The wooden roof structures of Żuławy Region arcaded houses of type III - research, current state and analysis

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Abstract: Historic arcaded houses of the delta of the Vistula were the subject of great interest of many researchers, but their work was focused mainly on historical-architectural aspects. There are no publications which would focus on details and comprehensive analyses of construction systems for this group of historic buildings. The article is the result of field research, archival query and calculations made by the author. The paper analyses the rafter framing constructions of the preserved arcaded houses of type III. The author has prepared a list of construction elements of roofs, carpentry joints, rafter inclination angles and described the state of preservation of roof structure. The paper also includes calculations of the average volume construction material of the roof structure per square meter of roof slope plan.

Keywords: arcaded houses, timber roof structure, carpentry joints.

1. Introduction

The arcaded houses in Żuławy Region are the part of the cultural heritage of the Delta of the Vistula. They can be found mainly in rural areas[1].There are three basic types of arcaded houses in Żuławy, according to Kloepel's typology[2] [1], also confirmed by Stankiewicz[3]. The buildings mentioned in the article belong to the type III (Fig. 1). It was the last form of development of the Żuławy house that took place in the second half of the 18th century. The type III differs from the others (the type I and II) by a risalit supported on columns and perpendicular to the ridge. The plan of the house resembles the letter T. The floor above the main body of the house does not exist, but is preserved in the risalit. The number of columns in the arcade, in the front part of the risalit, is reduced to six or four. The width of the passage is limited by the additional columns. The arcade no longer performs an utility role; it becomes a decorative element [2]. The Żuławy arcaded houses are a valuable example of old wood carving techniques, which are rarely used today.

Roof structure is relatively well-preserved building element of the Żuławy houses, which did not undergo any significant changes and has a large percentage of the authentic substance. They belong to the oldest types of wooden structures. Their main function is to

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1 The exception is a few arcaded houses located in cities: Gdańsk, Nowy Staw, Nowy Dwór Gdański.

2 Otto Kloeppel (1873-1942) architect, conservator, professor and rector of the Technical University of the Free City of Gdansk.

3 Jerzy Stankiewicz (1923-1994) graduate and professor of the Faculty of Architecture at the Gdańsk University of Technology.

transfer the loads due to weight of elements, roof covering, wind and snow pressure to the supports [3].

The aim of the article is to thoroughly describe the historic roof structure that has been preserved, to perform their typology, to determine the amount of wood used for the construction of the structure per square meter of roof slope plan and to classify the carpentry joints in its construction. This article is also supposed to indicate common features and differences in load-bearing systems of roof structures of arcaded houses from the end of the 18th and the first half of the 19th century.

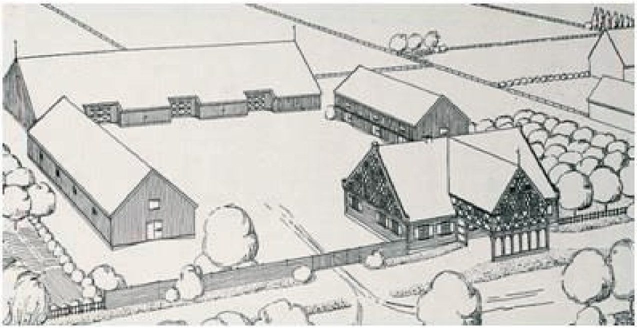

Fig. 1. An arcaded house – type III. Source: [1]

2. Literature research

The literature on typology, technology and design of roof structure is quite extensive [3], [4], [5], [6], [7], [8]. In recent years, there have been completed works that complement the systematics, division and nomenclature of the historic wooden roof structures [9] and carpentry joints [10].

The works devoted to arcaded houses focused mainly on their architecture, development of the building form and interior design [1], [2], [11]. In recent years, there have also been publications on technical and conservation issues related to the Żuławy arcaded houses, which are the result of the author's research [12], [13].

The first graphic designs presenting the structure of roof structure in Żuławy arcaded houses and their geometry can be found in Kloepel's pre-war study. However, these are rather general and simplified drawings of cross-sections of only a few houses (Gdańsk Lipce - type I, Miłocin - type II, Izbiska - type III, Przemysław - type III, Lubieszewo - type III)[4]. In the post-war years, there were inventories of some houses made by PP PKZ,Gdańsk Branch[5].The studies contain vertical sections of houses, but only of selected buildings (Klecie type I [14], Gdańsk Lipce type I [15], Miłocin type II [16], Lubieszewo type III [17], Żuławki type III [18]).

