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Wooden structures in the historic port of Rijeka

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Subject review

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A review of the use of wood in construction of the historic port of Rijeka is given in the paper. Traditional use of wooden structures for floors and roofs can be seen in ancillary structures and early warehouses, while the first temporary storage units were also wooden skeletal structures. The Grain Silo, a veritable masterpiece of carpentry skill, can be singled out by its demanding and unusual structure, together with half-timber structures of Quarnero Bathhouse, and those of rowing clubs on the breakwater.

Ključne riječi:
Port of Rijeka, wooden structures, skeletal structures, half-timber structures, grain silo, warehouses

Pregledni rad

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Drvene konstrukcije u povijesnoj luci Rijeke

U radu je dan pregled korištenja drva u izgradnji riječke povijesne luke. Tradicionalna upotreba drvenih konstrukcija za stropove i krovišta bila je prisutna kod pratećih građevina i ranijih skladišta, a prva privremena skladišta bila su također drvena, skeletne konstrukcije. Po zahtjevnoj, neuobičajenoj konstrukciji izdvaja se skeletna konstrukcija Žitnog silosa, pravo remek-djelo tesarskog umijeća, te kanatne konstrukcije Kupališta Quarnero i veslačkih klubova na lukobranu.

Ključne riječi:
riječka luka, drvene konstrukcije, skeletne konstrukcije, kanatne konstrukcije, žitni silos, skladišta

Übersichtsarbeit

Nana Palinić, Adriana Bjelanović

Holzkonstruktionen im historischen Hafen Rijeka

In dieser Arbeit wird eine Übersicht zur Anwendung von Holz beim Bau des historischen Hafens Rijeka gegeben. Der traditionelle Einsatz von Holz für Decken- und Dachkonstruktionen war bei Nebengebäuden und früheren Lagern vertreten, wobei vorläufige Lagerräume ebenfalls als Skelettkonstruktionen aus Holz gebaut wurden. Aufgrund anspruchsvoll und ungewöhnlich gestalteter Konstruktionen heben sich der Skelettbau des Getreidesilo, ein wirkliches Meisterwerk der Schreinerkunst, sowie die Fachwerkkonstruktionen der Badeanstalt Quarnero und der Rudervereine am Wellenbrecher hervor.

Ključne riječi:
Hafen Rijeka, Holzkonstruktionen, Skelettkonstruktionen, Fachwerkkonstruktionen, Getreidesilo, Lager

1. Introduction

The construction of the Port of Rijeka started in the late 19th century and was completed in the first half of the 20th century (Figure 1). The port building project, including also the railway network, was financed and organised by Hungarian Government soon after the unification of Austria and Hungary, when Rijeka was put under direct administration from Budapest. Traditional materials and structures, although quite novel at that time, were used to build the infrastructure and superstructure. Stone was the dominant material, and was used primarily for infrastructure works. Many quarries were opened, and a considerable earthwork was conducted to obtain necessary surfaces to accommodate railway and port infrastructure [1]. To build the railway and port facilities - warehouses, administrative and service buildings, stone was replaced by cheaper and more practical bricks, which were used, not only for construction, but also as external brickwork on facades. Iron and steel were used for the railway infrastructure and construction of port and ancillary buildings. Iron and concrete were jointly used as from 1881, and reinforced concrete was introduced in 1893 [2]. The use of wood was initially limited to temporary buildings or to roof structures, which are traditionally made of wood. Much later, advantages of the use of this material in the zone directly by the sea were recognized, and so several audacious non-standard wooden structures were planned and built. As this coastal zone is not a typical and autochthonous environment for building in wood, which is not traditionally used in these parts, the reasons for choosing wood as construction material can only be assumed as there are no available documents that could provide further information on the matter. In wooden structures the word *lightness* has two meanings: small nominal specific weight of wood (e.g. its value of 4,6 kN/m^3 for solid softwood of high bearing capacity classified into strength class C30 is approximately 5, i.e. it is 17 times smaller than the value for comparable strength classes for concrete and steel, C30/C37 and S 235) [3] reduces contribution of dead load in the total load exerted on the structure and substructure (walls and foundations),while also enabling fast assembly with minimum use of element handling equipment. The proximity of Gorski Kotar, which is a natural biotope of fir, spruce and beech, made the supply of timber easier. It is therefore not surprising that the Grobnik area established itself as the centre of timber trade in the 19th century. It should also be noted that the first steam powered saw-mill in Gorski Kotar was opened in 1850 in the community of Bijela Vodica near Crni Lug (the mill most probably perished in fire in 1885). After that, two more mills were opened, in Prezid and Ravna Gora. It is presumed that reasons for choosing wooden structures might be the prevailing influence of the Austro-Hungarian school of structural engineering which was known for its good construction practices, based on tradition. This also implies the use of carpentry joints realized according to strict rules, and structural wall systems of timber buildings realized at the time, typologically classified as the so called lightweight wooden structures. Half-timbered houses erected at that time have recognizable structural features typical for central European, and especially German, construction practices (germ. "fachwerkbau"), with longitudinal members joined together using carpentry connections, while the appearance of a stable truss system is created by dropdown angle (corner) braces, whose exposure on the facades is shaw special aestetics. Skeleton structures (also known as "beam-post" systems) were constructed modularly, on larger grids, with recognizable triangular stabilization braces and struts, and with board formwork as an additional stiffener, which is especially effective for assuming horizontal forces at wall level (as such houses were located in the zone of strong winds) [4].

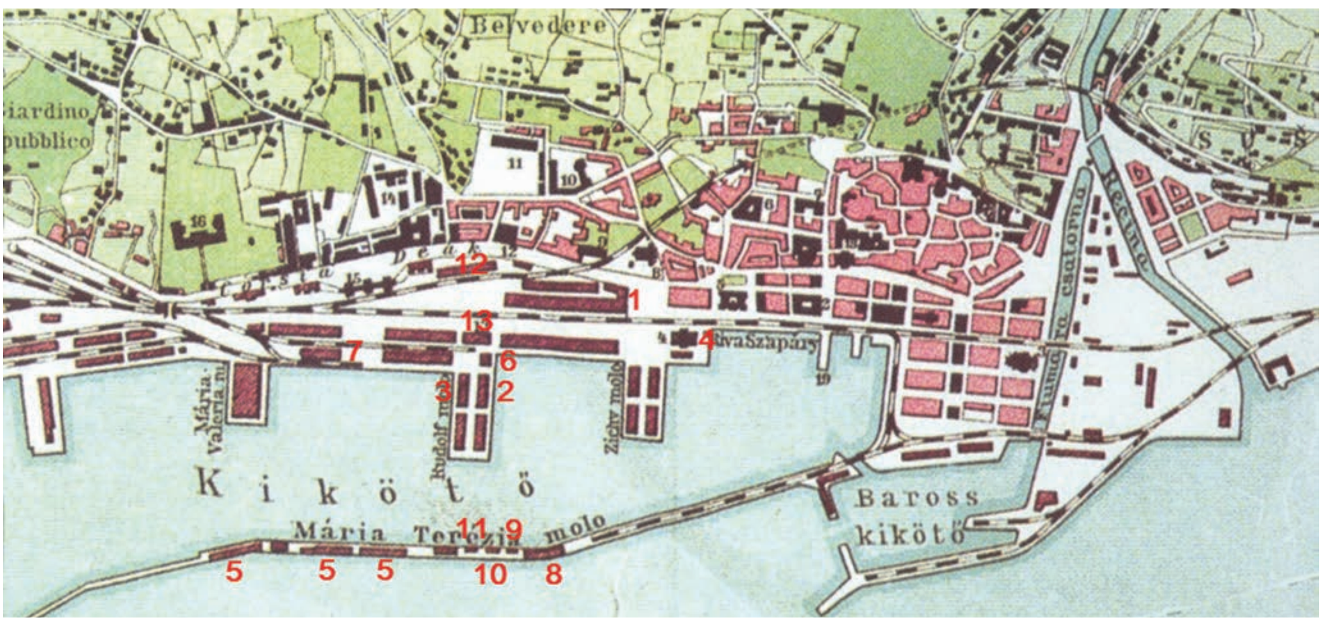


Figure 1. Plan view of Rijeka and its port, 1923, detail: 1.Warehouse 31; 2.Warehouse 8; 3. Warehouse 11, 4. Port administration building; 5. Coal warehouses; 6. Engine room; 7. Grain silo site; 8. Quarnero Bath; 9. Rowing club Quarnero; 10. Rowing club Canottieri fiumani; 11. Rowing club Liburnia; 12. Site of old railway station; 13. Customs house

2. Use of wood for floor and roof structures

Traditional use of wood for floor and roof structures could also be observed in the buildings located in the railway and port zone of Rijeka. These wooden structures were used, however, only the ancillary administrative and service buildings featuring standard span and load characteristics: Maritime Gubernium Administration Building, Main Customs House, Customs Office, Fire Station, Restaurant, and Engine Room. For buildings exposed to greater loads, i.e. warehouses, materials such as iron, steel, or reinforced-concrete constituted a much more favourable alternative to timber. However, a limited use of timber for roof structures and staircases was nevertheless observed, and this in warehouse built in an earlier phase of port construction, in the late nineteen century: coal storages at the breakwater, railway warehouse 31, and port warehouses 8 and 11.

