positioned along one of the longitudinal facades, remain preserved with certain constructive reinforcements or are replaced by the newly-designed ones, retaining the same position as in the original facility. If the number of existing staircases is not sufficient, the introduction of new ones occurs in the form of annexed vertical volumes, which rely on the external side of the longitudinal facade front (Figure 2). The service facilities (sanitary facilities, kitchens, etc.) are positioned to the inside of the plan, while the premises that need natural lighting (living room, dining room, bedrooms), to facade fronts.

In order not to reduce the existing spatial capacity at the expense of long internal corridors, and to provide the optimal area surface of the housing units, accesses can be in the form of shorter corridors along the external facades. When the cross depth of the building exceeds the optimal measure of 16m, the central atrium must be formed, between which staircases and corridors are positioned. Thus, the architectonic composition is in the form of a double-track solution (Figure 3). The access to each of the housing units is enabled via private corridors, which increases the degree of individualization. When buildings are under the regime of the heritage protection that does not allow additional interventions on the facades, the open areas of housing units cannot be designed (Figure 2). In some cases, when the former industrial building has a small number of floors, there is an extension and the formation of roof terraces for two-level or three-level dwellings (duplexes or triplexes). In multi-story buildings, if there is legally prescribed permission, consoled terraces appear as new facade elements (Figure 3). In ground-floor dwellings, open spaces are often in the form of courtyards, as in single-family housing.

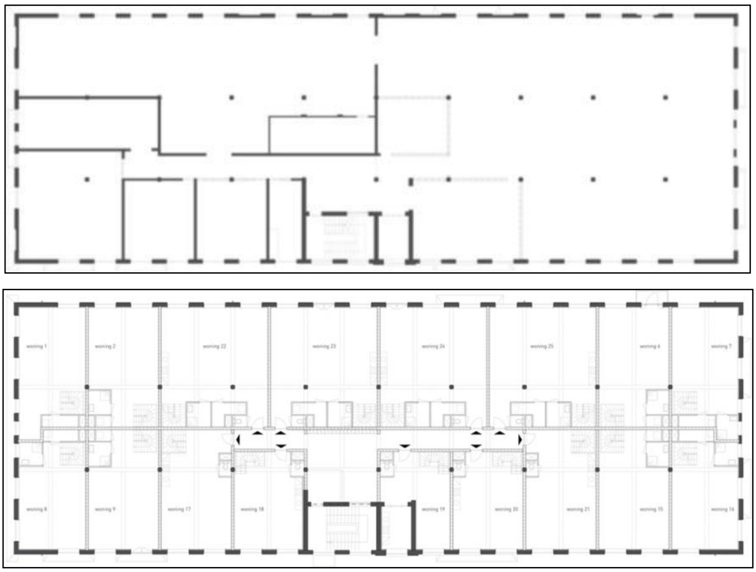

Fig. 1 Conversion into multi-family housing - De Lakfabrieken, Netherland, 1925/2018 (Source: https://www.archdaily.com/904708/de-lakfabriek-wenink-holtkamp-architecten)

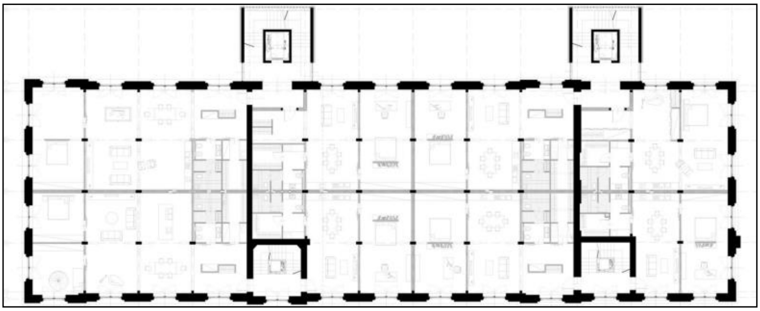

Fig. 2 Conversion into multi-family housing - Granary Gliwice, Poland, 1892/2008 (Source: https://www.archdaily.com/36172/adaptation-of-former-granary-medusagroup)

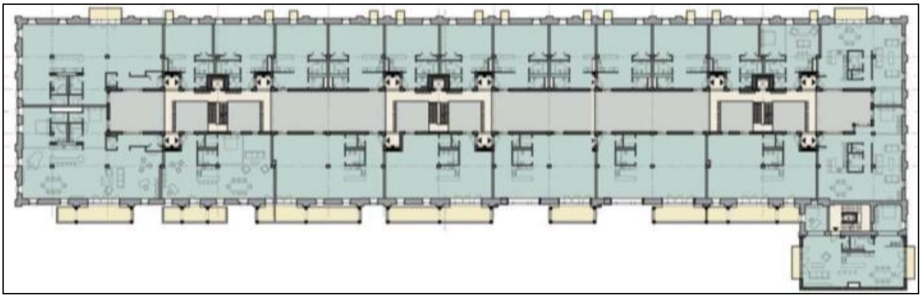

Fig. 3 Conversion into multi-family housing - Mill Lofts, Budapest, 1880/2008 (Source: http://www.capitalrealestate.hu/PDF/Mill/Malom_ENG_bel.pdf)

Single-story industrial facilities are mostly of elongated rectangular forms, built in the frame construction system. In the process of conversion into a single dwelling, the functional plan is not divided. In cases of conversion into two or more housing units division is done transversally, positioning the units along the longitudinal facades (Figure 4). In this way, each housing unit has double orientation, spreading over the entire depth of the structure, forming row dwellings. Often, a vertical division of one-volume spaces into duplexes is done, introducing celling construction or upgrading with a new volume. If there is no possibility for the formation of the courtyard, the roof terraces can be formed. The facilities with a jagged roof can be successfully converted, with the formation of roof-level penetration to create open area and additional interior lighting.

Fig. 4 Conversion into single-family housing - Plans of Prato Lofts, Prato, Italy, 1960s/2008 (Sources: https://www.archdaily.com/311426/prato-lofts-mdu-architetti)

3.2. Development of the functional plan of an individual housing unit

At the housing unit (dwelling) level, the following parameters should be taken into account, which also affects the flexibility (Živković & Jovanović, 2012):

- the layout of service facilities, daily and night zone of the dwelling;
- the position of the staircase in duplexes and triplexes;
- the orientation of the housing unit and the geometry of the functional plan;
- the implementation of open spaces.

The main motive of the layout of individual housing unit, in the process of conversion of industrial spaces, is the open plan, achieved by minimizing the interior division. The plan geometry is mostly compact, but there are cases of "L" shaped basis. The orientation of the dwelling ranges from one-sided or two-sided in multi-family housing, or more in single-family housing. In one-level dwelling, the daily zone is unique space, while the bedrooms, kitchen and sanitary facilities are isolated by walls. In case of two-level or three-level dwellings, the lower level represents a daily zone, while the upper levels, usually formed as a gallery, is a night block with a work space (Figure 5). By introducing gallery floors, the feeling of openness of the living space is created in the vertical plane. Similar principles are also applied in conversion of single-story industrial facilities. In some cases, bedrooms are separated by moving, light fixed walls or curtains (Figure 6). Open spaces are often in the form of roof terraces, while in multi-family housing there are balconies from the living rooms.

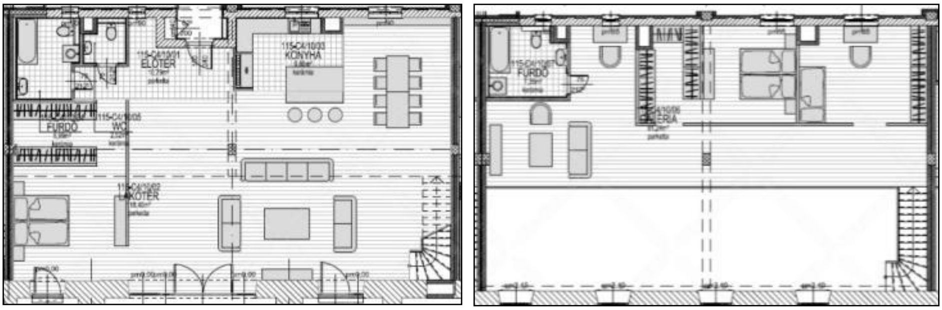

Fig. 5 Two-levels unit Mill Lofts, Budapest (Sources: http://www.capitalrealestate.hu/PDF/Mill/Malom_ENG_bel.pdf)

Fig. 6 One-family house - 102 Mill, Sidney, Australia, 1950s/2018. (Source: https://www.archdaily.com/902100/102-the-mill-carter-williamson)

4. ANALYSIS OF AESTHETIC TRANSFORMATION IN THE CONVERSION PROCESS

Analysis of the aesthetic transformation of industrial spaces in the process of their conversion into housing, will be considered through parameters such as the degree of preservation of the original form, construction supporting elements, materials, and their relation to newly - introduced design elements. Further, the transformation of the interior space will be observed concerning three characteristic epochs of the development of industrial architecture, considering the design of converted industrial facilities from the second half of the XIX century, the first half of the XX century, and the post-WWII period.