The subject of the roof structure of the arcaded houses in Żuławy was also discussed by Koperska-Kośmicka [11], somewhat on the margins of the general debate on the architecture of buildings. The author included in it a description of the shape of roofs, their

4 Some of Kloepel's drawings were reproduced in Stankiewicz's work.

5 The documentation of the The Polish Studios for Conservation of Cultural Property (PPKZ S.A.), of the Gdańsk Branch, is kept in the archives of the National Heritage Institute (NID) in Gdańsk. The materials include architectural and conservation inventories, reports on renovation works, expert opinions on the construction of arcaded houses from the 1950s to the 1980s. The entire documentation was submitted in 1995-2001 at the request of the Minister of Culture and Art [26].

construction and type of roofing. She also gives information about the types of roof structure arcaded houses, mentioning two types: two-collar beam roof structure and two-collar beam roof structure with posts. The paper also contains a diagram (for 8 houses) showing the angles of roof slope inclination depending on the covering material applied. It shows that for three hundred years (16th - early 19th century) the roof slope angle was about 47° to max. 49°. In the second half of the 19th century it dropped to 40° or even 30°.

In the above-mentioned works, however, there is no precise systematics of preserved roof structure for a larger group of arcaded houses with a division according to their types (I, II or III). There are no analyses encompassing details of the structure, size of construction elements, typology of carpentry joints and their state of preservation, nor chronological lists of these structures according to the date of construction of the house.

3. Methodology

The paper applies a mixed research method containing elements of the following methods: logical argumentation, historical-interpretation, case study, quantitative and analytical method [19]. A group of the arcaded houses of type III from the area of Żuławy Wiślane, entered into the register of monuments, was selected for the inventory [20]. Another criterion was the age of the roof structure and no renovations or modernisations conducted in the last seventy years. This was determined on the basis of an archival query of historical records [21], [22], [23], [24] and an interview with the residents[6].The last factor limiting the field of research was the lack of consent for research[7]. Finally, the measurements of the roof structure could be carried out in four arcaded houses of type III in: Bystrze (Fig. 2), Marynowy (Fig. 3), Nowa Kościelnica (Fig. 4) and Rybina (Fig. 5).

Fig. 2. The arcaded house in Bystrze (author's own photography)

6 In many cases, the arcaded houses are owned by descendants or relatives of people who came to Żuławy after the end of the war in 1945. The inhabitants confirmed that the roof structure has not been repaired.

7 In some cases, despite the good condition of the house, the owners did not agree to perform an inventory, or contact with them was difficult, which made it impossible to perform examinations. The arcaded houses are mostly private dwellings.

Fig. 3. The arcaded house in Marynowy (author's own photography)

Fig. 4. The arcaded house in Nowa Kościelnica (author's own photography)

Fig. 5. The arcaded house in Rybina (author's own photography)

The analytical part presented below includes calculations aimed at determining the amount of wood used in the construction of the rafter framing per square meter of roof slope plan[8] [25] according to the (Eq. 1).

$$S = \frac{V[\mathrm{m}^3]}{R[\mathrm{m}] \times D[\mathrm{m}]} \tag{1}$$

V – the volume of the structural elements of one truss [m^3]
R – average spacing of trusses [m]
D – roof span [m]

Only visible roof structure elements (collar beams, rafters, purlins, posts) are included in the calculation. Calculations were made for full trusses[9]. Truss beams are not included here, because they are encased in the floor and ceiling structure, which made it impossible to measure their cross-section. Wind beams, battens and other elements used for fixing the roof covering were not included in the calculations as they do not constitute the main load-bearing elements in the roof frame. In addition, the above-mentioned elements are frequently referred to when repairing roof coverings. The aim of the measurements was to examine the oldest parts of load-bearing structures of roof structure. The article also contains analogical calculations for the existing arcaded houses which were not accessible to the author for research. A source of knowledge about particular dimensions of structural elements was archive conservation and architectural documentation of PP PKZ[10].

4. Research results

The inventories of arcaded houses took place between July and September 2017. The aim of the measurements was to examine individual structural elements of roof structure and their dimensions, and to determine their state of preservation.