2.1. Railway warehouse 31

The railway warehouse, designed by engineer Richnitz, was built in two phases, in 1881 and 1882. This warehouse of exceptional proportions, 240 m long and 25 m wide, was laid out parallel to the coast and the port zone boundary, and was divided by walls into six separate warehouses [5]. The central load-bearing wall went throughout the length of the building and supported two parallel kingpost truss structures 12 m in span, whose shallow pitch required adjustment of typical geometry (therefore there are no principal rafters to off-load the common rafters). The wall also served as support to horizontal gutter for rainwater collection (Figure 2). The final eastern and the western parts of the building were allocated for offices, and were thus divided into small spaces and spans. The solutions for roof structures were also different: the biggest central span was covered by the double-pitched purline roof structure with double vertical props,

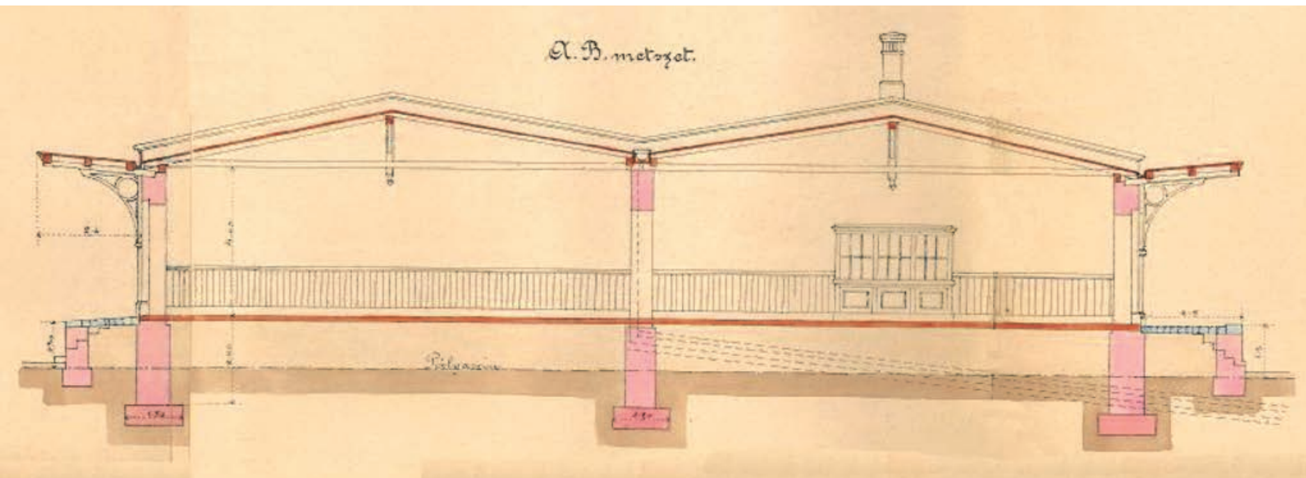


Figure 2. Railway warehouse 3, 1881, transverse section through storage part [5]

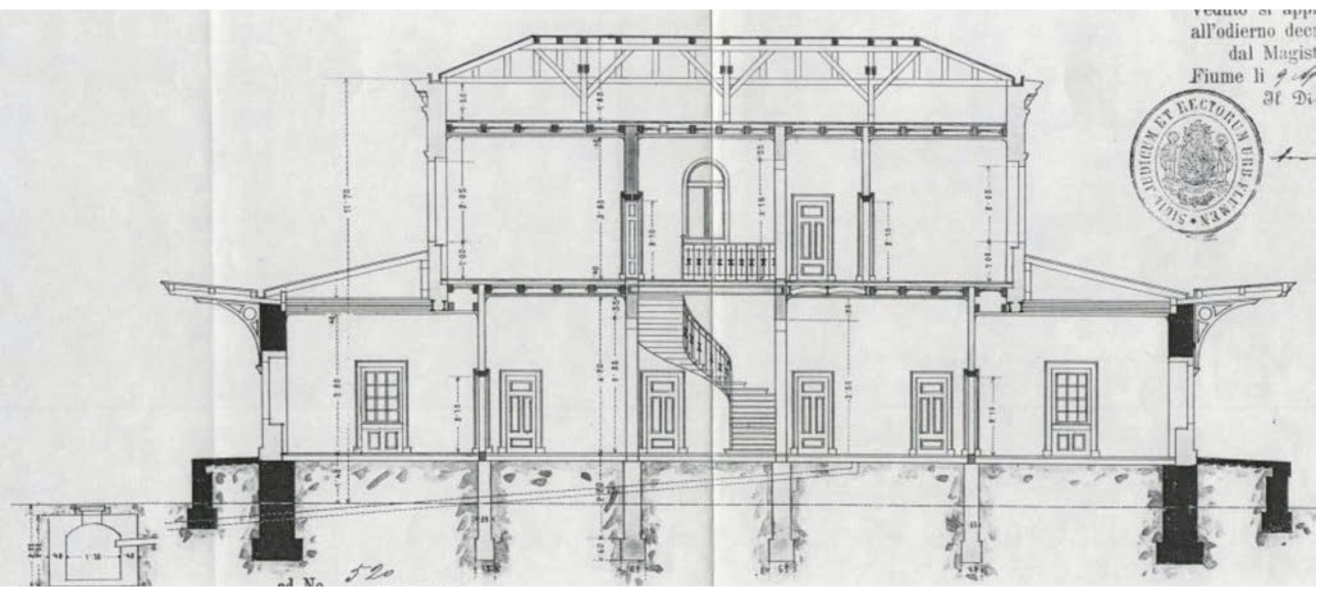


Figure 3. Railway warehouse 31, 1890, transverse section through office section [6]

hipped at both ends, and with a lower simple single-pitched purline roof with a single vertical prop, where shallow pitch prevented installation of principal rafters (Figure 3). Warehouse offices were renovated in 1890 according to the design by Ferenc Pfaff and the once again in 1895 based on the design by Gyula Hühn, when an additional floor was added [6]. The biggest renovation was made in 1907 when the wooden structure in the major part of the warehouse was replaced with skeletal reinforced-concrete structure designed by Ferenc Pfaff. There are no data in the available documentation about the way in which the original roof structure was fixed to the walls, nor about the reasons for changing the structure. The area with supports above the central wall was the place where water was retained (water reached the horizontal gutter from two roof areas totalling approximately 2,880 sq. m), which could have caused wood decay and dysfunctionality of joints and so, this could be the reason for such structural change. As the neighbouring warehouse 32 was being built at the same time, i.e. in 1907, as a reinforced concrete structure, it can reasonably be assumed that the same designer would use a similar structure on both warehouses [7].

2.2.Port warehouses 8 and 11

Port warehouses 8 and 11 on the Rudolf Pier (currently known as Orlando Pier) were built in 1888. The span between the load-bearing walls was 19.35m. In the basement and the ground floor, a metal frame structure with three rows of columns and down stand beams was interpolated inside this span, in order to support the timber structure of the first floor, itself covered with an open roof. These load-bearing structural systems were constructed as a series of triple purline roofs whose vertical props followed the pattern of metal studs of the two storeys beneath them. The ending purline roof studs were not supported by braces, which was often the case in old buildings. Most members were of square cross-section, which amounted to 25/25 for vertical props, 20/20 for struts, and 18/18 for common rafters. The remaining members were rectangular, with cross-sections measuring 25/30 for purlines and 2 x 12/20 for collar ties. The system was additionally stiffened by metal ties, interpolated directly under the ceiling joists. There are no data about the botanical species used for these members (Figure 4 and 5) [8].

2.3. Coal warehouses

Coal warehouses on the breakwater were built in 1898, based on the design by engineer Istvan Bacsak. Three simple single-space structures were placed directly alongside the protective wall of the breakwater, which served to them as longitudinal peripheral wall, while the other one was placed parallel to it at the distance of 7.5 m. Two warehouses rectangular in plan, and the third one of irregular plan, were covered with a mildly sloping wooden mono-pitched roof (unusual for this type of structure). The roof structure consisted of wooden purlins spaced at 4 m intervals, which supported the battens carrying the roof sheeting. Mildly sloping single-pitched rafter roofs were commonly used in the Mediterranean area, especially for the extensions of and additions to single-pitched and flat roofs. This type of roof structure with only two purlines is in the origin of more complex roof structures, king-posts and purline roofs with vertical props. Simplicity of structure made the replacement easier in case of decay, which was much more likely to occur in such an exposed location, compared to other parts of the railway- port area [9].