4.1. Aesthetic of converted industrial space from the 2nd half of the XIX century

Industrial multi-story buildings from the XIX century were characterized by a masonry or frame construction system, with a brick or stone walls, while the ceilings were of brick or timber. The openings placed in a uniform rhythm, as a facade and internal aesthetic elements, were arched from the above, with horizontal and vertical divisions. When construction combined the outer masonry walls with the inner pillars, the pillars and ceiling were of the timber structure. A large number of industrial buildings from this period is under protection regime, as a recognized part of cultural heritage. To preserve the proportion of the interior, characterized by a distinct floor height, the practice shows that in the conversion, the same floor division is maintained. In some parts of the living space, a suspended ceiling is often used to create new internal volumes (Figure 7, right). The most common applied pattern is the introduction of a gallery floor, which makes spatial capacity more functional while the sense of spaciousness is not endangered (Figure 8). From the aspect of construction, it is necessary to make certain reinforcements of the external walls by introducing new pillars as support, as well as reinforcing the ceilings. Floor coverings are made of contemporary materials, such as decking and parquet.

Fig. 7 Interior of Time Warehouse, Santana, Japan, 1896. and Yarn Works, Fitchburg, USA, 1900s (Sources: https://www.archdaily.com/877669/warehouse-of-time-ft-architects; https://www.archdaily.com/881830/yarn-works-the-architectural-team)

The common characteristic of conversion of industrial spaces from this period is the aspiration for the highest degree of preservation of the internal form, the existing construction elements, the openings of the outer envelope and its materialization. Timber ceilings and pillars are retained as original, giving a rustic note to space. White-colored parts of walls, ceilings, pillars, and gallery floors are recognized as aesthetic elements which contrast to traditional materials and textures (Figure 7 right, Figure 8). The brick walls are retained and combined with the timber, which gives a warm note to the living spaces. Newly introduced staircases are sometimes interesting interior elements that visually fit in the existing composition. They can appear as steel dark-colored structures, opposite to traditional materials (Figure 7, left). In some cases, the original interior is completely preserved, with interventions limited to equipping the space with the appropriate furniture. The emphasis is on the natural lighting of the interior, with the appearance of spot artificial lighting, implemented in the ceiling beams. The furniture is contemporary, often with timber elements, glossy surfaces, while new textures and strong coloring appear as individual pieces of furniture and details (Figure 8).

Fig. 8 Interior of Mill Lofts, Budapest, Hungary and Tribeca Loft, NY, USA, both from 1880. (Source: http://www.capitalrealestate.hu/PDF/Mill/Malom_ENG_bel.pdf; https://www.archdaily.com/611915/tribeca-loft-andrew-franz-architect)

4.2. Aesthetic of converted industrial space from the 1st half of the XX century

Multi-story industrial buildings from the first half of the XX century, suitable conversion to multi-family residential buildings and lofts, were built in frame construction system, most often of concrete pillars and ceilings. These buildings are specific for their openings of regular rectangular shapes, large surfaces, which were often spread all over the floor height and which had an orthogonal horizontal and vertical division.

The conversion of this type of industrial spaces into housing spaces shows certain common principles of aesthetic transformation. Existing construction elements and openings are completely retained. The pillars, beams, and walls are often white-colored (Figure 9). Sometimes, they retain original form, color, and texture, revealing the roughness of the concrete structure while emphasizing exposed installation pipes, the beams, pillars of square or circular cross-section, often integrated with" mushroom" ceilings (Figure 10). Different types of contemporary epoxy coating in neutral tones are used as final flooring. The primary characteristic of the transformed interior design lies in the minimalism present through the absence of color and details, the use of gray and white colors of walls, ceilings, floors, and stairs, as well as simple pieces of furniture. The accent is on large openings, their simple shape, and natural lighting. Artificial lighting arises in the form of inconspicuous lamps. Uniquely designed interiors of the open functional plan have a certain amount of elegance. In some cases, the user's equipment is fully integrated into the existing ambient and spatial composition in terms of neutral tones (Figure 9 on the right), while in others the accent is only on the furniture (Figure 9 on the left). The visual contrast of the monochrome scheme is achieved through specific details in bright colors, characterized by modern pieces of furniture or warm tones of certain timber elements (Figure 10).


Fig. 9 Interior of Collectors Loft, USA, 1920s and Clerkenwell, London, 1930s (Source: https://www.archdaily.com/127802/collector%25e2%2580%2599s-loft-poteet-architects; https://www.archdaily.com/794048/clerkenwell-residence-apalondon)


Fig. 10 Interior of Arts District Loft, LA, USA, 1924. and Art Loft Chai, China, 1920s (Source:https://www.archdaily.com/878049/arts-district-loft-marmol-radziner; https://hypebeast.com/2015/9/art-loft-chai-wan-by-mass-operations)

4.3. Aesthetic of converted industrial space from the post-WWII period

Industrial facilities built in the post-WWII period, occurring in the form of multi and single-story production halls and warehouses. They are characterized by a variety of forms and structures and built in a frame construction system made of concrete or steel. Openings are of different shapes and sizes. The facilities suitable for converting into housing are the small-span single-floor facilities that are simply transformed into single-family housing.

Due to the high degree of diversity of the original industrial structures from this period, the common principles of aesthetic internal transformation are not fully recognized. One of the main characteristics of the conversion process is retaining the existing construction elements. If there is no upgrading of new floors, roof construction, most often steel, remains visually attractive element in the interior. Interior transformation is usually done by adding a variety of volumes and radically changing the outer envelope in term of materialization and breaking of new openings (Figure 11). When there is a vertical space division by the introduction of the gallery floor, the staircase becomes a significant aesthetic element. Newly introduced volumes mostly comprise service facilities (kitchens, sanitary facilities, etc.) and the contents of the gallery floor. Floor coverings are of modern materials-parquet, epoxy coatings. White and bright colors dominate the interior of the living space and appear on the walls and ceilings, but also through the users' equipment. Apart from the construction, in designing the interior nothing indicates an industrial past. Equal attention is paid both to natural and artificial lighting, to maximize the opening of facade fronts and lightning daily zones. Wood is recognized as applied material, both in the floor covering and stairs, as well as through furniture (Figure 11). Coloring is usually reduced to a few warm tones, while the application of textures is limited by balancing the texture of wood and glossy surfaces of floors and kitchen elements.

Fig. 11 Interior of Bowstring Truss, USA and Up-cycled Warehouse, Australia, both from 1960s (Source: http://www.worksarchitecture.net/work/bowstring-truss-house; https://www.archdaily.com/879131/up-cycled-warehouse-zen-architects)

5. CONCLUSION

Adaptive reuse, as a concept developed with the promotion of the sustainable principles, offers a wide range of possibilities in the field of architectural design, to extend the life of buildings that are no longer in use but are part of architectural heritage. Supporting the idea that the past should be preserved and following the requirements imposed by contemporary spatial standards, many industrial facilities have been converted into various purposes, including housing as an important urban function. The paper has analyzed the principles of aesthetic and functional interior transformation in the process of converting industrial spaces into single-family and multi-family housing. The conducted research corresponds to the issues within the initial set of research aims.

Within the framework of the goal to determine the principles of the functional layout of converted industrial buildings at the architectonic composition level and the level of the housing unit (dwelling), the carried-out analysis resulted in the following conclusions:

- practically every type of industrial facility, with appropriate interventions, can be successfully converted into housing spaces;
- the depth of the industrial building is one of the most important physical parameters in the conversion process, as it affects whether the future residential building will be conceived as a single-tract or two-track design solution in case of multi-story facilities, or as single or dwellings in a row in case of single-story facilities;
- the division of the plan must be done within the existing constructive scheme, whereby staircases remain at the same positions with the introduction of new ones if needed;

- open areas, depending on the number of floors of the existing industrial facility, its morphological characteristics and the degree of protection regime, are formed as console terraces, roof gardens, or are not foreseen by the design project of conversion;
- service facilities are positioned to the inside of the functional plan, while the other rooms of the daily and night zone of the dwelling are oriented towards the facade fronts;
- the flexibility of the housing unit is achieved through an open plan, minimizing the internal walls and/or introducing gallery floors.