4.1 The houses made available for research

4.1.1. Bystrze

The arcaded house in Bystrze no. 5/7 was built in 1819 by Jakub Jamuet [21]. The historic building is located in the village, near the Mątowy Wielkie – Lisewo Malborskie road. The building has a wooden structure. The log walls are plastered. The risalit of the half-timbered structure is based on 10 columns. The foundation of the building is made of brick. The roof construction is two-collar beams[11] and the roof is covered with red pantile.

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8 The author applied the method used in the unpublished doctoral dissertation of A. Kapuściński, where similar calculations were made for the roof strucutre of Gdańsk churches. Thanks to this method, it is possible to estimate the amount of structure wood used in a given group of structures depending on the analysed time interval.

9 The full truss includes all the components of the roof strucutre (rafters, collar beams, posts, purlins, truss beams). In the arcaded houses mentioned in the article, not all collar beams are supported by posts.

10 The footnotes to the documentation are given at each house.

11 The rafter framing of the arcaded house in Bystrze has no columns. The roof structure is partially stiffened by partition walls of rooms located in the attic. They are located only at the risalit and at the gable wall. Before the war, they were used as guest rooms during the summer months.

The cross-sections of the individual elements of the rafter framing are as follows: rafters 15x28cm, collar beams 15x19cm (Tab. 1). The rafter framing construction of the arcaded house in Bystrze has been made with the use of traditional carpentry joints: lap and simple lap joints (Fig. 6).

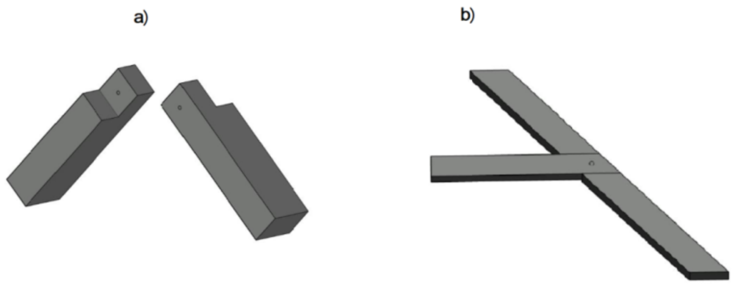

Fig. 6. Carpentry joints: a) lap joint , b) connection of collar beam with rafter with simple lap joint. (author's study)

The connection of rafters in the ridge is made with lap joints (Fig.7), the connection of the collar beam with the rafter with simple lap joints, for which two dowels are used (Fig. 8). The roof slope inclination angle is 45° (Fig. 9)[12]. The number of trusses above the main body of the house is 15, the span of the roof is 12.40m and the spacing of trusses is 1.25m. The condition of the structure is acceptable[13]. As a result of leakage of the roof covering, numerous dampness and damages are visible in the roof structure. Gravitational ventilation of the attic is not disturbed; there is constant air circulation.

Fig. 7. Bystrze– the view on the ridge. (author's own photography)

Nowadays, they are used as storage rooms. Partitions are not a constant element for all trusses, so their elements were not included in the calculations. The house in Bystrze is not the only building with such roof structure. Two-collar beam trusses are also found in arcaded houses in Balewo, Przymysław, Rozgarcie, Świerki [11].

12 Drawings of roof structure of Żuławy arcaded houses are simplified and present the main structural elements, their dimensions and inclination angle. They are a graphic supplement to the description contained in the text.

13 The house has two owners for whom the costs of renovation are too much of a financial burden.

Fig. 8. Bystrze – connection of a collar beam with a rafter. (author’s own photography)

