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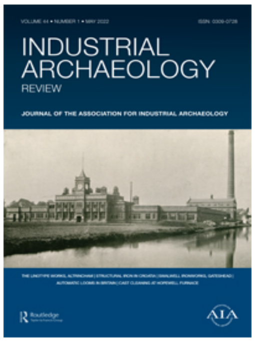
Source / Izvornik: **Industrial Archaeology Review, 2022, 44, 19 - 35**

Journal article, Published version
Rad u časopisu, Objavljena verzija rada (izdavačev PDF)

https://doi.org/10.1080/03090728.2022.2060549

Permanent link / Trajna poveznica: https://urn.nsk.hr/urn:nbn:hr:157:814416



Industrial Archaeology Review

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/yiar20

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To cite this article: Adriana Bjelanović, Nana Palinić & Marko Franković (2022) Structures of the First Industrial Age in Rijeka, Croatia — from Timber to Iron, Industrial Archaeology Review, 44:1, 19-35, DOI: 10.1080/03090728.2022.2060549

To link to this article: https://doi.org/10.1080/03090728.2022.2060549

Published online: 31 May 2022.

INDUSTRIAL ARCHAEOLOGY REVIEW
2022, VOL. 44, NO. 1, 19–35
https://doi.org/10.1080/03090728.2022.2060549

Structures of the First Industrial Age in Rijeka, Croatia — from Timber to Iron

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ABSTRACT
The article describes the use of iron in industrial buildings constructed in the first industrial age in Rijeka. Since the middle of the 19th century, the structural use of cast iron in internal skeleton structures in place of timber created opportunities for improved functional design of these multi-storey buildings. The analysis of some buildings indicates a lack of experience in the application of new structural typologies, while in others it indicates experimental and innovative structural solutions which reflected the progress of science, technology and high-quality workmanship in that period.

KEYWORDS
Rijeka; industrial architecture; construction; timber; iron; warehouses; tobacco factory; corn mill

Introduction

The industrialisation of Rijeka began in the first half of the 19th century and was preceded by numerous factories that were established following the city's proclamation as a free port in 1719. The first production zone was formed west of the city, between the historic core and the Lazaretto, built in 1725, with the Sugar Refinery as the main manufactory, while the second production zone was formed along the Rječina watercourse, north-east of the city, with a paper mill as the largest plant (Figure 1).[1] The architecture of these production facilities was characterised by massive masonry stone and brick structures.

Skeletal masonry systems combined with massive, vaulted ceilings were represented to some extent, and inner load-bearing systems with the classic construction of longitudinal and transverse massive walls, combined with timber ceilings of simple structure, were dominant. Work processes that required large, uninterrupted spaces imposed a new typology and the introduction of lightweight skeletal structures, which were entirely wooden in the first phase, during the interim, proto-industrial period.[2] In the second phase, combined wood-iron structures were applied, and complete metal structures appeared in the last decade of the 18th century. By introducing a new material, new technology and high-quality workmanship into internal skeleton structures, the development of structural principles and construction techniques took on an even more important role within architectural typology of these multi-storey industrial buildings. These buildings therefore marked a turning point in architecture and structural engineering. By bringing together traditional forms and functionally oriented design, at the same time they reflected the technical and social progress of that period. Brick façades provided massiveness and stability to the buildings whose monumentality then bolstered the impression of strong and prospering production companies. At the same time, engineers, rather than architects, became the true representatives of progress, as they had a better understanding not only the production processes but also of the qualities and potential of the new structures and materials.

The industrial buildings and peculiarities of their structures described in this paper are a testimony of the historical and industrial development of the Rijeka city, and the rare ones among them that have outlived the age of construction are currently the essential part of its cultural and architectural heritage (Tables 1 and 2).