Within the framework of the research goal to determine the principles of aesthetic transformation observed through the characteristic epochs of the industrial architecture, several conclusions were reached. Analyzing the design of converted industrial spaces from the second half of the XIX century the following is recognized:

- the high degree of preservation of the original form, materials and construction elements;
- the introduction of gallery floors due to large story height;
- diversity in the use of modern colors, materials, and equipment;
- the contrast between the old and the new, respecting the industrial past, while promoting contemporary styles.

Analyzing the design of converted industrial spaces from the first half of the XX century the following is recognized:

- the high degree of preservation of the original form, materials and construction elements;
- minimalism as a style present by neutral tones and simple furniture;
- contrast is emphasized using modern furniture.

Analyzing the design of converted industrial spaces from the post-WWII period the following is recognized:

- the low degree of preservation of the original form and materials;
- preservation of construction elements as parts of the industrial past;
- promotion of different contemporary styles, materials, and colors.

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FUNKCIONALNO I ESTETSKO PREOBLIKOVANJE INDUSTRIJSKIH U STAMBENE PROSTORE

Očuvanje objekata kroz njihovu adaptaciju novoj funkciji postalo je domen interesovanja u oblasti industrijskog nasleđa. Zbog postojanja potrebe za proširenjem stambenih kapaciteta u urbanim područjima, sve veći broj industrijskih zgrada se danas konvertuje u objekte za višeporodično i jednoporodično stanovanje. Rad se bavi analizom funkcionalnog i estetskog preoblikovanja industrijskih u stambene prostore. Istraživanje se zasniva na cilju utvrđivanja principa konfiguracije funkcionalnog plana u okvirima izvorne fizičke strukture objekta na nivou arhitektonskog sklopa i pojedinačne stambene jedinice, kao i ispitivanju postojanja zajedničkih obrazaca estetske transformacije konvertovanih prostora, sagledanih kroz tri karakteristične epohe razvoja industrijske arhitekture: period druge polovine XIX veka, period prve polovine XX veka i posleratni period.

Ključne reči: *unutrašnja arhitektura, konverzija, industrijski prostor, stambeni prostor, funkcionalna transformacija, estetska transformacija*

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APPLICATIONS OF THE ABRASIVE WATER JET TECHNIQUE IN CIVIL ENGINEERING

UDC 621.924.93

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Abstract. *Water jet processing techniques can be successfully applied in many fields of civil engineering, such as: structural engineering, structural reconstruction, renovation, demolition and recycling. The problem of cutting difficult-to-machine materials led to the development and application of today the most attractive method for contour cutting - Abrasive Water Jet Cutting (AWJC). It is a high-tech technique that provides unique capabilities compared to conventional machining processes. This paper, along the theoretical derivations, provides a study on use of water jet in construction and civil engineering. The particular part of this paper deals with the results of the original experimental research on granite and aluminum cutting.*

Key words: *Abrasive water jet cutting, civil engineering, damage mechanics, granite specimen test, aluminum specimen test.*

1. INTRODUCTION

In the 1960's, an American aerospace company faced the challenge of cutting fiber-reinforced, honeycombed, and sandwich materials. Conventional cutting processes destroyed the material's structure and could not be used. It was, therefore, imperative that a new cutting method is found so that the industry could go forward. The solution was found in pressurizing water to ultra-high pressures and focusing it into a high velocity stream. The first abrasive water jet machine was introduced in 1982. Since then, the technology has grown with the increased use of sophisticated materials and the need for complex shapes.

Abrasive water jet (AWJ) cutting is a non-conventional machining process that uses high velocity water with abrasives for cutting a variety of materials. It is the most suitable process for very thick, highly reflective or highly thermal-conductive materials, as well as hard

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materials. Abrasive water jets can cut a wide range of thicknesses. Typical thicknesses are 100 mm for stainless steel, 120 mm for aluminium, 140 mm for stone, 100 mm for glass, but not limited to that.

Abrasive water jet machining is appropriate and cost effective for a number of procedures and materials and is applied in nearly all areas of modern industry. Table 1 gives a review about industrial applications of the water jet technique [1].

Table 1 Industrial applications of water jet technique

Industrial area	Application
Manufacturing operations	Metal cutting with abrasive water jet
	Conventional machining with water-jet assistance
	Piercing and drilling by abrasive water jets
Civil engineering	Concrete hydro demolition
	Cutting of concrete sections
	Concrete surface preparation
	Surface cleaning
	Architectural profiles
Chemical process engineering	Pipeline cleaning and decoating
	Vessel, container and autoclave cleaning
Maintenance and corrosion prevention	Coating removal
	Emission-free surface preparation
Automotive engineering	Lacquer stripping
	Engine reconditioning
	Deburring
Environmental Engineering	Material recycling
	Emission-free decontamination

2. ABRASIVE WATER JET CUTTING PROCESS

An abrasive water jet is a jet of water which contains abrasive particles. Solid particles – the "abrasive" – join the water jet in a mixing chamber (Fig. 1) and are focused by the abrasive nozzle. High pressure water enters the upper portion of the nozzle assembly and passes through a small-diameter (d_0 = 0.08 - 0.4 mm) water nozzle to form a narrow jet. The water jet then passes through a small chamber where a Venturi effect creates a slight vacuum that pulls abrasive material and air into this area through a feed tube. The abrasive particles are accelerated by the moving stream of water, and together they pass into a long, hollow cylindrical nozzle. The abrasive and

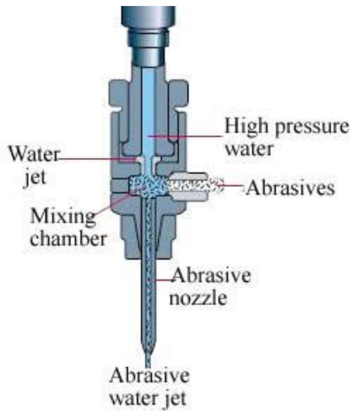


Fig. 1 Abrasive water jet cutting head

water mixture exits the abrasive nozzle as a coherent abrasive water jet and cuts the material.

In the process of abrasive water jet cutting the high pressure pump produces the required pressure up to p = 400 MPa. When the pressurized water comes out from the orifice, a water jet is created. The result is a very thin, extremely high velocity (approx. 900 m/s) water jet. Velocity of the water jet can be calculated on behalf of Bernoulli's law, and is expressed as:

$$v_{wj} = \sqrt{\frac{2p}{\rho_w}} \tag{1}$$

Leakage velocity of water jet from a nozzle is crucial because its role is to accelerate the abrasive particles. Due to the extra weight, abrasive particles, however, cannot achieve the velocity of water jet but only a part of that velocity [2].

The volume flow rate of water may be expressed as:

$$q_w = A_{orifice} v_{wj} \tag{2}$$

$$\text{for } v_{wj} = \sqrt{\frac{2p}{\rho_w}} \text{ and } A_{orifice} = \frac{\pi}{4} d_0^2$$

$$q_w = \frac{\pi}{4} d_0^2 \sqrt{\frac{2p}{\rho_w}} \tag{3}$$

The law of conservation of momentum says that the total momentum of any closed system, i.e., the vector sum of the momentum vectors of all the things in the system, is a constant. The momentum of air before and after mixing will be neglected due to very low density. Further, it is assumed that after mixing both water and abrasive phases attain the same velocity of abrasive water jet. Moreover, when the abrasive particles are fed into the water jet through the port of the mixing chamber, their velocity is also very low and their momentum can be neglected, and the general equation leads to:

$$q_w v_{wj} + q v_a = (q_w + q) v_{awj} \tag{4}$$

$$v_{awj} = \frac{q_v}{q_w + q} v_{wj}$$

$$v_{awj} = \frac{v_{wj}}{1 + \frac{q}{q_w}}. \tag{5}$$

As during the mixing process the momentum loss occurs as the abrasives collide with the water jet and at the inner wall of the abrasive nozzle multiple times before being entrained, the velocity of abrasive water jet is given as,

$$v_{awj} = \eta \frac{v_{wj}}{1 + \frac{q}{q_w}} \tag{6}$$

where η- momentum loss factor, whose values lies around 0.65-0.85 [3].

Then, solid abrasive particles are added and mixed with the water jet. The resulting abrasive water jet is focused to the material through the abrasive nozzle. The impact of solid particles is the main mechanism in the process of removing material by the abrasive water jet [4].