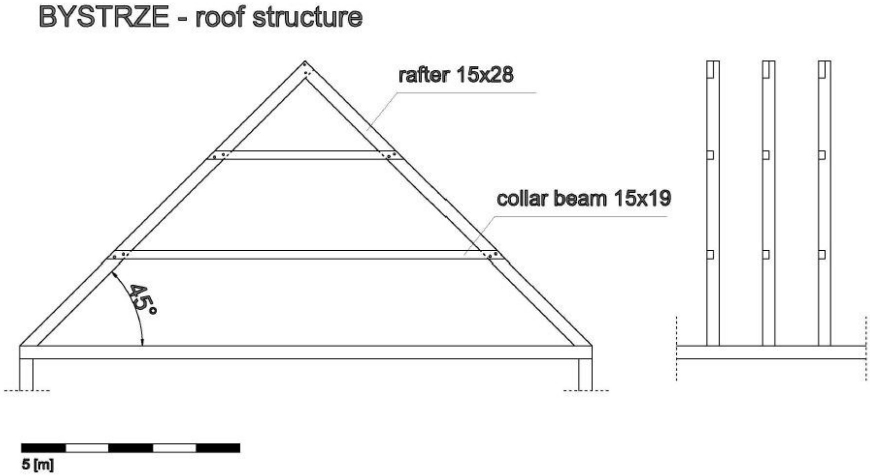

Fig. 9. The simplified scheme of the roof structure of the arcaded house in Bystrze. (author's study)

Table 1. The summary of the rafter framing elements of the house in Bystrze

No.	RAFTERFRAMING ELEMENTS	QUAN.	DIMENSIONS [m]			VOLUME[m³]
			width	height	length	
1.	rafters	2	0.15	0.28	9.25	0.78
2.	Upper collar beam	1	0.15	0.19	4.10	0.12
3.	Lower collar beam	1	0.15	0.19	8.75	0.25
					total:	1.14

The average volume of the construction material per square meter of roof slope plan:

$$s_1 = \frac{1.14\,\mathrm{m}^3}{1.25\,\mathrm{m} \times 12.40\,\mathrm{m}} = 0.074$$

4.1.2. Marynowy

The arcaded house in Marynowy no. 42 was built in 1804 by Hermann Hekker [22]. The building is located in the village near the Malbork – Nowy Dwór Gdański road. It has a wooden frame and the log walls are not plastered. The risalit of the half-timbered structure, with a filling of the yellow small brick in herringbone, is based on 10 columns. The foundation of the building is made of brick. Two-collar rafter construction; lower collar beam is supported by posts (Figs 10-11); the roof is covered with the red pantile. The individual cross-sections of the rafter framing elements are: 14x24cm purlin, 8x18.5cm post, 18x26cm rafters, collar beams: lower 15x25cm and upper 13x26cm (Tab. 2). Connection of the collar beam with the rafter with the simple lap joint; connection of the rafters with the ridge with the lap joint. The slope inclination angle is 43° (Fig. 12). The number of trusses is 18, their spacing is 1.10m, the roof span is 12.50m. Planks of 5cm thickness are placed on the lower collar beam. The condition of the structure is acceptable[14].As a result of leakage of the roof covering, numerous moisture and damages are visible in the rafter framing. Gravitational ventilation of the attic is not disturbed; there is constant air circulation.

Fig. 10. Marynowy – the view on the rafter framing with two collar beams (author's own photography)

Fig. 11. Marynowy– the posts supporting a collar beam (author's own photography)

[14] The Marynowy house also has two owners for whom the renovation costs are too much of a financial burden.

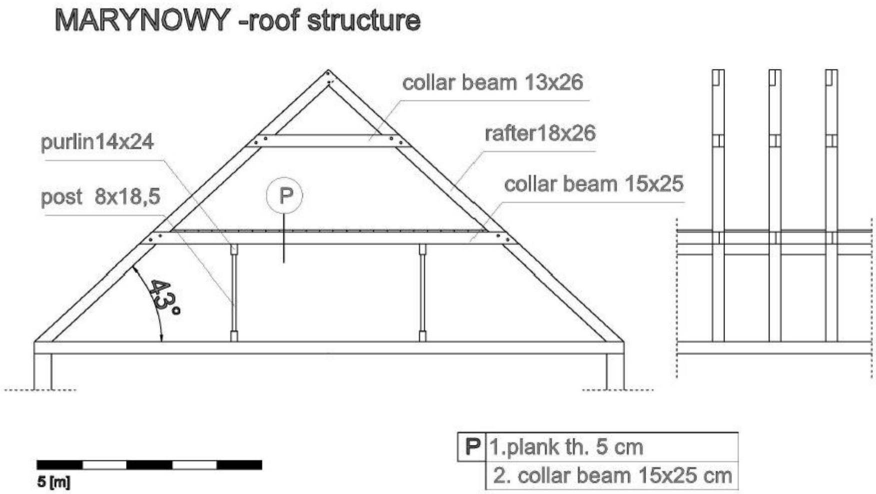

Fig. 12. The simplified scheme of the roof structure of the arcaded house in Marynowy. (author's study)