Iron in Construction

Until the first industrial age, the use of iron in construction was limited to: joints in classical timber roof systems with predominantly carpentry joints; anchors; cramps and wedges in stone masonry structures; and chains and ties in wooden ceilings, massive arches and vaults. Traditional carpentry joints (*ie* timber-to-timber connections), which were typical for the roof and ceiling structural systems of those times, entirely match a definition of these connection types, in which compressive and shear forces were transferred exclusively over stressed contact surfaces.[3] Iron fasteners (*eg* bolts, cut nails and rivets/dowels, as an alternative for wooden pegs, as well as staples/clamps) were employed not only to make the carpentry connections (*ie* to prevent separation of jointed members) but also to transfer tension forces, while fastening accessories (*eg* straps, stirrups, clamps, strips, *etc.*) had a similar purpose.[4] The Industrial Revolution dramatically changed the situation, leading to the rapid development of new structural materials, products and construction techniques. At the beginning of the 19th century, the state of knowledge was such that theory of structures was also ripe to enable the development of static systems, undoubtedly stimulated by the growth in the structural use of iron.[5]

The use of skeletal and lattice systems was further expanded thanks to the structural application of iron.[6] The trend of implementing structural members made from cast and wrought iron, which began in European countries with already-developed industrial production processes, took over in Rijeka as well, marking the second phase in the construction of Rijeka's production buildings in the 1840s. The 'post and beam' skeletal system still prevailed as the static system of inner structural walls of multi-storey buildings, but with iron columns (instead of timber posts, characteristic for the proto-industrial age) which rose to the height of one storey. The recognisable appearance of these columns was emphasised by capitals which had a structural and decorative function. The spacings of the columns grew, and so did the spans of the longitudinal beams of the ceiling structures.

It should be noted that the first fully iron skeletons, whose girders were simultaneously constituent members of the iron ceiling structures of Rijeka's industrial buildings, date only from the 1880s. In some buildings that were either constructed or reconstructed at that time, another of the iron-based ceiling structural systems was applied, and the ceiling was made as a series of iron girders combined with brickwork vaults. In almost all cases, I-girders were placed between the longitudinal girders of the internal iron skeleton, and the bottom flanges of the I-sections carried the 'jack arches'. This system also represents an example of what was then considered as a 'fireproof' ceiling structure.

Although there were several foundries in Rijeka at the time, they were oriented towards the casting of objects (*eg* bells,

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Figure 1. Rijeka, the main production zones of the first industrial age on the plan of the city from the end of 18th century made by Mayor von Benko: 1. central zone; 2. zone along the river Rječina (HR-DARI , original in Österreichisches Staatsarchiv, Kriegsarchiv, sign. Glh 175 Fiume). State Archives in Rijeka (HR-DARI), reproduced with permission.

Table 1. Dates of construction/modification and structural solutions of described buildings.

Building	Date of construction	Original structural solution	Date of modification	Modified structural solution
Žakalj Corn Mill	Unknown: end of 18th or beginning of 19th century	Unknown, probably completely massive (classical) construction	1862, after great fire	Massive peripheral walls and three inner transverse ones, combined interior skeleton — first local use of cast-iron columns. Roof structure: purlin-tie roof with central king post
T-building of Tobacco Factory	Mid-19th century, first new building plant dates from 1867	Massive basement structure (stone pillars and cross-vaulted brick bays) and peripheral walls on other three storeys — combined interior skeletal system (cast-iron columns and wooden beams). Roof structure above longitudinal attic walls: hipped purlin-tie roof	1949, after repurposing the building as a factory and service department for marine engines	The ceiling between the ground floor and the basement was strengthened with reinforced-concrete slabs over the cross-vaults; a prefabricated ribbed concrete slab replaced the wooden ceiling structures of the ground and first floor, and the ceiling of the second floor was strengthened with reinforced concrete girders
Eastern Warehouse	Between 1867 and 1875	Massive basement structure, peripheral and two inner transverse walls, inserted combined skeleton in north and south wings on two storeys. No data about basic outlines and roof structure	–	–
Western Warehouse	Between 1882 (or even 1880) and 1883	Similar to the structure of the Eastern Warehouse. Roof structure: purlin-tie roof with double 'upright chairs' combined with and king post truss above the central corridor	–	–
H-building of Tobacco Factory	1750	Classically combined (stone and brick) structure with massive internal structure between the transverse and longitudinal walls; internal pairs of pillars divided the space into three aisles, supporting the vaulted brick ceilings.	*c.* 1850 and *c.* 1892 (also 1946 and 2018)	1850 — by connecting of the two buildings of former Sugar Refinery plant, the H-building was formed. 1892 — combined skeleton was inserted in the larger part of the building; the vaulted brick ceiling was retained on the ground floor of the western wing and on the connecting part of the H-building. Complex hipped roof structure: purlin-tie roof with double 'racking chairs' and king post truss
Port Warehouses 8 and 11	1888	Masonry peripheral walls and internal, full-metal skeletons: basement ceiling was made of shallow concrete vaults and iron girders; ground-floor ceiling was a grid of I-girders in both directions. Roof structure: purlin-tie system with triple 'upright chairs'	–	–
Tobacco Drying Facility	In the 1880s	Massive outer walls (brickwork façades) and interior metal skeleton	1899	Similar to the structure of the old part, but the ceilings in the new part were examples of what then was considered a 'fireproof' system: longitudinal I-girders supported jack arches