Hashish [5] proposed a general model for the material removal mechanism, in which a stable cutting process takes place to a certain depth of penetration of the abrasive water jet, followed by the formation of steps on the surface of the cut. Below the critical depth, the processing is unstable resulting in the creation of striated or wavy surface of the cut (Fig. 2).

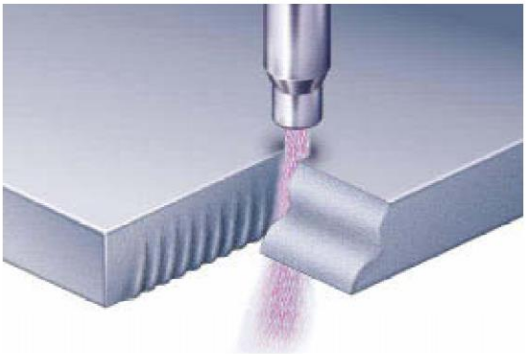


Fig. 2 Development of the cut surface by abrasive water jet cutting

With increasing depth and creating steps, the removal mechanism is changing from cutting to the separating material by plastic deformation. The above-described mechanism, cyclic repeating, resulting in different types of material damage, which is the subject of the study of damage mechanic.

The cut surfaces produced by the abrasive water jet cutting typically exhibit a smooth upper zone followed by a lower striated zone (Fig 3).

These phenomena can be related to the jet loss of energy during the cutting process, e.g. deformation of the sharp edges of the abrasive particles as illustrated in Fig. 4 [6].

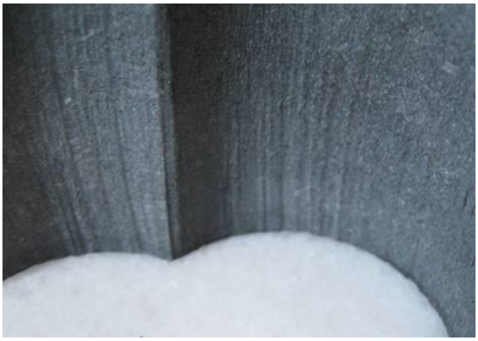


Fig. 3 Cut surface generated by abrasive water jet cutting of granite

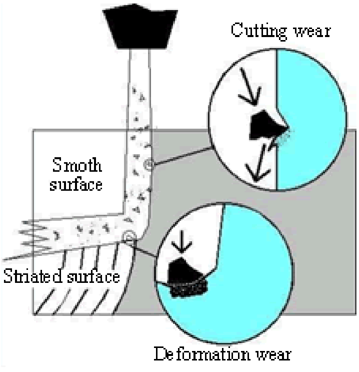


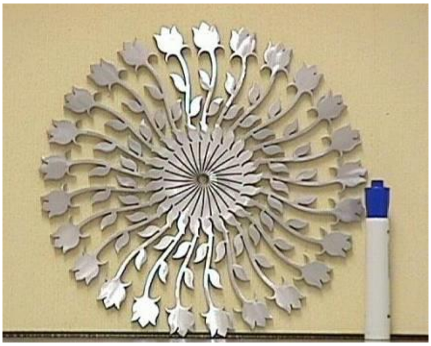
Fig. 4 Formation of different regions in abrasive water jet cutting

Application of cutting by abrasive water jet lie in the field of: non-metallic materials (glass, ceramics, marble, granite, concrete, polymers, composite materials, tool ceramics) and metallic materials (medium and high strength alloy steels, tool steels and stainless steels, abrasion resistant steel, cast iron, aluminum, copper, titanium, tungsten, manganese, hard alloy). Modern abrasive water jet cutting is gaining popularity because of the ability of processing almost any material of significant thickness (Fig. 5). Materials that are reflective, with a high heat transfer coefficient or sensitive to heat treatment, are suitable for cutting with abrasive water jet. As the thickness of the material increases the abrasive water jet cutting is becoming more convenient method of machining, especially when it is necessary to maintain accuracy.

Concrete

Marble and stone

Ceramic



Steel

Fig. 5 The possibility of cutting different materials by abrasive water jet

3. POSSIBLE APPLICATIONS OF ABRASIVE WATER JET TECHNIQUE IN CIVIL ENGINEERING AND CONSTRUCTION

The water jet is a promising tool not only for manufacturing industries but also for the civil engineering field due to its distinctive features of low vibration, little dust, and low impact or disturbance to areas adjacent to the operation. This makes the water jet an environmentally-friendly technique over conventional cutting and dismantling methods such as the use of drilling and blasting, a hydraulic jackhammer, and a diamond saw cutter. Where there is concrete to be removed or prepared for reapplication water jetting is the cost effective solution.

Following are some examples where the water jet has already been used or has been tested and found to be suitable for the application [7].

Concrete hydrodemolition

Hydrodemolition is the process of removing concrete with minimal or no vibration with a water jet (Fig. 6). Hydrodemolition is used for various procedures where deteriorated or damaged concrete has to be removed, but leaving the reinforcing steel washed clean, intact and undamaged. The remaining concrete surface has a rough washed clean finish, with great bonding properties, to allow superior repairs.

Fig. 6 Selective removal of deteriorated concrete

Hydrodemolition is widely used in the construction industry for bridge repairs/ strengthening. The benefits are: no vibration (does not cause stress fractures sometimes called micro cracks), no dust (because you are cutting the concrete with water the area remains dust free and is washed clean at the same time), no damage to steel reinforcing (the steel reinforcing gets cleaned during the jetting process and remains undamaged), thus enabling a fast and cost effective repair.

Concrete Surface Preparation

Surface preparation is used for preparing a surface ready for inspection; repair or maintenance, another form of surface preparation is coating removal. Surface preparation of concrete also known as scabbling or scarifying, it is often done by ultra high pressure water with rotary nozzles. This nozzle has 4 to 6 jets which reduces the impact of water jet and has a larger coverage compared to a standard single nozzle (Fig. 7).

Fig. 7 Surface preparation

Surface Preparation and coating removal with Ultra high pressure water is a technique that has many advantages over sand/grit blasting. When removing coatings from steel surfaces, the water jet only removes the coating and leaves the steel undamaged and clean (Fig. 8). Water jetting does not create dust and reduces the cost of cleanup and disposal of spent abrasive.

Fig. 8 Decoating of reinforced concrete with hand-held high-pressure water jet equipment

Cutting of concrete sections

In the construction industry, the abrasive water jet will most likely be used for cutting steel beams and concrete sections (Fig. 9). For steel, the cutting rates are slower with the water jet than for other tools, such as plasma arcs. However, often the cost is offset by the time saved by reducing or eliminating finishing steps. This is because there is no heat affected zone with the water jet. The water jet has also been able to cut through thick slabs of concrete. This will save in the cost of buying diamond tipped saws and sharpening them [8].

Fig. 9 Cutting of heavily reinforced concrete ceilings

Architectural Profiles

Abrasive water jet cutting has revolutionized the decorative fabrication industry. Many shops experience benefits using this new wave of technology. From simple block letters to complex and intricate designs, abrasive water jet cutting bring ideas of architects and designers from concept to completion within a short time [9]. Extraordinary results and superior edge finishes can be achieved with the state-of-the-art abrasive water jet equipment in cutting diverse materials from marble to glass and brass to wood. Typical applications are ranging from cutting of marble and granite floor inlays to cutting of small labels for name plates (Fig. 10). The variety of shapes and designs in which the signages can be crafted is endless.

Fig. 10 Custom flooring from stone

For use of abrasive water jets in civil and constructive engineering it is specific that equipment often is not located in shops, but these systems can be supplied for mobile operation at construction sites (Fig. 11).

Fig. 11 Mobile equipment and concrete removal with hand-held water jet tools

4. Experimental Work

A series of water jet cutting experiments were conducted in order to determine linear cutting speed at which a complete cut still happens, i.e. to just barely cut through material. In this way a boundary line that separates the area in which the cut is complete, and the one where we have only a partial cut (Fig. 12) is defined.