Table 2. The summary of the house rafter framing elements in Marynowy

No.	RAFTERFRAMING ELEMENTS	QUAN.	DIMENSIONS [m]			VOLUME[m³]
			width	height	length	
1.	Rafters	2	0.18	0.26	8.90	0.83
2.	Upper collarbeam	1	0.13	0.26	3.00	0.10
3.	Lower collarbeam	1	0.15	0.25	7.60	0.29
4.	Purlin	2	0.14	0.24	1.10	0.07
5.	Post	2	0.08	0.185	1.70	0.05
					total:	1.34

The average volume of the construction material per square metre of roof slope plan:

$$s_2 = \frac{1.34\,\mathrm{m}^3}{1.10\,\mathrm{m} \times 12.50\,\mathrm{m}} = 0.098$$

4.1.3. Nowa Kościelnica

The arcaded house in Nowa Kościelnica no. 50/51 was built in 1840 [23]. The building is located in the village, near the Ostaszewo - Niedźwiedzica road. It has a wooden construction and the log walls are not plastered. The risalit of the half-timbered structure is based on 10 posts. The foundation is made of stone. The rafter roof structure is two-collar beams, the roof is covered with red pantile. Individual sections of the rafter framing elements are: rafters 17x30cm, collar beams: lower 16x23cm and upper 12x20cm (Tab. 3). Connection of the collar beam with the rafter with the simple lap joint, connection of the rafters in the ridge with the lap joints (Fig.13). The slope inclination angle is 47° (Fig. 15). The number of trusses is 15, their spacing is 1.40m, the roof span is 11.80m. On the lower beam there are 5cm thick plates. The structure is in good condition. The roofing is sealed. The components of the rafter framing are well preserved and despite their age, they do not show any major damage. Some elements of the rafter framing show carpentry markings, one may see the symbol IIII on a collar beam (Fig.14). Gravitational ventilation of the attic is not disturbed, there is constant air circulation.

Fig. 13. Nowa Kościelnica – connection of the rafter (author's own photography)

Fig. 14. Nowa Kościelnica – connection of the rafter with the collar beam(author's own photo.)

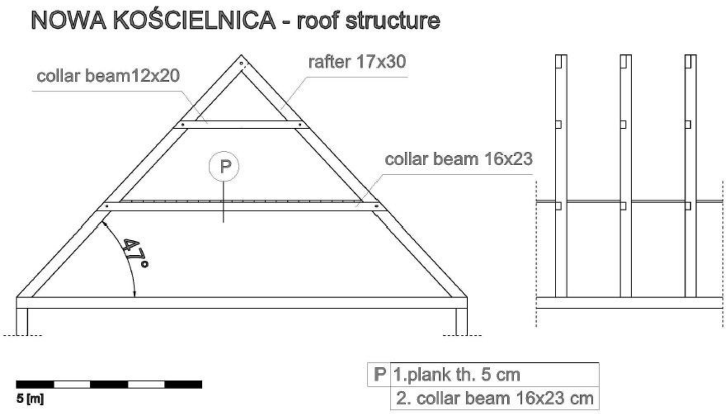

Fig. 15. The simplified scheme of the roof structure of the arcaded house in Nowa Kościelnica. (author's study)

Table 3. The summary of the house rafter framing elements in Nowa Kościelnica

No.	RAFTERFRAMING ELEMENTS	QUAN.	DIMENSIONS [m]			VOLUME[m³]
			width	heigth	length	
1.	Rafters	2	0.17	0.30	8.90	0.91
2.	Upper collar beam	1	0.12	0.20	2.90	0.07
3.	Lower collar beam	1	0.16	0.23	7.00	0.26
					total:	1.24

The average volume of the construction material per square meter of roof slope plan:

$$s_3 = \frac{1.24\,\mathrm{m}^3}{1.40\,\mathrm{m} \times 11.80\,\mathrm{m}} = 0.075$$