Table 2. Date of demolition and current status of described buildings.

Building	Date of demolition	Current status
Žakalj Corn Mill	Unknown	Only ruins of the outer walls survive
T-building of Tobacco Factory	–	Currently undergoing reconstruction and renovation to become a library and cultural centre
Eastern Warehouse	2006	–
Western Warehouse	2006	–
H-building of Tobacco Factory		The best-preserved structure of its type. Today, the building houses of the Rijeka Agricultural and Industrial Complex and the Museum of Modern and Contemporary Art
Port Warehouses 8 and 11	Destroyed by Allied bombing during Second World War	–
Tobacco Drying Facility	2019/20 — only the original outer brick walls have been retained	Incorporated into a new Children's Centre, completed in 2021

mooring bitts) or machines, rather than structural elements for buildings. Structural elements were procured from abroad and were shipped by sea (for example, the cast-iron columns of the Municipal Theatre, purchased in 1883 from the United Kingdom) or by railway (for example, cast-iron columns and wrought-iron beams of the tobacco drying facility purchased in 1899 from Hungary).[7] Unfortunately, there is no reliable data on which firms in the UK and Hungary were involved in the production of these iron structural members.

Timber Ceilings and Roof Structures

Most of the ceilings were timber structures, despite the potentially excessive deflections of the longitudinal main beams. The floors were of a simple structure of plank flooring composed of boards (wider than in strip flooring). The planks, usually in a staggered arrangement, were laid over secondary ceiling beams (*ie* timber joists above longitudinal main beams) in a transverse direction. It makes sense to assume that the spacings and dimensions of the timber beams in both directions were determined by appropriate calculations. Roofs were timber structures of traditional forms, executed in accordance with good carpentry practices of that time. The attics of the buildings were functional spaces (e.g for storage), so the roof structures always leaned on elevated attic walls. Thanks to historical circumstances and geographical location, structural systems characteristic to Central European areas prevailed. They were mostly either traditional purlin roofs or variations slightly modified in the way they were engineered, intended to overcome the greater span and cover the large attic above the highest storey with an open floor space. Besides the strong influence of the Austrian and Hungarian school of structural engineering, the use of timber also had an economic basis. The proximity of Gorski Kotar (the area in the hinterland of Rijeka), which is a natural biotope of fir, spruce and especially beech trees, made the supply of timber easier. It is therefore not surprising that the Grobnik area established itself as the centre of the timber trade in the 19th century. It should also be noted that the first steam-powered sawmill in Gorski Kotar was opened in 1849 in Prezid (the mill most probably perished in a fire in 1885), and after that, two more mills were opened, in Crni Lug (1850) and Ravna Gora (1860).[8]

Structures with a Combined Interior Skeleton System

In Rijeka, the first examples of the use of iron for structural applications appeared in the middle of the 19th century. In 1852, the substitution of the wooden roof structure of the city's theatre with an iron one, which was believed to be more resistant to fire, was suggested. The substitution was not made because the price estimation showed that an iron structure would be twice as expensive as the wooden one.[9] The first structural implementation of iron happened in the following decade, in the new skeletal structure of Žakalj Mill.