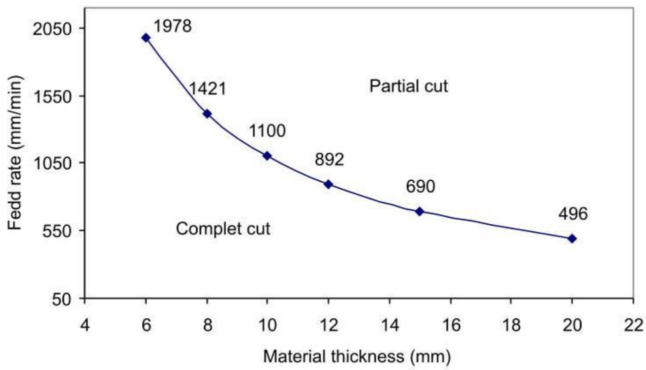


Fig. 12 Cut-through speed boundary line

Work piece material, aluminium alloy AA-ASTM 6060 (Al MgSi) and granite was used. These materials are chosen as a work piece material because they are very attractive and can provide significant value for the end user. Also, aluminium and its alloys are characterized by high reflectivity and thermal conductivity. This makes them relatively difficult to cut with lasers. Abrasive water jet cutting, which does not create an observable heat affected zone, is much more useful for cutting aluminum for modern applications. Granite is a widely used material in construction industry. A high efficiency and high quality cutting method for granite cutting is always demanded by industry. The AWJ cutting may also be used for other rock cutting [10].

The survey was conducted on prepared specimens with thickness of: s = 6, 8, 10, 12, 15 and 20 mm. Other parameter values of the process were:

- workpiece material: granite and aluminium alloy,
- water pressure: p = 400 MPa,
- water nozzle diameter: d_0 = 0,30 mm,
- abrasive nozzle diameter: d_A = 1,02 mm,
- abrasive flow rate q = 300 and 400 g/min and
- distance of the cutting head to workpiece z = 2 mm.

Feed rate (v) is, for each cut, gradually increased, until there was no cut in which the sample is not completely cut through, as shown in Fig. 13.

Fig. 13 Incomplete cut

The value of the cutting speed at which there is a complete separation of material through its whole thickness is influenced by many factors, among which the most important are: the type of material, its thickness, and abrasive flow rate and water pressure [11]. With consideration that, in practice, for cutting we always use the maximum pressure that the machine can achieve, the influence of water pressure, even though it has a major impact on the ability of AWJ cutting has not varied, but the maximum value of water pressure of p = 400 MPa was used.

Diagram showing the influence of the type of material, thickness of the work piece and the abrasive flow rate on cut-through cutting speed (feed rate) is presented in Fig. 14.

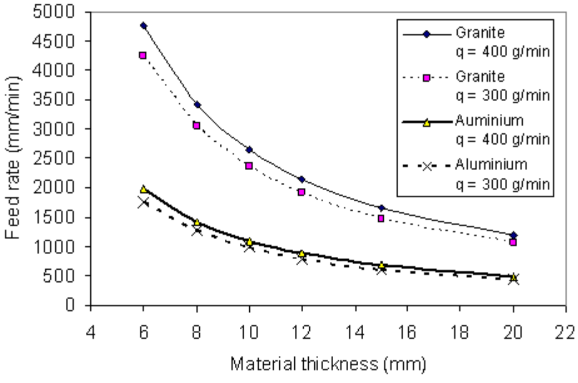


Fig. 14 Effect of process parameters on separation speed

Experimental studies, presented in this paper, were carried out in real working conditions, in which the measured parameters are depending on the parameters of the machining. With the increasing use of abrasive water jet cutting, there is a need for quantitative description of the processing operations, and therefore are necessary mathematical models to describe the process parameters [12].

5. Conclusion

Water jet technique could be successfully employed in many areas of civil engineering and construction, such as: structural engineering, foundation engineering, construction repair, renovation, demolition and in recycling.

Abrasive water jet cutting is of great interest for various reasons. Almost any material can be cut, with a wide range of thickness. The abrasive water jet makes it possible to cut random contours, very fine tabs and filigree structures.

Although there are no restrictions on the types of work piece material by the use of AWJ, however there is a limit to the thickness of the workpiece that can be cost-effectively machined, compared to other cutting processes. Therefore, the knowledge of material cutting speed limit and influence of process parameters is step towards ensuring optimum cost of production and meeting the demands of customers.

In this study, the maximum cutting speed of the machined material in terms of process parameters in AWJ-machined aluminium alloy and granite was investigated experimentally. Summarizing the main features of the results, the following conclusions may be drawn:

- The value of process parameters at which the cut is complete, depend primarily on the type of material and thickness of the work piece. During the processing of aluminum, cutting speed is over two times less than processing granite of the same thickness.
- As the feed rate increases, the AWJ cuts narrower kerf. This is because the feed rate of abrasive water jet allows fewer abrasives to strike on the jet target and hence generates a narrower slot.

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PRIMENA OBRADE ABRAZIVNIM VODENIM MLAZOM U GRAĐEVINARSTVU (GRAĐEVINSKOM INŽENJERSTVU)

Tehnika obrade vodenim mlazom može se uspešno primenjivati u mnogim oblastima građevinskog inženjerstva, kao što su: strukturalno inženjerstvo, rekonstrukcija konstrukcija, renovirenje, rušenje i u potupcima reciklaže. Problem sečenja teško obradivih materijala doveo je do razvoja i primene, danas naj atraktivnije metode za konturno sečenje materijala abrazivnim vodenim mlazom. To je visoko tehnološki postupak koji poseduje jedinstvene karakteristike u odnosu na uobičajene postupke obrade materijala. U ovom radu su, pored teorijskog osvrta, predstavljene mogućnosti primene ove tehnike u građevinskom inženjerstvu, dok su u delu rada predstavljeni rezultata ispitivanja na uzorcima od granita i aluminijuma.

Ključne reči: *Sečenje abrazivnim vodenim mlazom, građevinsko inženjerstvo, mehanika oštećenja, ispitivanje uzorka od granita, ispitivanje uzorka od aluminijuma.*

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CLIMATE ADAPTED HOUSES IN IRAN: HOT, COLD AND HUMID CLIMATE

UDC 72:551.583(55)

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Abstract. *The issue of Climate Change has raised so much attention for decades, specifically in recent years. Modern trends in urban architecture which tried to create living machines similar to each other in any context, have now been proven to be insufficient and unless we decide to respect nature and make our buildings cooperate with their contexts as soon as possible we cannot address further threads regarding our future life. If we take a look at traditional architecture existing in old towns and rural area, we can see how people managed to bond a new construction with its surroundings. In this article we study different architectural patterns which exists in old architectures of towns and villages in Iran; the country which can be a good case study due to its rich diversity of nature, climate zones and architectural background. In Iran we have a range of climate of cities from hot and dry to humid and very cold ones. So, depending on the city climate, water supplies and energy sufficiency people tried to create best residential buildings. Here we try to check out some examples.*

Key words: *Iran, climate change, houses, architecture*

1. INTRODUCTION

The issue of Climate Change has raised so much attention for decades, specifically in recent years. We can now see and feel how everyday life is being affected by the consequences of this global concern and the urge of taking the knowledge into action needs to be addressed more than ever. While more than half of the world population live in cities, Urban Architecture seems to play a significant role in energy usage and sustainability. The way that our buildings respond and bond with their nature can have a crucial impact on energy sufficiency. Modern trends in urban architecture which tried to create living machines similar to each other in any context, have now been proven to be

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insufficient and unless we decide to respect nature and make our buildings cooperate with their contexts as soon as possible we cannot address further threads regarding our future life. If we take a look at traditional architecture existing in old towns and rural area, we can see how people managed to bond a new construction with its surroundings.

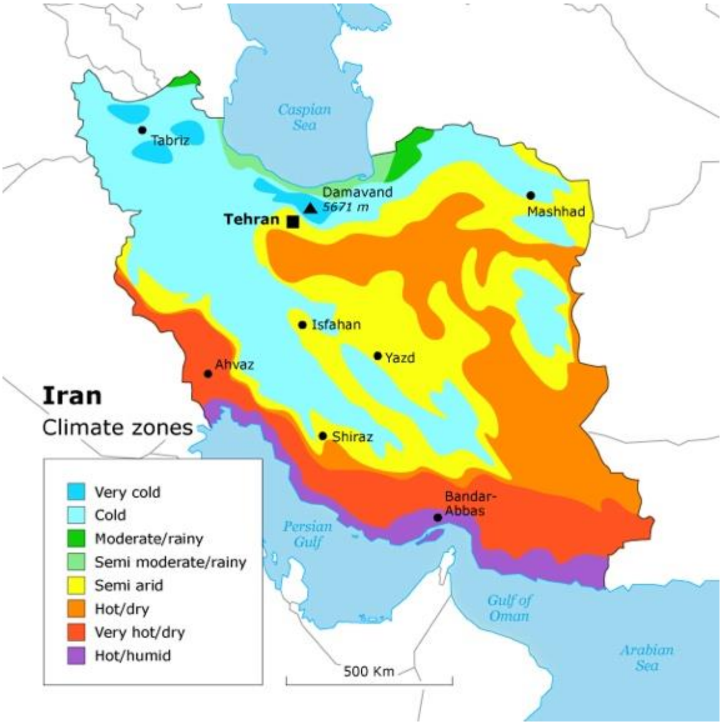

Fig. 1 Iran Climate Zones (Iran Geography, n.d. Archive of Fanack[1])

In this article we study different architectural patterns which exist in old architectures of towns and villages in Iran; the country which can be a good case study due to its rich diversity of nature, climate zones and architectural background. In Iran we have a range of city climates from hot and dry to humid and very cold ones which are shown in the figure below (Fig.1). So, depending on the city climate, water supplies and energy sufficiency, people tried to create best residential buildings. Here we try to check out some examples. To better study the subject, four major climates zones now existing in Iran are classified into 'Hot and Dry' climate, 'Hot and Humid' climate, 'Cold and Very Cold' climate and 'Moderate and Humid' climate. We study the main characteristics of each climate zone and then we mention architectural ideas which helped the building collaborate best with its settings.