4.1.4. Rybina

The arcaded house in Rybina no. 12 was built in the first quarter of 19^{th} century [24]. The historic building is located in a hamlet about two kilometers from the centre of the village. It has a wooden frame and the log walls are not plastered. A risalit of a wooden log construction; at the top a boarded timber beam construction, based on 8 columns. The foundation is made of the brick. The rafter roof structure is two-collar-beam, the roof is covered with red pantile. Individual sections of the rafter framing elements are: rafters 16x23cm, collar beams: lower 16x18cm and upper 14x16cm (Tab. 4). Connection of the collar beam with the rafter with the simple lap joint (Fig. 16), connection of the rafters in the ridge with the lap joints. The slope inclination angle is 46° (Fig. 18). The number of trusses is 15, their spacing is 1.25m, the roof span is 11.50m. On the lower beam there are 4.5 cm thick boards. The structure is in good condition. The roofing is sealed. In 2017 the house was completely renovated. One roof truss was repaired by replacing a collar beam (Fig. 17). Gravitational ventilation of the attic is not disturbed, there is constant air circulation.

Fig. 16. Rybina – roof structure (author's own photography)

Fig. 17. Rybina – a new collar beam in the structure (author's own photography)

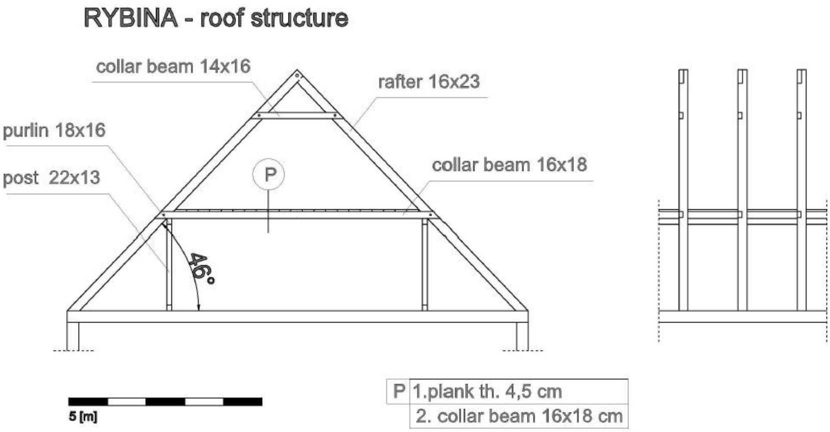

Fig. 18. The simplified scheme of the roof structure of the arcaded house in Rybina. (author's study)

Table 4. The summary of the house rafter framing elements in Rybina

No.	RAFTERFRAMING ELEMENTS	QUAN.	DIMENSIONS [m] width	height	length	VOLUME[m³]
1.	Rafters	2	0.16	0.23	8.60	0.63
2.	Upper collarbeam	1	0.14	0.16	1.80	0.04
3.	Lower collarbeam	1	0.16	0.18	6.75	0.19
4.	Purlin	2	0.16	0.18	1.25	0.07
5.	Post	2	0.13	0.22	2.18	0.12
					total:	1.06

The average volume of the construction material per square meter of roof slope plan:

$$s_4 = \frac{1.06\,\mathrm{m}^3}{1.25\,\mathrm{m} \times 11.50\,\mathrm{m}} = 0.074$$

4.2. Houses not available for research

Other examined buildings are the arcaded houses in Lubieszewo (Fig. 19) and Żuławki (Fig. 20). Because it was not possible to make inventory of the attics, the current state of preservation of the rafter framing constructions cannot be described, nor can a typology of carpentry joints be made. In the conservation documentation of both houses there are no photographs that show details of the construction of roof trusses or information on their joints [17], [18]. On the basis of plans and vertical sections it was possible to obtain data for calculating the amount of wood used for the construction of the rafter framing structure. Additionally, on the basis of the analysis of available conservation documentation, it was possible to determine the types of rafter framing structures and make simplified schemes of trusses.

Fig. 19. The arcade house in Lubieszewo (author's own photography)

Fig. 20. The arcade house in Żuławki (author's own photography)

4.2.1. Lubieszewo

The arcaded house in Lubieszewo no. 29 was built in the first half of 19^{th} century [20]. The historic building is located in the village, near the Ostaszewo – Nowy Dwór Gdański road. It has a wooden construction and the log walls are not plastered. A risalit of a half-timbered structure is based on 8 columns. The foundation is made of the brick and stone. The rafter roof structure is two-collar beams; the lower collar beam is supported with posts. The roof is covered with red pantile. Individual sections of the rafter framing elements are: rafters 17x28cm, collar beams: lower and upper 11x23cm, purlin 13x15cm, post 15x15 cm (Tab. 5). The slope inclination angle is 46° (Fig. 21). The number of trusses is 15, their spacing is 1.50m, the roof span is 11.65m [17].