2.4. Main Royal Hungarian Customs House

The Royal Hungarian Customs House was designed in 1890 and built in 1891 based on the design by Egan Lajos and Antal Hajnal, two leading engineers of the Maritime Gubernium. Offices were located in the basement and the high ground floor, the apartments were on the first floor, and two apartments were also situated

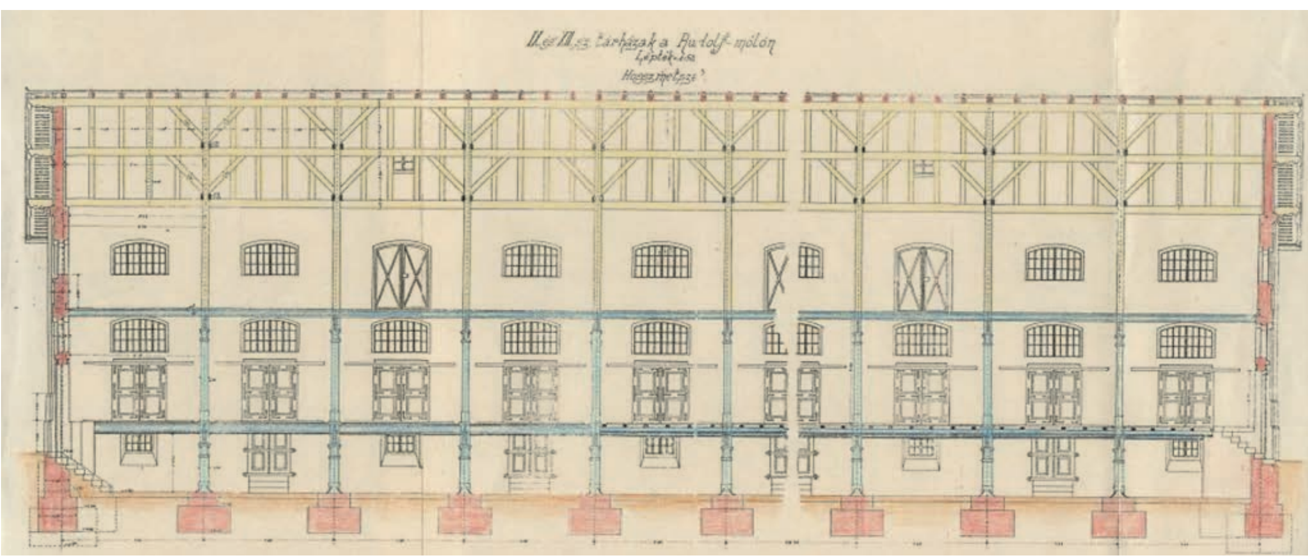


Figure 4. Port warehouses 8 and 11, 1888, longitudinal section [8]

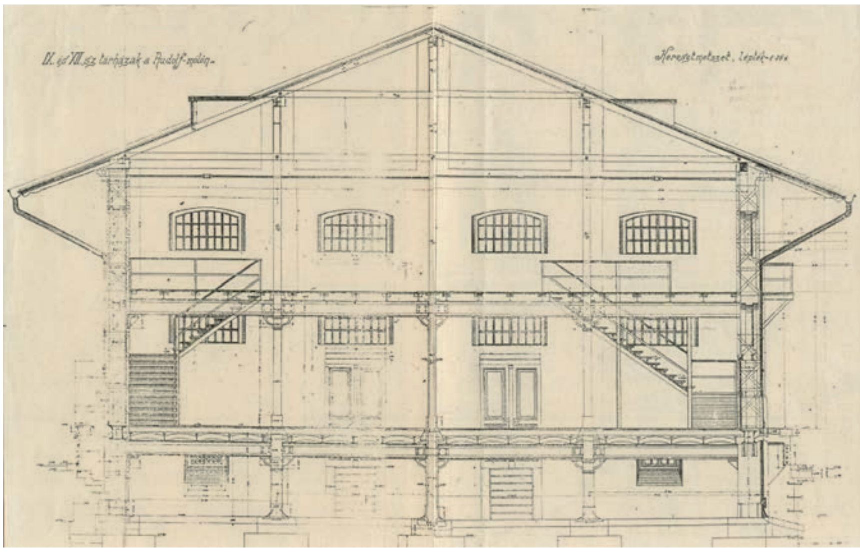


Figure 5. Port warehouses 8 and 11, 1888, transverse section [8]

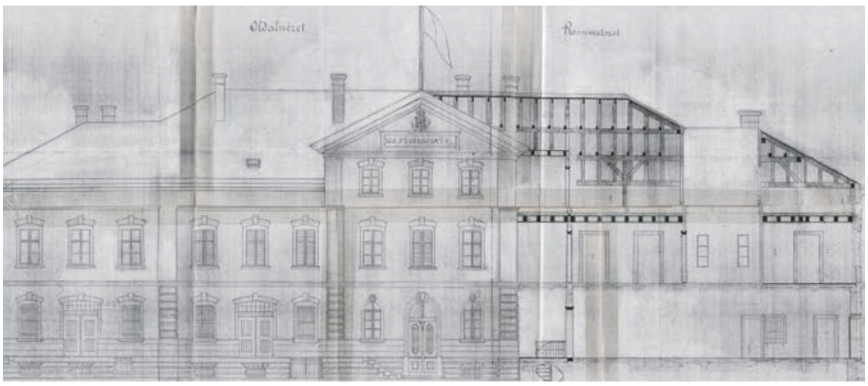


Figure 6. Main Royal Hungarian Customs House, 1891, façade and section [10]

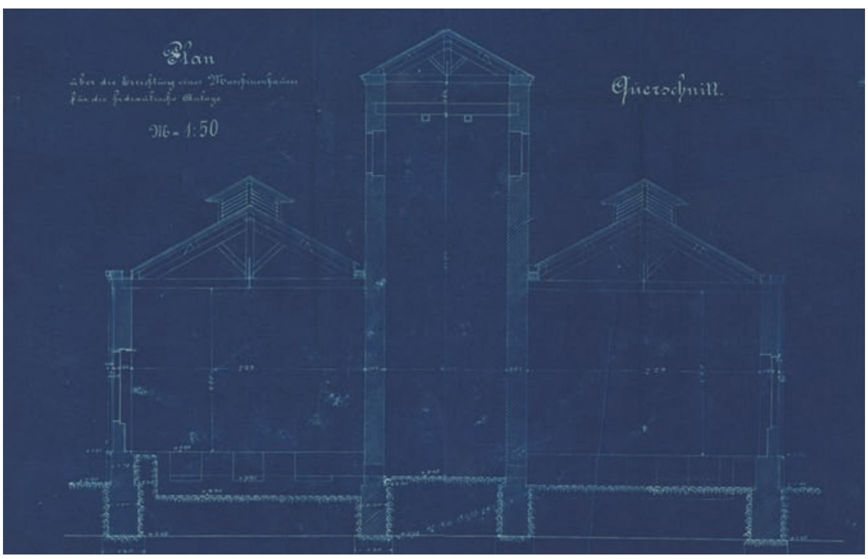


Figure 7. Engine room for hydraulic plant, 1884, transverse section [11]

in the attic. The structure was massive, with masonry walls consisting of peripheral walls and two central longitudinal ones, which provided support in the lower two storeys to floor structure made of iron (or steel) I-sections and shallow segmental concrete vaults (patented by William Fairbairn). The floor structure between the first floor and the attic (residential area) carried a smaller load, and was realized as a wooden beam structural system. The roof, characterized by diverse horizontal and vertical elements, was realized as a purline roof structure whose vertical props, stabilised by principal rafters, were leaning on strengthened ceiling joists [10]. The Customs house was spared from war damage. It was demolished after World War II to make space for an unhindered transport within the port zone. There are no data about poor state of the structure as a possible reason for demolition (Figure 6).

2.5. Engine room for hydraulic plant

The engine room for hydraulic plant was built in 1884 based on the design made by engineer Francesco Placsek. Originally, this triple-nave building was covered with complex roof made of three separate kingpost roof truss structures (Figure7) [11]. In 1908, only 14 years after the construction, the roof was renovated and, at that, the external roof geometry and structure were partly altered. The reasons for such rapid replacement of the wooden roof structure are unknown, although it is quite likely that the water occasionally spilled from horizontal gutter along the long and narrow roof bays between steep roofs, thus wetting the wooden structure and causing the problem similar to that described for Warehouse 31.

This explanation is backed by the way in which renovation work was conducted. The central nave was renovated using a similar structure, while the side nave ridge was moved towards the inner edge, thus reducing the inner roof area and the quantity of water to be handled by central horizontal gutters. The type of the structure was also changed, i.e. two asymmetrical combinations were made involving purline roofs with double vertical props (without principal rafters) and the king-post roof (Figure 8) [12].

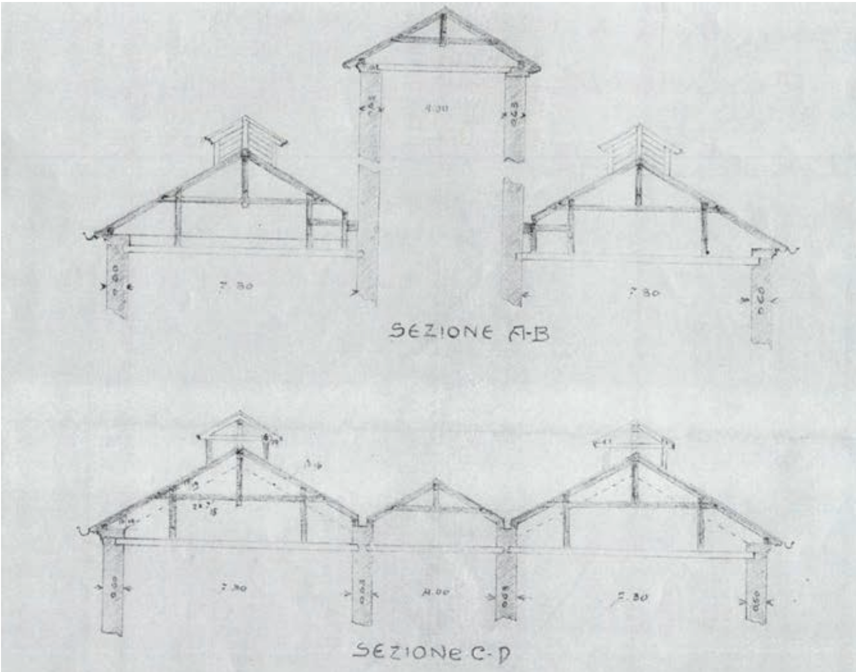


Figure 8. Engine room for hydraulic plant, roof renovation, 1908, transverse section [12]

the structural system. Better solution involved nailing the board lining from both sides of horizontal beams (external and internal) and the layer of air "entrapped" between the lining layers improved impermeability of the wall and thermal insulation properties. Such solutions were applied in cases when people remained in warehouses for a longer period of time and when highly delicate goods were stored. Smooth sloped double-pitched roofs involved the use of purlin roof structures, mostly with vertical props. Principal rafters provided stability to vertical props in transverse direction, while only struts ("arms") were used for horizontal stabilization in longitudinal direction. Angle braces provided additional stiffness to external walls [13]. The quality and durability of the wooden structure was not the priority in these buildings, since they were dismantled after a few years and replaced with more durable masonry warehouses. The evidence for that are the foundations, which were also wooden. (Figure 10).