The method of research in work is adjusted to the nature of the research, which requires the application of several methods. The methods used here are: analysis, synthesis, comparative method.

[1] https://fanack.com/iran/geography/

2. Hot and Dry Climate

In this climate we have

- Burning sun
- Very high temperature in day in very low temperature at night
- Hot summers and Cold winters
- Dry weather, little raining and lack of water
- Sand and dust thunders

Cities like Yazd, Kerman, Shiraz and Kashan which are mainly located in the middle of Iran comprise this category (Hassan, 2015, 3).

The most important building characteristics are ordered into:

2.1. Orientation

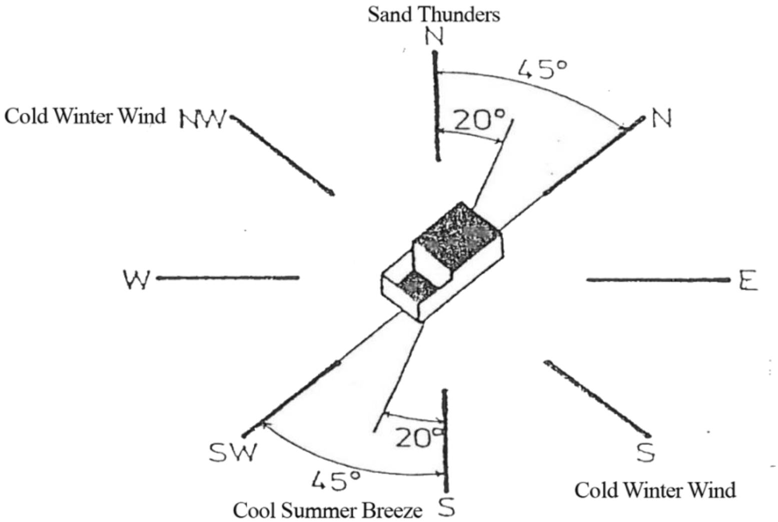

Fig. 2 Winds Orientation in Center of Iran (Source: Hassan, 2015)

Building the house in Northeast-Southwest Orientation to receive cool summer breeze and reject cold wind. (Fig.2)

2.2. Compactness

Houses are dense and have joint walls. Alleys are narrow and curved so that unwanted winds cannot easily enter the house and this characteristic also helped defending the city in old times.

These curved paths also provide more shadow for pedestrians. (Fig.3)

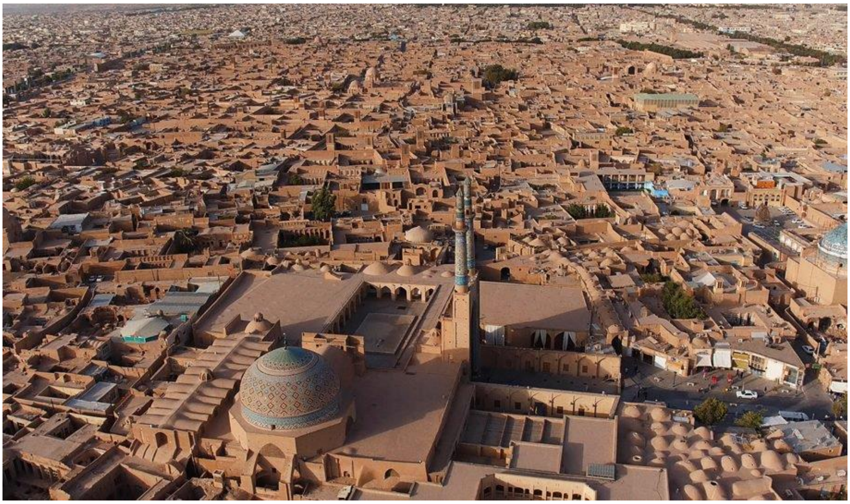

Fig. 3 Bird View of Yazd, Iran (Source: Archive of Kayhanlife[2])

2.3. Materials

Using materials which is accessible around the city and has a high heat capacity is very important. The combination of soil and water creates a perfect match! So “clay” and “Mudbrick” are the main materials to build the houses. Not only have they got a high heat capacity but also their bright color helps the building to absorb less heat in summer and reveal less heat in winter. Also people try to use bright colored coverings on the wall; Things like Plaster. (Fig.4)

Fig. 4 Brick and Mudbrick as the Main Materials (Source: Archive of Kayhanlife)

[2] https://kayhanlife.com/unesco-inscribes-iranian-city-yazd-world-heritage-list/

2.4. Form of the Building

In order to reduce the outside openings and preserve the inside space from sand storms the shortest side of the building would be facing the wind. Overall the cubic form is the best matching form. Walls are thick, ceilings are high and openings are mainly inside the house, facing the main central yard. So, the houses built in this climate are mostly introspective. (Fig.5)

Fig. 5 Introspective Housing, Yazd, Iran (Source: Archive of Kayhanlife)

2.5. Down-level Central Courtyards

The courtyard is built in the middle of central yard and is usually deeper than the whole building so it can be at lower temperature. Courtyards are usually including a big fountain and some trees to reduce the temperature on a whole of 3-4 degrees. (Sadat, 2013) (Fig.6)

Fig. 6 Down-level Garden in a House in Yazd, Iran Døskeland (Source: Archive of Kayhanlife)

2.6. Wind Catchers

Wind tower (wind catcher) is a traditional Persian architectural element to create natural ventilation in buildings. Windcatchers tend to have one, four, or eight openings. In the city of Yazd, all windcatchers are four- or eight-sided. The construction of a windcatcher depends on the direction of airflow at that specific location: if the wind tends to blow from only one side, it is built with only one downwind opening. This is the style most commonly seen in Meybod, 50 kilometers from Yazd: the windcatchers are short and have a single opening.

Depending on the direction and type of wind, windcatchers are designed in many different types and if there is a small fountain under them, they can create a very cool atmosphere underneath. To keep buildings free of dust and sand blown in from the desert, windcatchers were built facing away from the wind. (Hengameh, 2013) (Fig.7,8,9,10)

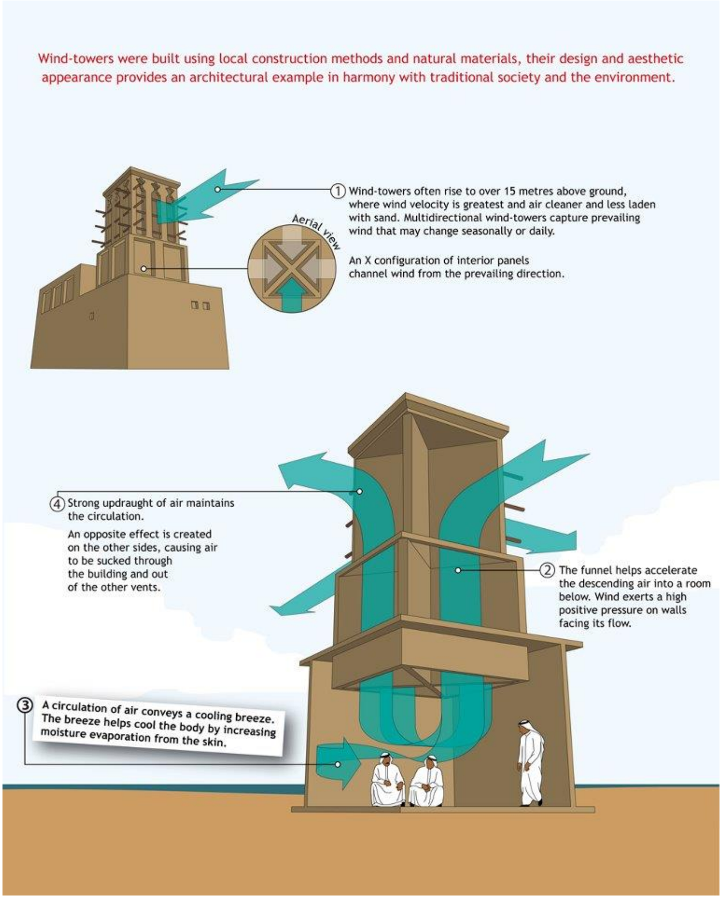

Fig. 7 Wind Catcher Functionality (Source: Archive of Goumbook[3])