Žakalj Corn Mill

Carlo d'Ottavio Fontana and Marco Pigazzi, two businessmen from Trieste, bought the mill that was located on the right bank of the river Rječina in the area of Žakalj under Orehovica, from Gašpar Matković, sometime between 1839 and 1841. A branch road from the Louisiana road was constructed and a bridge was built over the canyon at its narrowest part. The mill first used American, and later Belgian, technology, employing around 300 workers. In 1862, after a great fire, a new mill building was constructed according to the design of architect Giovanni Randich, and this would be the one that would be significant for the first local implementation of metal columns in a skeletal structure (Figures 2 and 3).[10]

The large mill building, in its basic outline, 83.40m long (about 85m, together with its western extension) and 19.25m wide, was constructed as a symmetrical building, with a larger middle section and two lateral wings. The load-bearing structure consisted of massive peripheral walls, transverse walls which were positioned at the compounds of the wings and one more transverse wall in the eastern part of the inner middle footprint. Within each of the three larger spaces of the storeys (five of them, with the exception of the attic), a lightweight skeletal structure with three rows of iron columns and wooden main beams was interpolated. The columns of cast iron (*colonne di ghisa*) were of circular cross-section, with an outer diameter of 236mm (in the middle space unit), *ie* 160mm (in the wing spaces).[11] From the layout and transverse section of the building, it can be seen that the columns had a base, body and extended capitals. The spacings between the rows were about 4.0m, and the columns within them were arranged at distances of about 3.5m in the wing spaces, and up to about 4.5m in the middle section. The storeys were of varying heights — from 3.40m in the basement and the ground floor, up to 3.95m on the first floor, and the height of the columns matched the height of the storeys.

The longitudinal main beams were probably constructed as continuous beams over two spans, leaning on extended capitals, and the end ones were supported by massive walls, the boundaries of the space. These beams supported transverse beams above which plank flooring was laid. Due to the specified spacing of the massive longitudinal walls of the middle section (17.95m), it can be presumed that the transverse beams were constructed either as two continuous beams somewhat longer than 9.0m, or as three beams, of which the inner one, 8.m long, was leaning on the main beams, and the outer ones, somewhat greater than 5.0m in span, were supported on one end on massive longitudinal walls. This other variant seems relevant due to the equalisation of the beam lengths because it can be presumed that the transverse beams of the ceiling structures of both wings of the building were constructed as two continuous beams 8.0m long.

The roof was executed as an interesting timber structure with two middle purlins and a ridge one, but deviates somewhat from the traditional system, common to Central European construction practice. Vertical struts, so-called 'upright chairs', characteristic compression members of traditional purlin-tie roofs support the middle purlins, transferring the loads onto a ceiling