3. Skeleton timber structures

3.1. Temporary warehouses

Skeleton structures (or beam-post structures) with bigger spacing of the posts and beams were most commonly used for the construction of temporary warehouses, which were characteristic for the first phase of development of the railway-port zone (Figure 9). They were usually one-storey buildings of simple rectangular shape, while in rare cases their shape was more complex, adjusted to the locality. The dimensions and spans were standard, with posts spaced at up to 5m intervals in several longitudinal rows, the end ones being peripheral elements. The façade lining was solved in several ways. The cheaper versions consisted of one-layer planks which were butt-jointed and directly nailed only from outside onto horizontal beams of

3.2. Grain silo

As most freight traffic in the port of Rijeka involved, in addition to wood and sugar, the trade in grains, special warehouses had to be built to enable their storage and easy handling. Austrian architect Christian (Keresztily) Ulrich was chosen to design the grain silo in the Port of Rijeka. In 1881, ten years earlier, he designed a similar structure in the river port of Budapest. The masonry exterior of the silo in Budapest was built in the representative style of historicism, while the interior was functional, involving skeletal steel and wooden structure [14] (Figure 11). The design for the silo in Rijeka was made in 1889 and the silo was built a year later. The architect renounced the

Figure 9. Photo of warehouses at the foot of the Marie Valerie pier (Visinpier), and at the Wharf to the wartime harbour (Prague wharf)

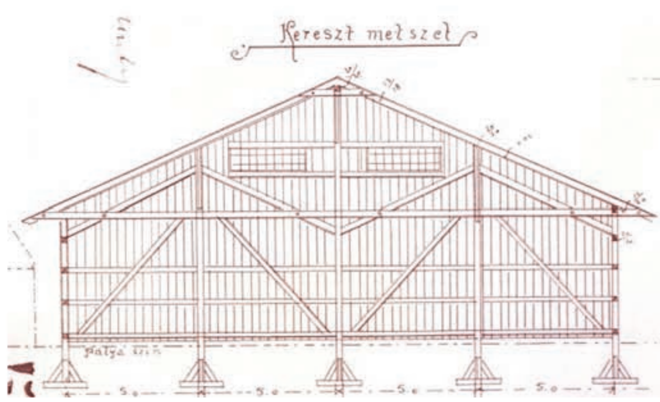


Figure 10. Transverse section through temporary warehouse [13]

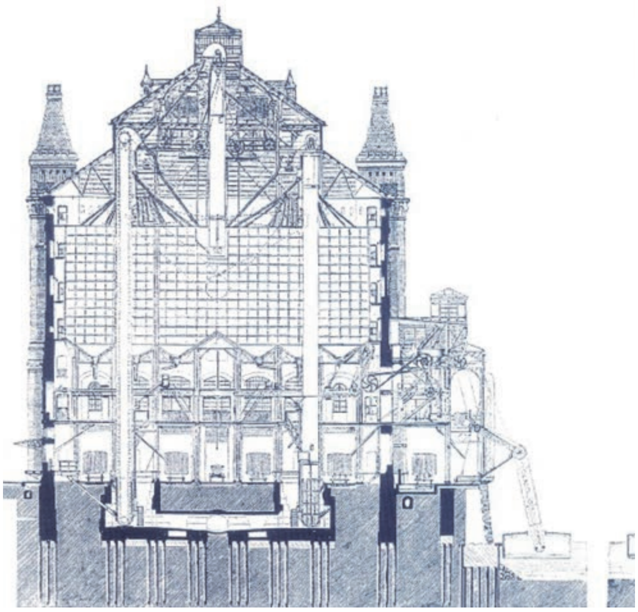


Figure 11. Grain silo in the river port of Budapest, 1881 [14]

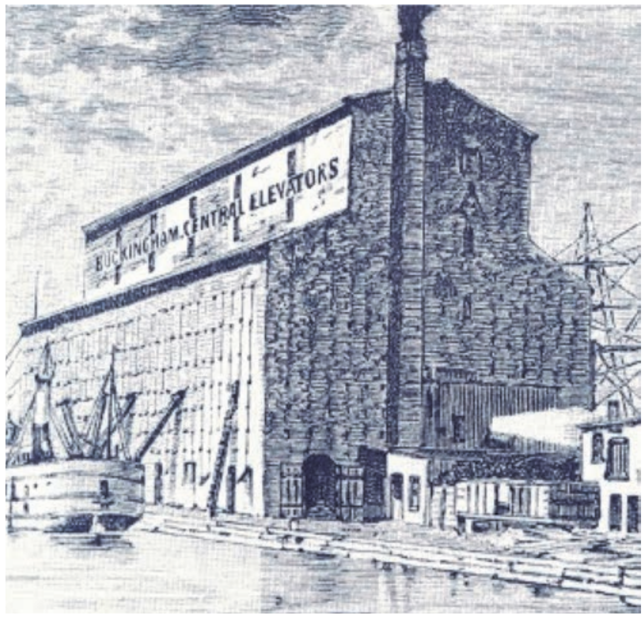


Figure 12. Grain silo in Chicago, 1899 [15]

architectural typology of the silo in Budapest and built a modern, avant-garde structure similar to silos that were built at the time in the USA [15] (Figure 12).

The massive structure was limited only to foundations (made of stone and concrete), external ground-floor walls (made of bricks and stone) and the floor structure above the ground floor (a combination of steel I-girder and concrete vaults according to Fairbairn patent). The interior of the ground floor was supported by metal posts arranged in grid consisting of 6 arrays, each with 16 lines. Two railway tracks passed through the building in between the side arrays and the central array of posts.

All other storeys were realized as wooden skeletal structures with platform posts that ran from floor to floor and timber floor supported by lower storey posts. Both materials, metal and wood, were chosen for their low weight, which was suitable for the tallest building in the port, founded on filled soil. The ground floor (5.2 m high in the handling area and 6.5 m in the area with tracks) supports a tall storey above it (3 times taller than standard height, as can be seen from cross-section of the staircase) with a set of funnel-bottomed grain chambers (cells). The storey above it contains the storage area throughout the width of the structure. The third, fourth and fifth storeys took up only the central part of the building, and the last one consisted of three roof dormers only.

Except for the 12 m tall storey with chambers, all other storeys were of standard height, which varied between 3.30 and 5 m (Figure 13 and Figure 14) [1]. The grains were raised up to all storeys of the silo using elevators, while further transport was operated with conveyors, Redler systems, or flutes. All upper storeys were built as traditional storages in which the cargo is

Figure 13. Grain silo, view on western front [26]

Figure 14. Grain silo, view on southern front [27]

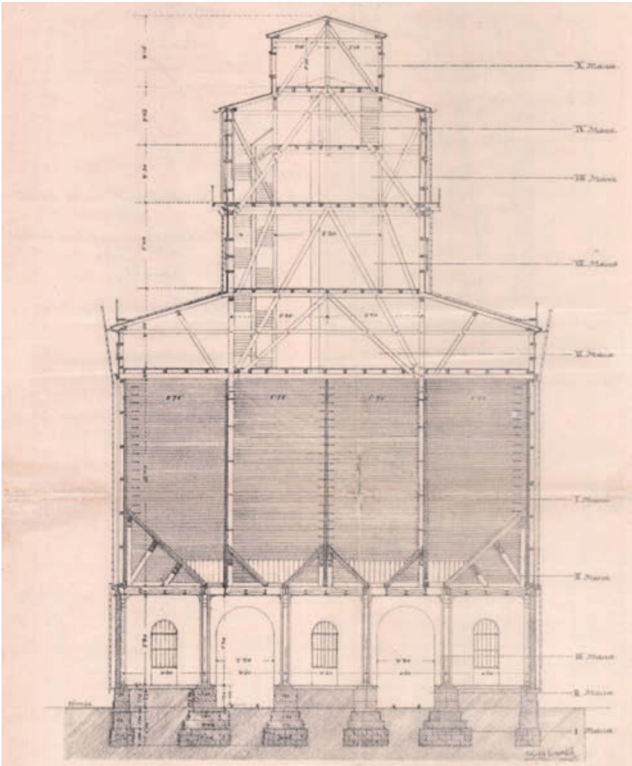


Figure 15. Grain silo, transverse sections a-b [16]