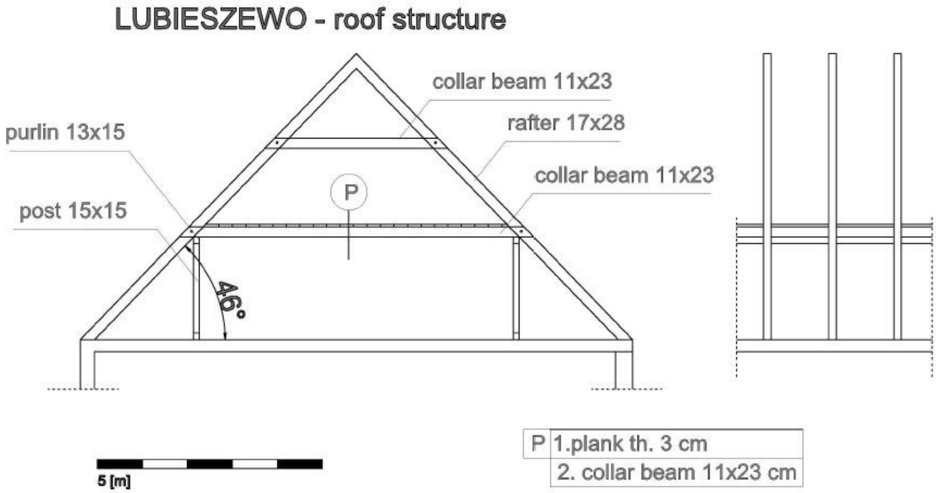

Fig. 21. The simplified scheme of the roof structure of the arcaded house in Lubieszewo (author's study)

Table 5. Summary of the house rafter framing elements in Lubieszewo

No.	RAFTERFRAMING ELEMENTS	QUAN.	DIMENSIONS [m]			VOLUME[m³]
			width	height	length	
1.	Rafters	2	0.17	0.28	8.40	0.80
2.	Upper collarbeam	1	0.11	0.23	3.45	0.09
3.	Lower collarbeam	1	0.11	0.23	7.25	0.18
4.	Purlin	2	0.13	0.15	1.50	0.06
5.	Post	2	0.15	0.15	2.00	0.09
					total:	1.22

The average volume of the construction material per square meter of roof slope plan:

$$s_5 = \frac{1.22\,\mathrm{m}^3}{1.50\,\mathrm{m} \times 11.65\,\mathrm{m}} = 0.070$$

4.2.2. Żuławki

The arcaded house in Żuławki no. 32-33 was built in 1797 for Cornelius Froese. The arcade was added in 1851. The historic building is located in the village, near the Ostaszewo – Mikoszewo road. It has a wooden construction and the log walls are partly plastered. A risalit of half-timbered structure construction is based on 8 columns; the filling is made of the red small brick. The foundation is made of the brick. The rafter roof structure is two-collar-beam; the lower collar beam is supported by posts. The lower collar beam is covered with plates. The roof is covered with red pantile. Individual sections of the rafter framing elements are: rafters 16x21cm, collar beams: upper 13x18cm and lower 17x25cm, purlin 14x16cm, post 14x13cm (Tab. 6). The slope inclination angle is 48° (Fig. 22). The number of trusses is 14, their spacing is 1.40m, the roof span is 10.70m [18].