[3] http://goumbook.com/wind-tower-traditional-zero-energy-cooling-system/

Fig. 8 Dowlat Abad Garden and Wind Catcher, Yazd, Iran
(Source: Archive of Chasingtheunexpected[4])

Fig. 9 Fountain under Dowlat Abad Wind Catcher, Yazd, Iran
(Source: Archive of Chasingtheunexpected)

[4] https://www.chasingtheunexpected.com/beneath-yazd-tallest-wind-catcher-beautiful-dolat-abad-garden/

So here is a complete example of House featured above:

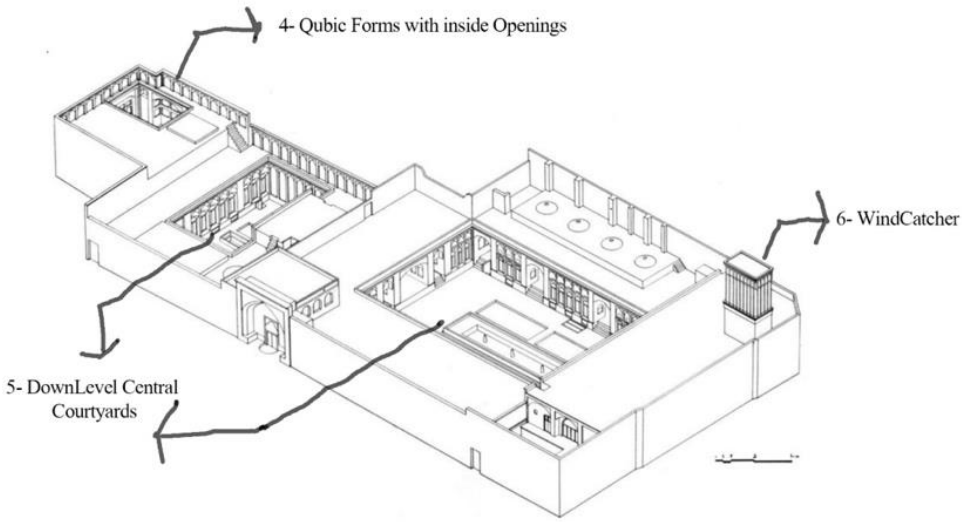

Fig. 10 Lari's House in Yazd, Iran (Hassan et al, 2015)

3. HOT AND HUMID CLIMATE

A thin line of cities near the Persian Gulf in south of Iran like Bushehr and Bandar Abbas are in this climate. In this Climate we have:

- Low annual rain
- Very High humidity throughout the year
- Very Hot weather in summer and moderate in winter
- Little temperature fluctuation in day and night
- Poor vegetation (Shahryiar, 2008)

The most important building characteristics are ordered into:

3.1. Semi-Introspective buildings with central courtyards

They also connect to the outside of the house in reverse to hot climate buildings:

3.2. Very high ceiling and windows

The height of windows sometimes reaches 4 meters. Hot air would climb up and get out of the room through the windows below the ceiling (Fig. 11).

Fig. 11 High Windows in a House in Bushehr, Iran (Source: Author's collection)

3.3. Wide and high Balcony (Shenashil)

Balconies are important part of the house, because when it is hot and humid there is better shadow and ventilation there and most of time of residents is spent in Shenashils.

3.4. No underground construction

Because of the sea level they cannot have underground constructions, so the ground level is important for storage of food and the rooms are in first and second level to receive better ventilation.

3.5. Flattened ceilings

No curved or round ceiling is common here. So people can sleep on the roof at nights.

3.6. Materials

Here also people use materials with high capacity of heath and bright colors such as white plaster and brick. Wood is also used for windows (Mohammad, 2015, 10). (Fig.12)

Fig. 12 Outside of a House in Bushehr, Iran (Source: Author's collection)

4. COLD AND VERY COLD CLIMATE

Cities Located in west of Iran, Mostly around the Zagros Mountains Like Sanandaj, Kermanshah and Tabriz. (Fig.13,14) In this Climate we have:

- Long-lasting cold winters
- Short cool summers
- Downfalls mostly in Snow
- Significant temperature Fluctuation in day and night
- Low Humidity (Majid, 2010)

The most important building characteristics are ordered into:

- Orientation and Compactness in Plans (trying to receive the most winter sun and the least winter wind)
- Least surface/volume ratio (cubic form of Plans)
- Introspective buildings with central yards
- High heath capacity materials (they use stones and wood to build a house and where possible they use clay)
- Low height ceiling
- Flattened roofs (to use snow as an insulation)
- Small openings and gardens (because of the cold weather most of residents' time is spent indoor. They use windows to trap sun in the room and warm it) and
- Thick walls (Mohammad, 2015)

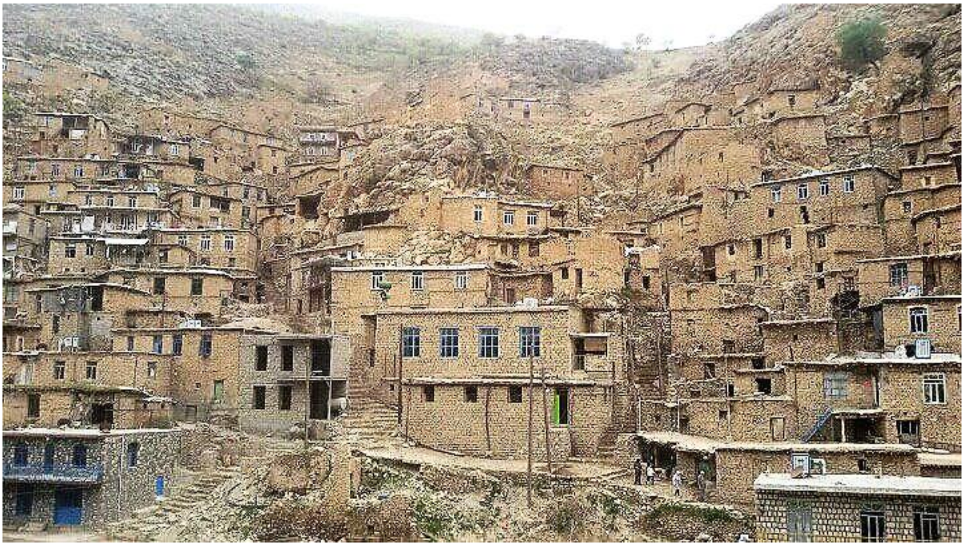

Fig. 13 Houses in Cold Climate, Palangan, Kurdistan, Iran (Source: Author's collection)

Fig. 14 Houses in Cold Climate, Palangan, Kurdistan, Iran (Source: Author's collection)

5. Moderate and Humid Climate

A thin line of cities near the Caspian Sea in North of Iran - from east to west - are in this climate. In this area the short distance between Sea and Alborz Mountains caused the weather to be always humid. Cities such az Mazandaran, Golestan and Guilan are in this climate zone. In this Climate we have:

- Warm and Humid Summers and Moderate Winters
- High rain level and Humidity
- Low temperature fluctuation in day and night (Yusuf, 2000)

The most important building characteristics are ordered into:

- Orientation (generally east-west stretched House plans)
- Openings (in all sides of the house there are high openings)
- No underground constructions (because of the humid level ground houses are mostly built on a wooden foundation)
- Materials (low heath capacity materials such as wood, cement, stones and rice shoots are used)
- Gable roof (buildings closer to the sea have higher ceiling and sharper Gable roofs)
- Extrovert Houses and Ivans (Ivans are of the most importance. Humidity causes the residents to spend most of their time out of buildings and so Ivans can provide both wind and a shelter to the rain) (Fig.15)