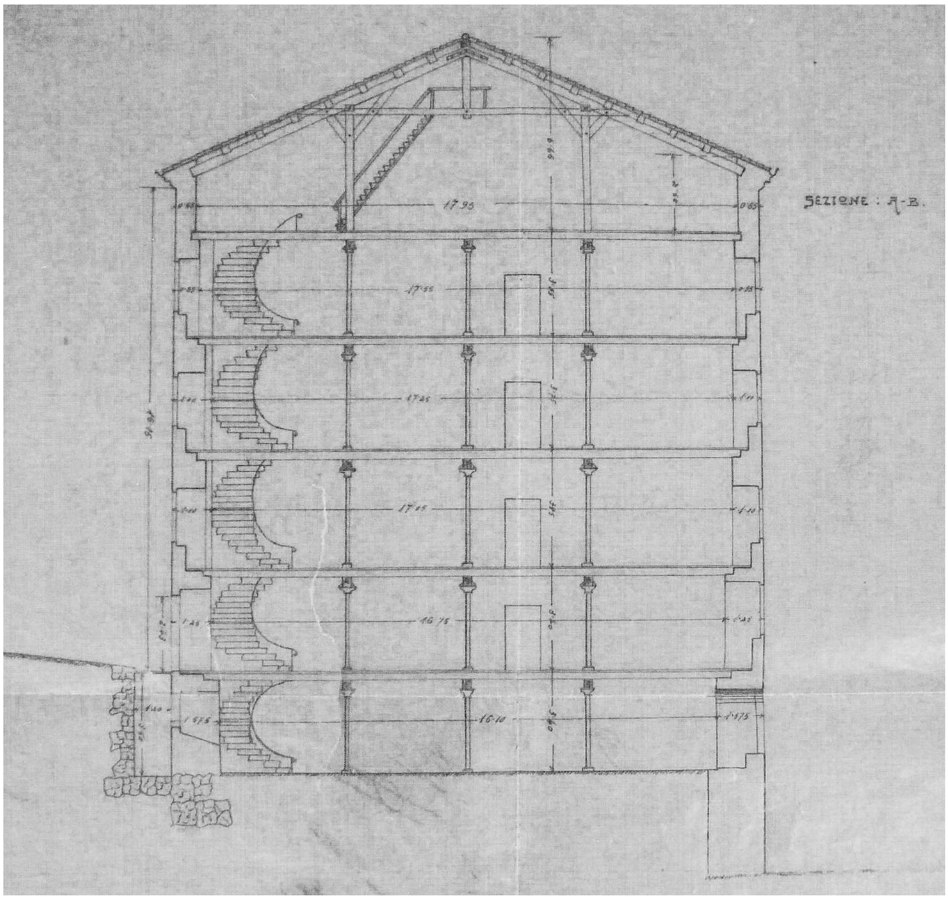

Figure 2. The large industrial Žakalj mill, 1865, by Giovanni Randich, cross-section. State Archives in Rijeka (HR-DARI), reproduced with permission.

joist, while a king post, as the vertical tension member, provides additional support at the centre of a collar-tie.[12] The rafters were a bit longer than 10m and had a slope of about 28°. At the lower end, the rafters must have been grooved (using either a mortise and tenon joint, or a simple dado joint) at the wall plate (a foot purlin) anchored in the massive attic walls, while the notch, combined with a tenon (with an additional iron bolt rather than a wooden peg), was probably used at the upper end to join them on to the king post, supported at the centre of a collar-tie. Traditional birdsmouth joints were used to connect rafters to the middle purlins. A collar-tie of double cross-section, as a tension member typical for such purlin-tie roofs, provided stability in the transverse direction, connecting the principal rafters.

To connect a collar-tie to the principal rafters, triangular cuts were made in those members, while the collar-tie was cut into an opposing shape so that they fitted one another. The vertical surface was used to transfer the tension force from the collar-tie, wherein a fastener secures the joints and transfers the compression force that may occur. A similar principle was applied to join the two tension members in the king post to the collar-tie connection.

In the transverse direction, as substitution for the principal braces of vertical struts, stability was enhanced by a pair of 'arm' (knee) braces. The 'arm' braces were at an angle of 45° to the strut, and the longer one between these two in a pair passes between parts of the double section of collar-ties. The connections of the arm braces are not clearly visible, and it is possible that they were eccentric, made by an angled lap or half-dovetail lap joint (rather than as a single notch with a mortise and tenon joint) and secured with a bolt, also provided to transfer tension forces in the joint.