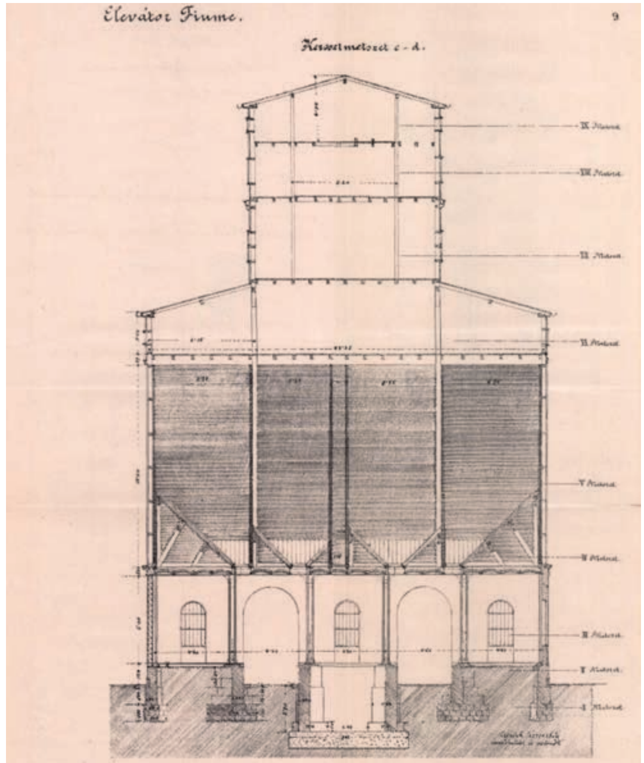


Figure 16. Grain silo, transverse sections c-d [16]

stored on the ground in layers or sacks. The floor had openings to lower the goods from one storey to another. The storey with chambers had two rows of openings–the top one, intended for insertion, and the narrower bottom one, for loading the goods onto railway wagons.

The skeleton timber structure was executed in rectangular modular grid, with 3.95 m spans in longitudinal direction and 4.6 m spans in transverse direction. Solid cross-section posts, or double or triple built-up timber posts, were placed at the point of intersection of modular axes, and the type of their cross-section varied from storey to storey. The cross-section of load-bearing posts in lower storeys was 28/28cm, and it was up to 20/20 for roof dormers. The roofs were executed as purline roof structures with multiple angle props. The cross-section of the posts was double at joints, and the joints were additionally strengthened. The cross-section of purlines varied from 28/30 to 16/20 cm. The ceiling joists were double, with cross-section from 2 x 22/34 cm to 2 x 14/20 cm. Principal rafters were of square cross-section 16/16 cm, and common rafters of rectangular cross-section of 14/20 and 14/18 cm (Figures 15, 16, 17 and 18) [16].

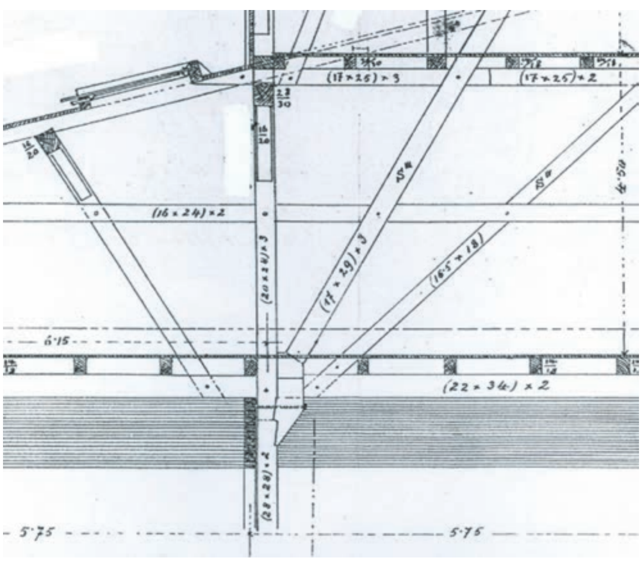


Figure 17. Grain silo, structural details [16]

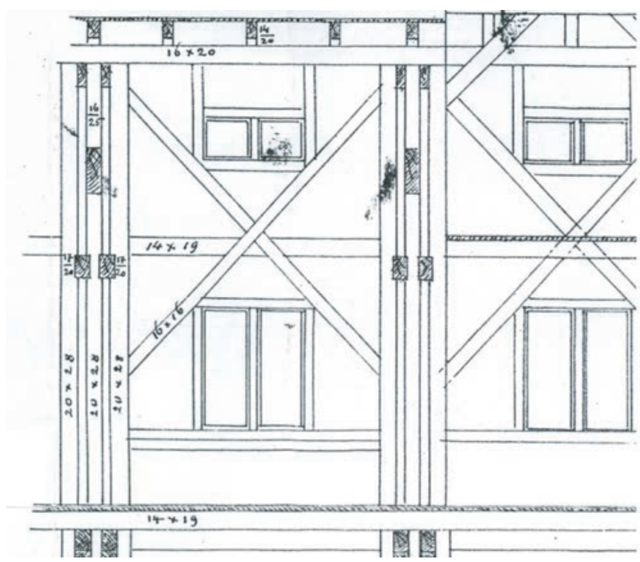


Figure 18. Grain silo, structural details [16]

The structural system was spatially stabilized with braces and struts in both directions. Exterior walls were stabilized in an interesting and effective way: a cross board formwork was nailed onto the double-gridded battens (in interrelated perpendicularly arranged layers of alternating directions). This type of spatial stabilization ensured the system's resistance to racking (when walls are exposed to horizontal wind forces of alternating directions). Structures between the storeys were executed as simple timber floors consisting of joists 14/18 cm in cross-section, spaced at 115 cm intervals, with the top board sheeting, which was at the same time the floor lining (completed floor). The impermeability of the storey with chambers was ensured along the entire height with a thick formwork of horizontally laid boards (Figure 19) [16].

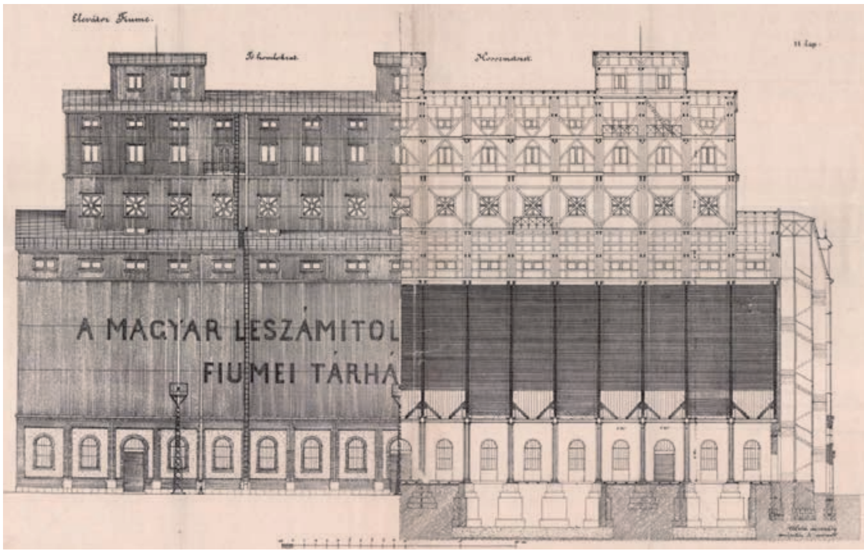


Figure 19. Grain silo, northern front and longitudinal section [16]

4. Half-timbered structures

Half-timbered structures, with visible and thickly arranged posts and beams were not part of the building tradition in Rijeka. Although Hungarian engineers working in the Northern Croatia Littoral mostly used international styles such as historicism and Art-Nouveau, and the related decorative and structural elements, several half-timbered structures exhibiting features of traditional Hungarian architecture were nevertheless built during Hungarian administration in the port and railway area of Rijeka. Carpentry joints with direct transfer of compressive and shear forces, or with indirect transfer via additional elements and connections (nails, rivets and later on wire), were normally used in such structures, [17]. Brick units finished with a layer of lightly coloured plaster were most frequently used as fill between wooden elements.

4.1. Old railway station

The old railway station was built in 1873, which coincided with completion of the railway that connected Rijeka via Karlovac and St. Peter (Pivka) to other centres of the Monarchy. It was conceived as a temporary building which in fact determined its final structure. It is possible that the railway station was planned only in one (western) part of the zone, with the other (eastern) part perhaps reserved for a traditional warehouse or for some other economic use related to railway transport. Unfortunately,

Figure 20. Old railway station (1873-1888), southern façade and part of western facade [1]

the design was not preserved, and so we now have only two photographs showing its smaller parts, i.e. one shows parts of its southern and western façades (Figure 20), and the other the eastern façade. It can be discerned from the photos that this was a rectangular building, typologically similar to warehouse 31, but with wooden structure. The building had two parallel slightly sloping double-pitched roofs, which extended from the eastern (probably also the northern) side into canopies supported by cantilevers. The central part of the station was somewhat elevated with regard to its sides, and was accessed via laterally placed (probably both sided) wooden stairs. The station was not a traditional half-timbered building, but rather a skeletal and half-timbered combination. The posts of the structure were spaced at smaller intervals in longitudinal direction, while the spacing in transverse direction was greater compared to the one typically used for half-timbered structures. The wall structure between internal posts was divided by beams into four sections, while cross-diagonal braces for side-post stiffening were set in two central sections of the corners. The wall infill of the half-timber structure probably consisted of bricks finished with plaster [1].