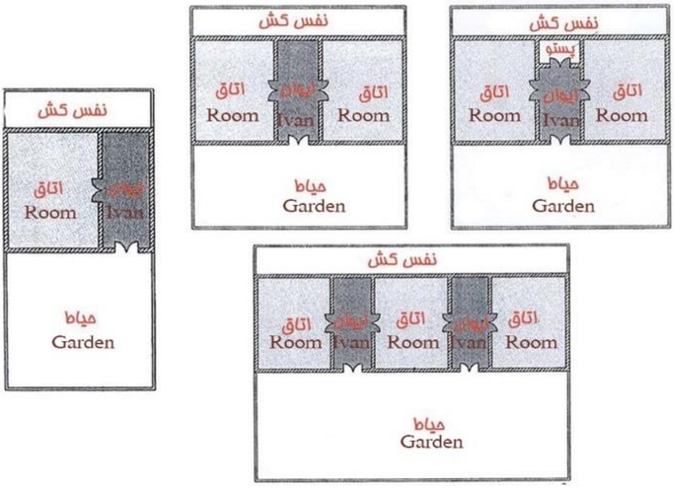

Fig. 15 Ivan's Significant Role in Northern Houses, Iran (Source: Author's collection)

- Wind ventilation (the most important feature is to provide wind circulation in the house with proper positioning of the windows) (Mohammad, 2015). (Fig.16)

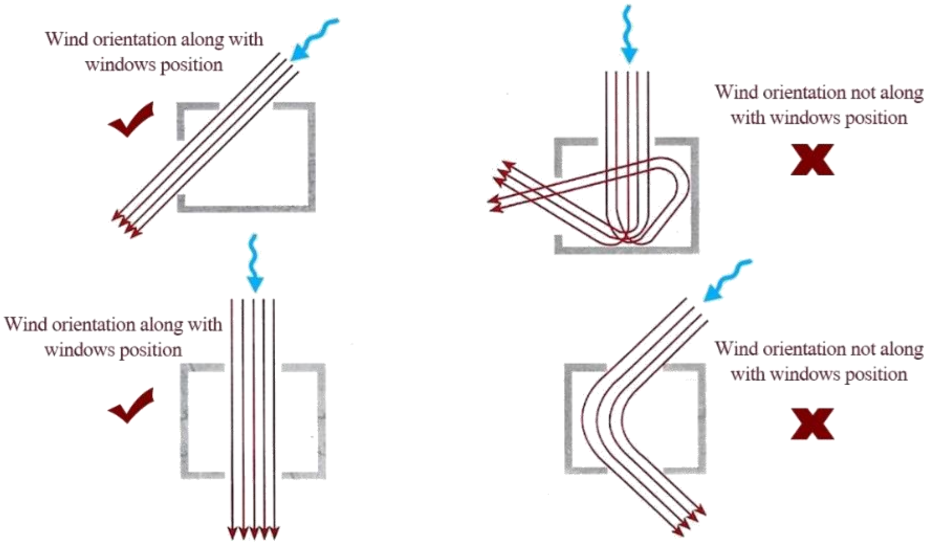

Fig. 16 Wind Ventilation in Northern Houses, Iran (Source: Author's collection)

So, here is a complete example of House featured above (Fig. 17, 18):

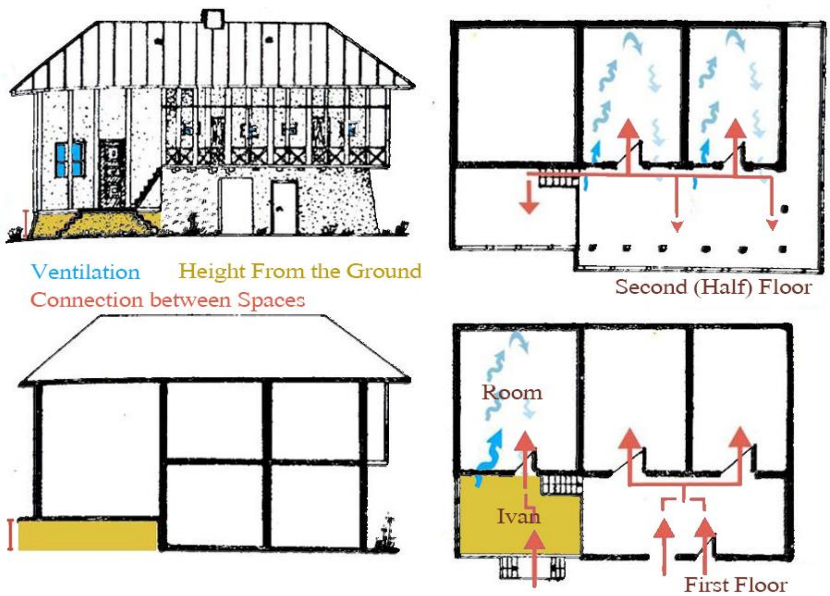

Fig. 17 A Northern House Functionality (Source: Author's collection)

Fig. 18 Rafiee's House, Guilan, Iran (Source: Archive of Guilan Rural Heritage Museum[5])

[5] http://www.gecomuseum.com/LandingPage.aspx

6. Comparative Analysis

The following table presents (Tab.1) a comparative analysis of the examples presented in four climate systems in Iran.

Table 1 Features of Residential Architecture in four main climates of Iran

Climate	Hot And Dry	Hot and Humid	Cold and Very Cold	Moderate and Humid
Annual Rain	Very Low Annual Rain	Low Annual Rain	Mostly Snow	High
Day/Night Temperature fluctuation	Significant Fluctuation	Little Fluctuation	Significant Fluctuation	Little Fluctuation
Humidity	Dry Burning Sun	High Humidity Moderate Sun	Low Humidity	High Humidity
Summer/Winter Intensity	Hot Summer Cold Winter	Hot Summer Moderate Winter	Cool Summer Very Cold Winter	Warm Summer Moderate Winter
Other Features	Sand and Dust Thunders	Poor Vegetation	-	-
Plan orientation	Northeast-Southwest	East-West	Northwest-Southeast	East-West
City Fabric	Cubic Dense Fabric	Intensive and Continuous	Cubic Dense Fabric	Linear stretched Fabric
Material	Clay Mudbrick	White plaster Wood Brick	Stone Wood Clay (if available)	Stone Wood Cement Rice Shoots
Introspective/extrovert Architecture	Introspective	Semi-introspective	Introspective	Extrovert
Other Features	Down-level Courtyards Windcatchers Flattened Roofs	Central Yards Shenashis (Balcony) High Ceiling Thick Walls Flattened Roofs	Low height ceiling Small opening Thick Walls Flattened Roofs	Numerous Openings No Underground Construction Gable roofs

(Source: Author)

7. Conclusion

In this paper four main different types of climate in Iran have been studied. As shown in the table below, we can see that in the middle of the country dry weather (Cold/Hot) has resulted into introspective houses in Northeast-Southwest Floor Plans with denser city fabric; while by approaching north and south we have more humidity in result of Caspian Sea and Persian Gulf and therefore houses tend to look outward with East-West Floor Plans to receive the best wind and city fabric becomes more spread.

Overall the use of local material is a key element in old Persian Architecture and it is depicted how buildings have been adapted to the nature and people built their houses with complete respect and collaboration with their surroundings, coming up with specific ideas for different climates, feature that we highly lack in today's architecture specially in regards to the recent climate change issues.

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KUĆE U IRANU PRILAGOĐENE KLIMI: TOPLA, HLADNA I VLAŽNA KLIMA

Pitanje klimatskih promena je izazvalo puno pažnje, posebno u poslednjih deset godina. Savremeni trendovi u arhitekturi i urbanizmu koji su pokušavali da stvore žive mašine slične jedna drugoj u bilo kom kontekstu, sada su se pokazale nedovoljnima. Ukoliko se ne odlučimo da poštujemo prirodu i učinimo da naše zgrade budu u skladu sa svojim kontekstima, ne možemo se baviti daljnjim životnim temama. Ako pogledamo tradicionalnu arhitekturu koja postoji u starim gradovima i ruralnim područjima, možemo videti kako su ljudi uspeli povezati novu građevinu s okolinom. U ovom članku proučavamo različite arhitektonske obrasce koji postoje u starim arhitekturama gradova i sela u Iranu, u zemlji koja može biti dobra studija slučaja zbog svoje bogate raznolikosti prirode, klimatskih zona i arhitektonske pozadine.

U Iranu postoje, u pogledu klime, različiti gradovi: topli, suvi, vlažni i veoma hladni. Zavisno od gradske klime, vodosnabdevanja i dovoljne energije, ljudi su pokušali da naprave najbolje kuće za stanovanje. U ovom radu su analizirani neki od karakterističnih primera.

Ključne reči: *Iran, klima, kuća, arhitektura*

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