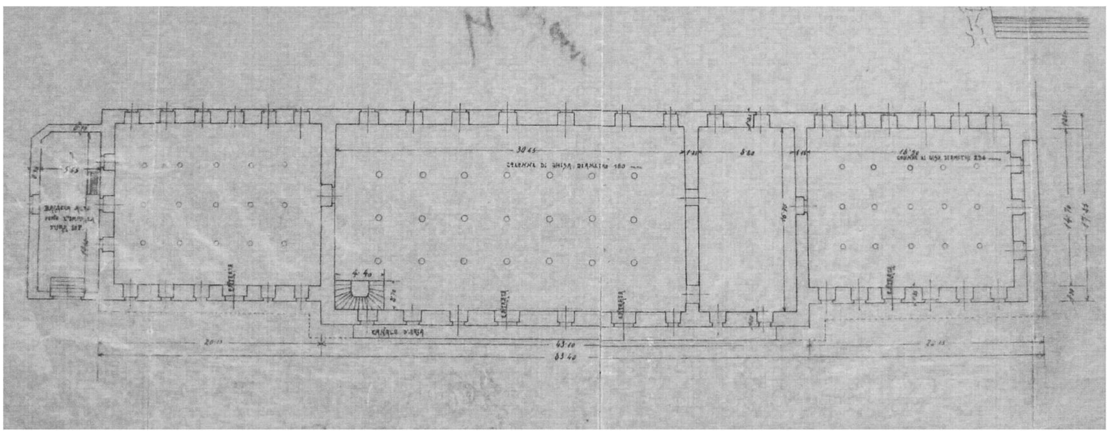

Figure 3. The large industrial Žakalj mill, 1865, by Giovanni Randich, ground floor plan. State Archives in Rijeka (HR-DARI), reproduced with permission.

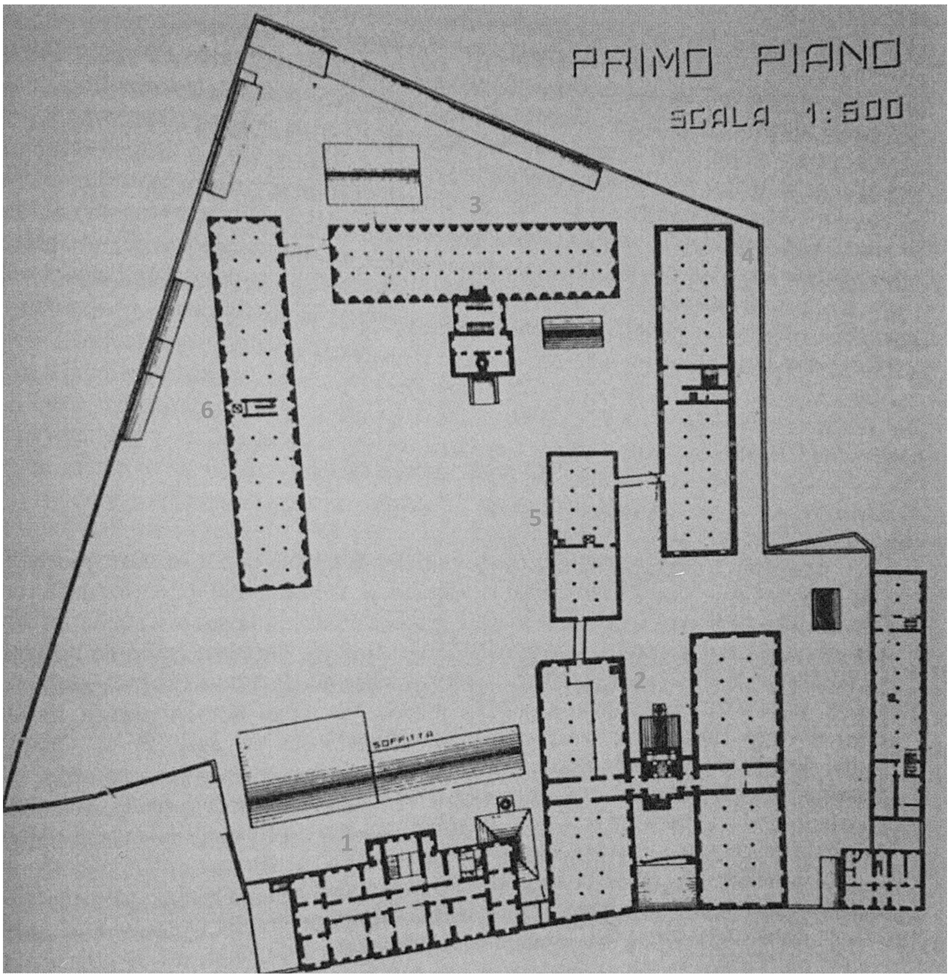

Figure 4. Tobacco Factory, situation plan from 1882: 1. Administration building (Palace); 2. H-building; 3. T-building; 4. Eastern Warehouse; 5. Tobacco Drying Facility; 6. Western Warehouse; 7. Wax paper production plant. State Archives in Rijeka (HR-DARI), reproduced with permission.