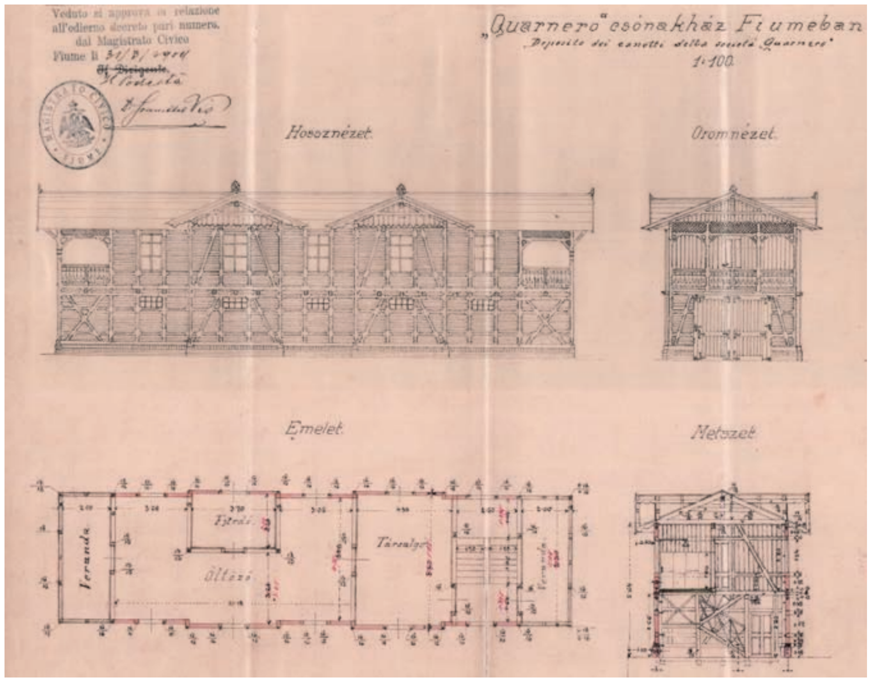


Figure 21. Rowing club Quarnero, design from 1904 [18]

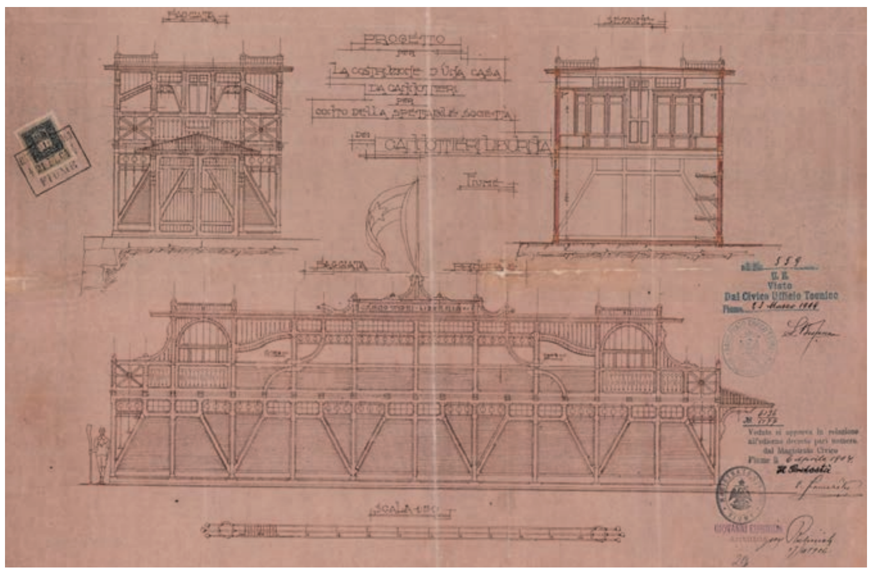


Figure 22. Rowing club Liburnia, design from1904 [19]

4.2. Rowing clubs *Quarnero, CanottieriFiumani* and *Liburnia*

In 1904, three rowing-club buildings of similar form, structure and size (approx. 22.0 x 5.5. x 5.5 m) were erected in the western part of the Rijeka breakwater: *Quarnero*, *Canottieri Fiumani*, and *Liburnia*. The arrangement of space was similar in each of these buildings: storage room for boats at the ground floor, and club facilities, dressing rooms, bathrooms, and terraces on the first floor. All were built as half-timbered structures. The *Quarnero* club was designed by Hungarian engineer Imre Berger, and the *Canottieri Fiumani* and *Liburnia* by architect Giovanni Rubinich from Rijeka. The solutions presented by the two architects greatly differed from one another. Berger offered a design in the style of historicism which was a textbook example of a half-timbered structure with posts measuring 16/16, 15/15 and 18/18 in cross-section, and beams axially spaced at approximately 1,0 m intervals, and with angle braces placed in wall corners and in peripheral parts of avant-corps (acting as struts).

Two avant-corps were additionally emphasized by roof surfaces perpendicular to basic geometry of the roof. The exterior walls mainly consisted of brick infill, whereas interior walls and walls on the veranda were wooden, made of vertically placed boards, attached on the one side to the external face of horizontal load-bearing beams. All structural elements were profiled in their central zones, while full sections were kept in nodes and at intersecting points (Figure 21) [18].

The design of the clubs *Liburnia* [19] and *Canottieri Fiumani* [20] by Rubinich were more modern and creative, with clear features of Art-Nouveau, which was the main architectural style at

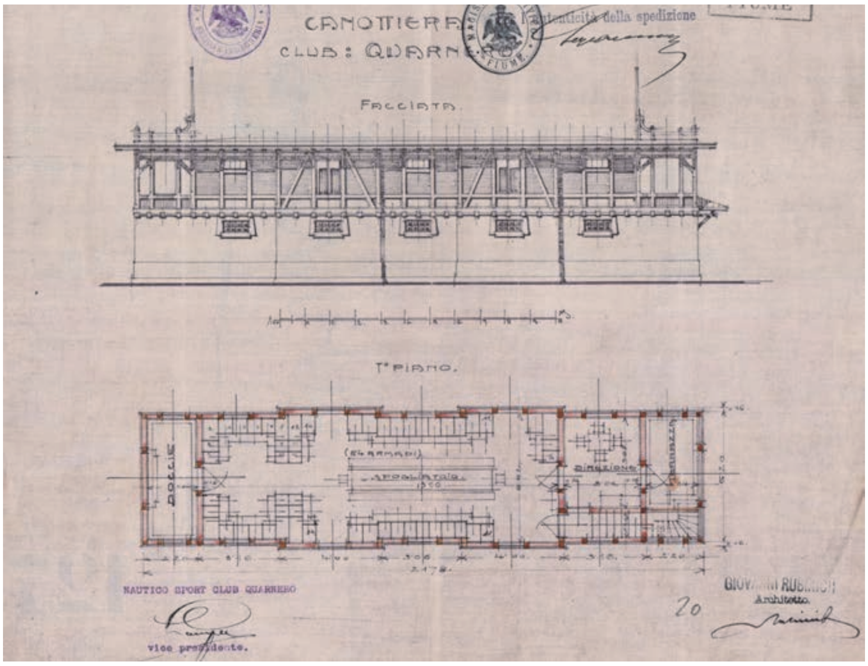


Figure 23. Rowing club Quarnero, renovation design from 1910 [21]

that time. Nevertheless, the architect deviated from standard solutions in both buildings: the posts of longer facades were spaced at 2,0 m intervals, while a denser spacing of structural elements was keptat the sides and in the parapet zone of the first floor.

The structure of the rowing club *Liburnia* is especially distinct, with corner braces, as recognizable elements of half-timbered structures, not placed diagonally within one section (between the opposing corners), but rather extending from the corner of one section to the centre of the section opposite to it. In some wall sections, arch-shaped beams were placed as additional elements, whereas the impression of arch was most probably achieved by mechanical joining of boards. All structural elements were profiled in the same way as it was done in the *Quarnero* club (Figure 22). Exterior walls of both buildings were completely in filled with bricks. The interior space was minimally partitioned with wooden walls of the dressing rooms. The flat roof was a simple wooden structure, made of wooden beams and boards, which were most probably protected with steel sheeting [19, 20]. An uneven appearance of the rowing clubs was probably the reason why the *Quarnero* club was renovated several years later, in 1910, by Giovanni Rubinich. He removed the slant roofs which gave the building its feeling of continental aesthetics, and covered the half-timbered structure of the ground floor, while interpolating new horizontal elements on the first floor in the style of Art Nouveau. He also renovated the interior, in the style of neighbouring club buildings (Figure 23) [21].