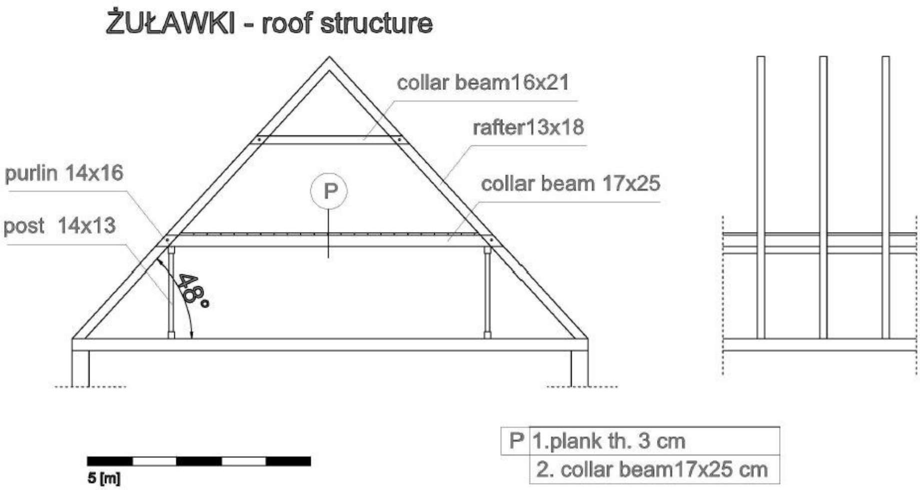

Fig. 22. The simplified scheme of the roof structure of the arcaded house in Żuławki. (author's study)

Table 6. The summary of the house rafter framing elements in Żuławki

No.	RAFTERFRAMING ELEMENTS	QUAN.	DIMENSIONS [m]			VOLUME[m³]
			width	height	length	
1.	Rafters	2	0.13	0.18	8.55	0.40
2.	Upper collarbeam	1	0.16	0.21	3.05	0.10
3.	Lower collarbeam	1	0.17	0.25	7.25	0.31
4.	Purlin	2	0.14	0.16	1.40	0.06
5.	Post	2	0.14	0.13	1.75	0.06
					total:	0.93

The average volume of the construction material per square meter of roof slope plan:

$$s_6 = \frac{0.93\,\mathrm{m}^3}{1.40\,\mathrm{m} \times 10.70\,\mathrm{m}} = 0.062$$

4.3. The summary of calculations

Table no. 7 (Tab. 7) presents a summary of the values of rafter inclination angles and the average volume of construction material per square meter of the roof slope plan for the arcaded houses analysed above. The objects in the table were listed chronologically, along with the number of trusses.

Table 7. Summary of the results of the analysis of arcaded houses

No.	Location:	The date of building of the house	The no. of trusses	angle [°]	Average vol. s_n[-]
1.	Żuławki	1797	14	48	0.062
2.	Marynowy	1804	18	43	0.098
3.	Bystrze	1819	15	45	0.074
4.	Rybina	1st quarter of 19th century	15	46	0.074
5.	Nowa Kościelnica	1840	15	47	0.075
6.	Lubieszewo	1st half of 19th century	15	46	0.070
			average:	45.83	0.075

5. Conclusions

The analysis of six objects revealed that the most common construction method of the roofs of the Żuławy arcaded houses of type III, from the end of the 18th century and the first half of the 19th century, is a two-collar roof truss. In four arcaded houses (Marynowy, Rybina, Lubieszewo, Żuławki) there are posts supporting the lower collar beam. In five arcaded houses, the lower beam was covered with plates from the top, which created a bare ceiling construction, with the exception of the roof structure of the house in Bystrze.

The volume of construction material per square meter of roof slope plan of the analysed arcaded houses is from 0.062 to 0.098; the average value for all houses is 0.075. The rafter inclination angle varies from 43° to 48°, which gives the average value for the analysed six historic buildings of 45.83°, approximately 46°. The number of trusses ranges from 14 to 18, most often it is 15. Similar dimensions of cross sections of structural elements of collar beams and rafters, as well as the way of their connection draw one's attention. In all houses in Bystrze, Marynowy, Nowa Kościelnica and Rybina the collar beams are connected with rafters with the simple lap joint and rafters in the ridge with the lap joint.

The study confirms the durability of wooden constructions. Despite the passage of many years, the main elements of the rafter framing in the Żuławy arcaded houses still fulfill their role in load transfer. The research also brings conclusions regarding the maintenance of wooden building constructions. The condition for good preservation of rafter framing is a sealed roof covering and lack of excessive moisture in construction elements. Good examples are houses in Nowa Kościelnica and Rybina. The roof constructions of arcaded houses in Bystrze and Marynowy require renovation of the roof covering. Their technical condition deteriorates year by year. Another factor contributing to the proper functioning of the construction is the undamaged gravitational ventilation of the attics. Constant air circulation guarantees the maintenance of proper wood humidity. Unfortunately, this does not eliminate the negative effects of leaking roof covering. None of the houses in Bystrze, Marynowy, Nowa Kościelnica, Rybina had any ventilation problems. Attics do not have sealed structure.

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