In the longitudinal direction, stability was ensured with 'arm' braces, joined in a carpentry manner to vertical struts and a middle purlin, forming a braced wall. Vertical struts were set above the columns of the skeletal structure of the lower storey, on the axial spacing of 8.0m, where their distances of 4.0m matched the longitudinal arrangement of the skeleton's columns

Figure 5. Tobacco Factory T-building, production hall of the first floor. State Archives in Rijeka (HR-DARI), reproduced with permission.

Figure 6. Tobacco Factory T-building, first-floor skeletal structure (Marko Franković, 2018).

and principal rafters. The secondary structure, the beams above the principal rafters, which were mutually spaced at about 1.25m and used to support either common rafters or sheathing boards (wooden formwork) itself, as a base for roofing, points to that.[13]

This kind of roof structure, without bracing of the vertical struts, most probably imposed excessive loads on the skeletal system of the lower storeys. So, a few years later, this roof structure was replaced with queen post purlin roof of Central European typology.[14]

T-Building of the Tobacco Factory

The examples of the implementation of combined skeletal structures can also be found in other Rijeka's industrial buildings from the first industrial age. In the mid-19th century the Tobacco Factory was situated in the western part of the complex of the former Sugar Refinery. The growth of the market share of this factory and an increase in production created the need for new production plants, and so in the 1860s a large plot on the northern side between the Brajda stream and the road (Via Germania) was annexed to the existing factory complex (Figure 4). The first new building was a plant for the production of Virginia cigars (*Virginia Zigarren Fabrication*) constructed in 1867.[15] Due to its distinctive layout, it became known as the T-building.[16]

Just like the structure of the Žakalj Mill, the load-bearing structure of the T-building was also hybrid. Its foundations were set on a terrain of dredged loam mixed with stone. The massive peripheral walls were constructed of roughly chiselled and broken stone. The inner structure in the basement was constructed with massive stone pillars and cross-vaulted brick bays, and in each of the upper storeys a skeletal system of cast-iron columns and longitudinal wooden main beams was constructed (Figure 5).[17]

Two rows of columns divided the interior space of the raised ground floor, first and second floors into three aisles (Figure 4 and Figure 6).[18] Originally, the columns were probably made as single castings but three different parts can be identified — a base, a cylindrical body (*ie* conical pipe) which was slightly narrowed upwards, and a capital with enlargements on both sides around the tubular part on which the base for fitting the body of the column of the upper storey was assembled (Figure 7).

The tubular parts of the iron columns of the ground floor had a diameter of 240mm and 3mm thick walls, while the smaller load-bearing columns of upper storeys were more slender, with an outer diameter of 220mm and 2.5mm thick walls.[19] The decorated capitals also, besides their aesthetic value, had a very important structural function of positioning the head plates, the iron bearing plate which the longitudinal main girders were mounted on. In the storeys of the raised ground floor and the first floor, head plates (820l × 300w × 50d mm) were supports to the pair of longitudinal main beams, whose parts of double square cross-section (2 × 300 × 300mm) were spaced for the outer diameter of tubular extrusion in the middle of the head plate. Low protrusions on the edges of the head plates of the capitals emphasised the impression of the planned bearing of the main girders. These longitudinal beams supported the transverse, secondary members of the ceiling structures on all storeys: in the attic, there were beams with a rectangular cross-section of about 160w × 220d mm, while on the lower storeys, edgewise settled planks were used instead of beams and arranged on double denser spacings. The length of the secondary members was probably about two-thirds and one-third of the transverse span of the building, so they could be put in a staggered arrangement, supported by main girders at one end, and at the other one they leaned on the massive walls over the wall plates. It is presumed that the joints were made in a carpentry manner. The floor was executed as simple plank flooring with structural function as well. It can be concluded that the system represented a stable structure, and was built completely according to its primary purpose, within the spirit of the time and the achievements in engineering of the period, at which the manner of construction and the assemblage of columns were thought of, and the alternate staggered arrangement of continuations of the ceiling beams of both directions ensured an additional robustness to the lightweight load-bearing structure of the interior.