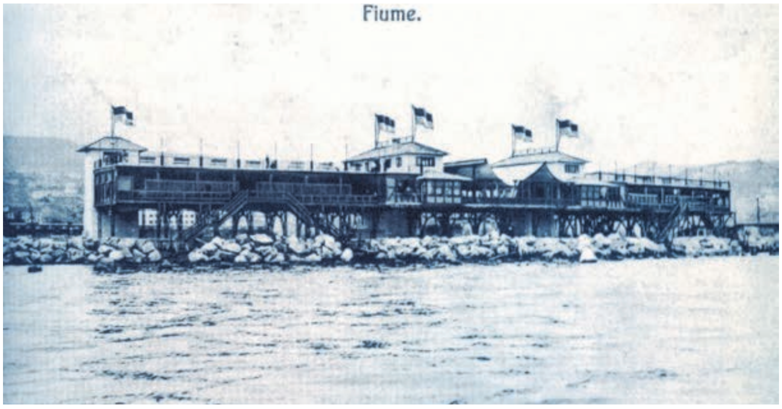
In the same year, Rubinich reconstructed the rowing club *Liburnia* by completely covering the entire half-timbered structure [22], and engineer Vjenceslav Celligoi from Rijeka added the fourth rowing club called *Eneo* to the west of the existing ones, but it was realized as a masonry structure [23].

4.3. *Quarnero* Bath

Several years later, in 1913, the *Quarnero* Bath was built to the east of the rowing clubs. The City's technical office entrusted the project to the experts Luigi Bescocca, Luigi Luppis and Vjenceslav Celligoi. Engineers Luppis, Hugo Hering and D. Marussig developed the preliminary design for the contractor *Impressa constuzioni M. Müntz & Co.* [24].

The bathing area was located in the central part of the breakwater, at the place of its refraction, i.e. in the zone where it turns from west to northwest. The real problem was the very small width of the breakwater, which amounted to only 12 m in this zone, and half of it was taken up by the railway tracks, i.e. by the width of the train that ran through the breakwater and the port. The architects used the entire available width of the breakwater, that is, they added to the flat part the width of the wall and the breakwater thus ensuring 19 m of space to accommodate the bath building. The problem of the railway traffic was solved by raising the entire bath building, propping it onto a structure supported by steel posts, thus providing 5

Figure 24. Quarnero Bath, northern front facing the town, next to rowing clubs Quarnero, Canottieri Fiumani, Liburnia and Eneo [24]



Gigure 25. Quarnero Bath, southern front towards the bay [24]

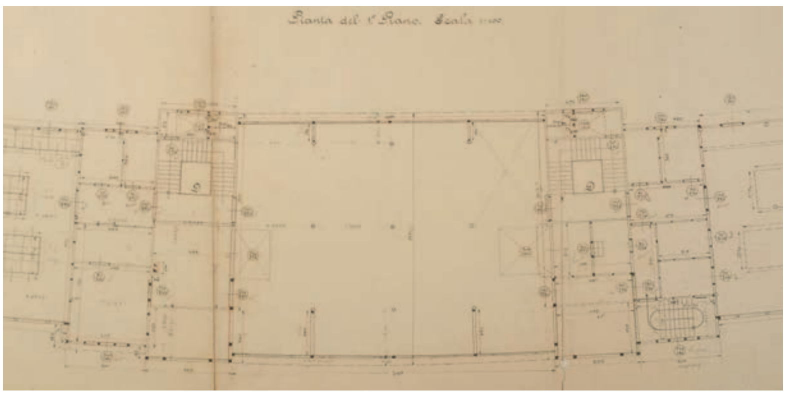


Figure 26. Quarnero Bath, plan of the central part of the first floor [25]

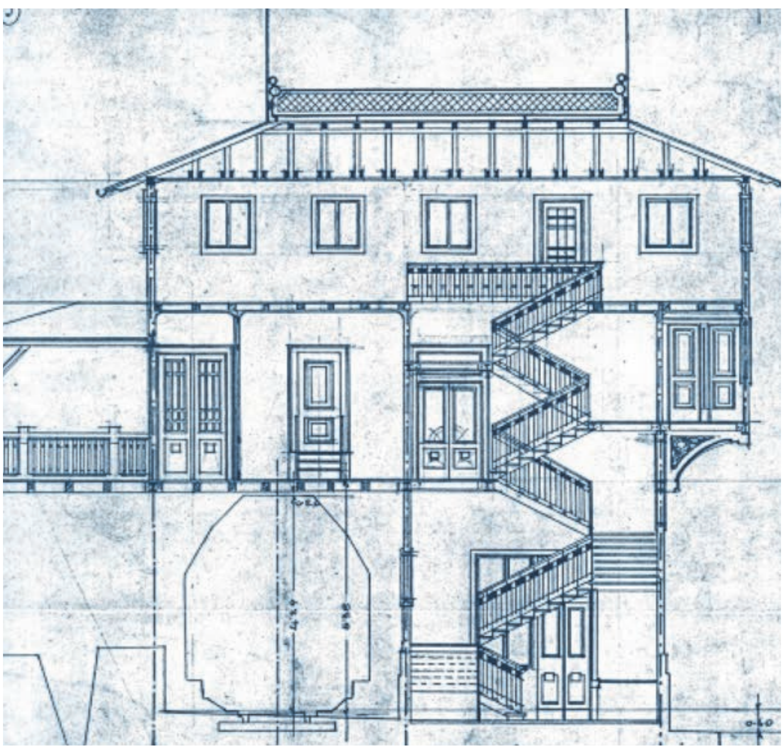


Figure 27. uarnero Bath, transverse section through central staircase tower, realized as steel and timber structure [25]

meters of clearance for the passage of trains. The high ground floor area was constructed as a skeletal steel structure, while the upper storeys were realized asa half-timbered and skeletal structure (Figures 24, 25).

The bath building was approximately 100 m long, and 14 to 16.5 m wide. It had three storeys: the ground floor area of the structure with communication space, the first storey with the main terrace, and the second storey with roof terraces. Masonry staircase towers were constructed in the corners from the internal side of the bay and, between them, two additional staircase towers with protruding upper parts were built. The spacious central terrace was open to the south and north: on to one side, it was oriented toward the bay, while facing the town and the port on the other side.

There were two closed-in areas on two sides of the terrace. These areas were used as bars intended to be used when it was raining. In the western part, there was a buffet and a kitchen with utility rooms, main staircase, two rooms for laundry and valuables, and a passage leading to a big western wing of the terrace with dressing rooms for gentlemen. On the eastern side of the main terrace, there was a small summer theatre and children dressing rooms, main staircase with identical utility rooms, and passages leading to the eastern wing of the terrace with dressing rooms for ladies. The access to both lateral terraces on the south side was solved with wooden double staircases, which were used by bathers to go down to the bounded part of the sea and small pools. On the other side, there were staircases leading to the upper terrace designated for sunbathing.

The northern and lateral sides of the upper storeys were realized as a half-timbered structure, whose modular disposition was 3 times smaller compared to the steel structure of the ground floor. The disposition of the wooden skeletal structure of the southern front in the larger part concurred with the steel structure of the ground floor, except for the lateral modules next to central towers, which were also realized as a half-timbered structure. With the exception of details, the half-timber structure did not deviate in its concept from standard solutions. The spacing of posts in the skeletal structure varied from 4,8 m to 5m, and in the half-timbered structure from 1 m to 2 m. The exterior and interior walls of the bath building were entirely wooden in the upper storeys. The board cladding, nailed on both sides of cross-section onto structural elements improved the stiffness and stability of the structural system thus providing better thermal insulation (Figure 26, 27) [24].

5. Durability of structures and destiny of buildings

All described buildings that were located in the port and railways zone disappeared over the years. The oldest building was built in 1873, and the youngest in 1913. The only building that survived to this day is the railway warehouse 31, but it no longer has its original wooden structure. There are many reasons as to why the buildings have not been preserved. The old railway station perished in fire in 1888, and was replaced with a new, more representative station that was built on a neighbouring location as a masonry structure that still exists today. In 1907, a new railway warehouse 33, a combined masonry and RC structure, was built at the place previously occupied by the old railway station. In the same year, a fire broke out in the grain silo. Helped by a gale-force wind, the fire was not subdued for three days, and it completely destroyed the building and the grain it contained. In both cases, the choice of wood as combustible materials and the design of the structure helped the fire to develop and spread. Port warehouses 8 and 11 as well as most other buildings in the port were extremely devastated in the allied bombing of Rijeka in 1945. Since great financial funds were needed to be secured for its reconstruction after the war, it was estimated that it was more cost-effective to demolish them than spend money reconstructing them. The coal warehouses on the breakwater, as well as the rowing clubs were also pulled down, and were never rebuilt on the same spot. Most of these buildings were removed after World War II. The customs house and the engine room building were demolished during the 1960s. The same fate was reserved for *Quarnero* Bath. None of these buildings were seriously damaged during the bombing and, just before they were demolished, they had been used on a regular basis and were in a relatively good condition.

Durability of wooden structures had a different effect on their disappearance and decisions made to reconstruct or demolish them. If we exclude parts of wooden structures completely immersed in water, whose durability could be considered almost unlimited in case present conditions remain unchanged, and the interior and covered parts, whose durability is measured in centuries, the durability of wooden elements and parts of a structure exposed to wetting and changes of moisture regime, combined with insufficient maintenance, can be considered as relatively limited. The causes of degradation and decay of material and damage to wooden structures which were situated in the port and railway zone of Rijeka could be:

- accidental: such as fire
- natural: exposure to strong winds and environmental influences with their implications on durability and technical properties of materials (exposure to wetting – caused by rain, frost or sloshing, condensation and capillary moisture; alternating of moisture regime which provokes crack propagation on wooden surfaces; aggressive impact of the sea area that influences metal parts of connections provoking their corrosion; UV radiation),
- structural: materials/botanical species of insufficient natural durability (spruce, fir), weak structural properties (resistance of cross-sections, stability of elements and systems), incorrectly designed connections or insufficient number of connections with sub-structure / non-bearing elements from materials other than timber, insufficient structural-physical preservation (drainage and cladding) and structural protection of elements (moisture buildup at connection zones), incorrect planning and realization, construction based mostly on experience and insufficient regulatory framework,
- human factor: ideological, economic, loss of function, change of taste, low level of maintenance, design and construction shortcomings.

If we exclude natural disasters (buildings destroyed in fires lasted 15, i.e. 17 years), as well as conscious or unconscious human interventions (buildings destroyed by bombing were between 41 and 57 years old), and if we look for reasons only in degradation of material properties due to the surrounding microclimate influences, we may find some answers by consulting data on documented reconstructions or subsequent interventions.

In two cases (railway warehouse 31 and engine room), roof structures were replaced after 26 and 24 years, respectively. In the first case, timber was replaced with another material, and in the second case, the wooden structure was rebuilt. This leads to the conclusion that the reason for these reconstructions could be related to poor condition of timber, and the cause can be found in the faulty design and execution (human factor being the cause). Nevertheless, it is also likely that there were benefits in using wood for this type of structure, which had a favourable effect on the use of this material in the zone study (Figure 28) [11].

The situation is somewhat different with the buildings on the breakwater, which were extremely exposed to environmental influences. A highly illustrative example are the half-timber

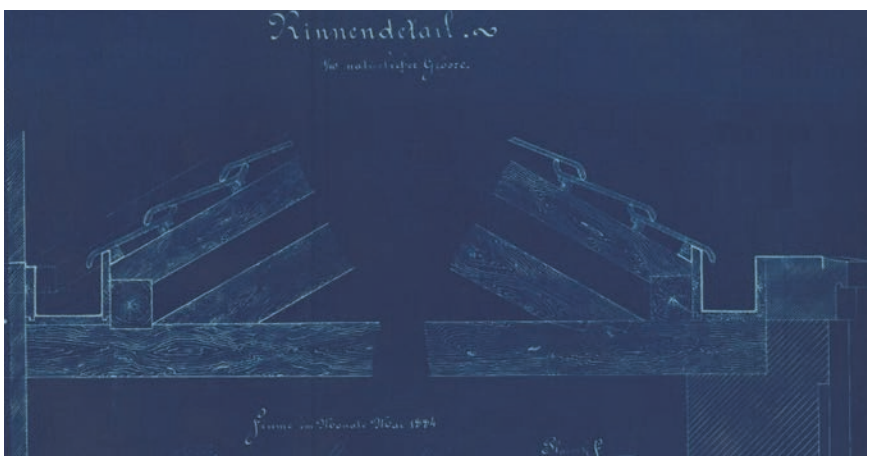


Figure 28. Engine room for hydraulic plant, 1884: structural detail [11]

structures on the ground floor of the rowing clubs *Quarnero* and *Liburnia*, which were walled off (but not replaced) already after 6 years. In the fourth club *Eneo*, which was built last, the use of wooden structure was not even considered. Due to location of these clubs, which were situated only few meters away from the sea, aggressive effects of the sea on the exposed ground-floor structures were certainly highly detrimental (splashing, alternating drying and wetting with accompanying cracking, and reduced technical properties of material in elements exposed to wetting). The half-timber structure of the *Quarnero* Bath lasted more than 40 years, but it was raised on a higher storey and was therefore less exposed to direct impact of the sea, waves and chloride (which primarily affected metal fasteners).

6. Conclusion

In the Port of Rijeka, wooden structures were mostly used in temporary buildings, and as floor structures of traditional masonry buildings and roofs. Under the influence of mostly Hungarian engineers and architects and the styles that prevailed at that time in architecture and building construction – historicism and Art Nouveau, some specific skeletal and half-timbered structures, previously unknown in this area, were introduced in the port of Rijeka. It was those structures that gave Rijeka and its port a particular, continental and international character at the turn of the twentieth century.

Unfortunately, these historically significant timber structures were not preserved to this day. The reasons for that are only to a lesser extent related to external influences and durability of wood in specific micro-climate of the port zone. As it is often the case with other architectural heritage, the reasons are mostly related to the activity of humans, who have always been the greatest threat to the longevity of their own creations. It can be concluded that main motives for the disappearance of the described buildings were functional (loss of primary function), technological (new ways of manipulating the cargo in the port, which demand bigger free spaces), spatial and urban (new regimes in the port, which becomes a zone closed to citizens), but also ideological - negative attitude of post-war art historians, architects and engineers towards historical architecture, especially historicism and Art Nouveau (which were regarded as „foreign" architecture, stylistically unadjusted to the ambient), as well as the lack of clear conservation criteria regarding renovation of this type of buildings. Today, as this zone is once again undergoing great transformations, one is considerably more appreciative of the architecture that originated in the era of the greatest economical prosperity and urban development of Rijeka. In standard and especially non-standard use of materials and structures, we discover new values and specificities, which have significantly influenced the history of construction in this part of the world, and the building profession in general.

REFERENCES

[1] Palinić, N.: Prometne zgrade – željeznica i luka, Arhitektura historicizma u Rijeci, Muzej moderne i suvremene umjetnosti Rijeka, Rijeka, 2001., pp. 374-419

[2] Palinić, N.: Rane armiranobetonske konstrukcije u riječkoj luci, Građevinar, 61 (2009) 5, pp. 435-444

[3] EN 1991-1-1:2002: Actions on structures - Part 1-1: General actions – Densities, self-weight, imposed loads for buildings, CEN Brussels, 2002

[4] Schwaner, K.: Beam and post structures – Principles, STEP 2 lecture E15, STEP 1/EUROFORTECH, First Edition, Contrum Hout, The Netherlands,1995

[5] Državni arhiv u Rijeci,Fond Tehnički uredi grada Rijeke, sign. DARI, JU 51, kut. 118, br. 30/2/1881.

[6] Državni arhiv u Rijeci, Fond Tehnički uredi grada Rijeke, sign. DARI, JU 51, kut. 129, br. 34/1890.; DARI, JU 51, br. 43/1895.

[7] Državni arhiv u Rijeci, Fond Tehnički uredi grada Rijeke, sign. DARI, JU 51, kut.152, br. 145/1907.

[8] Državni arhiv u Rijeci, Fond Tehnički uredi grada Rijeke, sign. DARI, JU 51, kut. 27; JU 51, kut. 128, br. 16/5/1889.

[9] Državni arhiv u Rijeci, Fond Tehnički uredi grada Rijeke, sign. DARI, JU 51, kut. 139, br. 110/1898.

[10] Državni arhiv u Rijeci, Fond Tehnički uredi grada Rijeke, sign. DARI, JU 51, kut. 130, br. 12/1891.

[11] Državni arhiv u Rijeci, Fond Tehnički uredi grada Rijeke, sign. DARI, JU 51, kut. 121, br. 124/6/1884.

[12] Državni arhiv u Rijeci, Fond Pokrajinski tehnički uredi u Rijeci, sign. DARI, JU 50, kut. 97

[13] Državni arhiv u Rijeci, Fond Tehnički uredi grada Rijeke, sign. DARI, JU 51, kut. 118, br. 33/1881.

[14] Sisa, J.: Historizmus, Magyarország építészetének története, Vince Kiadó, Budapest, 1998., pp. 227

[15] Glibota, A.: Edelmann, F.: Chicago 150 Ans d'Architecture 1833-1983, Paris, 1985., pp. 12

[16] Državni arhiv u Rijeci, Fond Tehnički uredi grada Rijeke, sign. DARI, JU 51, kut. 129, br. 1/1890.

[17] Kuklik, P.: History of timber structures, Handbook 1: Timber structures, Leonardo da Vinci Pilot Project (CZ/06/B/F/PP/168007), TEMTIS, 2008, Chapter 1, pp. 1-14:

[18] Državni arhiv u Rijeci, Fond Tehnički uredi grada Rijeke, sign. DARI, JU 51, kut. 147, br. 24/2/1904.

[19] Državni arhiv u Rijeci, Fond Tehnički uredi grada Rijeke, sign. DARI, JU 51, kut. 147, br. 22/2/1904.

[20] Državni arhiv u Rijeci, Fond Tehnički uredi grada Rijeke, sign. DARI, JU 51, kut. 147, br. 20/2/1904.

[21] Državni arhiv u Rijeci, Fond Tehnički uredi grada Rijeke, sign. DARI, JU 51, kut. 157, br. 127/2/1910.

[22] Državni arhiv u Rijeci, Fond Tehnički uredi grada Rijeke, sign. DARI, JU 51, kut. 157, br. 128/1910.

[23] Državni arhiv u Rijeci, Fond Tehnički uredi grada Rijeke, sign. DARI, JU 51, kut. 157, br. 129/1910.

[24] Magaš, O.: Komunalni objekti, Arhitektura secesije u Rijeci, Moderna galerija Rijeka, Rijeka, 1997., pp. 284-309

[25] Državni arhiv u Rijeci, Fond Tehnički uredi grada Rijeke, sign. DARI, JU 51, kut. 84

[26] Smokvina, M.: Rijeka na povijesnim fotografijama, Dušević i Kršovnik, Rijeka, 1997., pp. 149

[27] Rotim Malvić, J.: Lučka skladišta, Riječka luka: povijest, izgradnja, promet, Muzej grada Rijeke, Rijeka, 2001., pp. 202