It should be mentioned that the factory operated at reduced capacity even after the fall of the monarchy, and the factory's production ended during the Second World War, after which its purpose changed. The building then became part of the complex of the 'Rikard Benčić Machine and Tractor Factory'

Figure 7. Tobacco Factory T-building, first-floor skeletal structure — detail of capital and pillar (Marko Franković, 2018).

(1945–95) and was then repurposed as a factory and service department for marine engines.[20] As the historical circumstances in many ways influenced the fate of production, so the destiny of the building changed. Despite the damage caused by these adaptations and a subsequent long period of disuse, the building remains a significant part of the industrial heritage of the city. The roof structure is hipped, built on an elevated attic wall (Figures 8 and 9). From the architectural survey (Figure 10), and site inspection of the existing condition, it can be concluded that the structural system is not a typical purlin-tie roof structure with double 'upright chairs'.[21]

With the exception of parts where the ceiling covering is damaged or missing (*eg* the space in the annex, with the visible structural members), the material is generally in good condition, with deterioration, such as cracks or more significant dimensional changes (especially noticeable for collar-ties) due to long-term humidity, only visible in a few places. The interventions during the reconstruction, which were probably the consequence of not only the repurposing but also of the state of the wooden roof structure, are also visible. In some places, the rafters and the additional vertical posts above the collar-ties have been replaced, and there are significant changes to the original timber structure

Figure 8. Tobacco Factory T-building, existing condition of the roof structure, transverse section (Marko Franković, 2018).

Figure 9. Tobacco Factory T-building, roof structure detail (Marko Franković, 2018).

of the ceiling of the second floor. The transverse reinforced-concrete beams, which are executed with bearings on the exterior longitudinal massive walls of the second floor, and over brick columns along them at one end, and iron columns of the skeleton which are supports at the other, point to that. Above the concrete beams, the short wooden beams are placed to enable the grooved connection of central 'chairs'. At the places where the new concrete beams have been set, originally longitudinal main beams of the skeleton (*ie* lower plates of 'chairs') are interrupted. Next to the central 'chairs', the longitudinal side beams of variable length were set above the main beams of the skeleton. These long beams have the same cross-section as the main beam and their primary function is to serve as suspension to the interrupted main beams over the transversal ceiling beams. The flooring remains wooden, and where this is damaged the transverse ceiling beams are visible.

Although the roof structure mainly matches the original concept of this kind of traditional structural system, it is a variant structure of this typology.[22] There is no secondary truss (since the secondary beams support sheathing boards and roof cover), so every transverse section of the roof represents a principal truss.[23] As is shown on the section plan (Figure 10), the arrangement of the vertical struts follows the pattern of the iron columns in the skeletal systems of the storey below, with the exception of the hip rafter zone, where they are smaller (about 2.51m). Thanks to the specific supporting detail that enables the indirect transfer of forces, the longitudinal main girders of these skeletal systems support both central 'chairs'.[24]

Along the entire attic there is a corridor, defined by rows of central 'chairs' and with a collar as its upper transversal borderline. The pair of middle purlins supports the rafters and lies on the collars, defining the upper longitudinal borderline of the corridor. In the part of the roof where the structural members are accessible to view, it can be seen that the collars (*ie* collar beams), supported by central 'chairs', connect each pair of rafters in the upper third of the attic's height. In this sense, the described system of central 'chairs' and collars as compressive structural members act as a kind of the framework which contributes to the stiffness and stability of the entire roof in the transverse direction.

Along the attic wall, there are 'short upright chairs' which enable the positioning of the collar-tie. These tensional members are laid down on wall plates (foot purlins) above massive attic

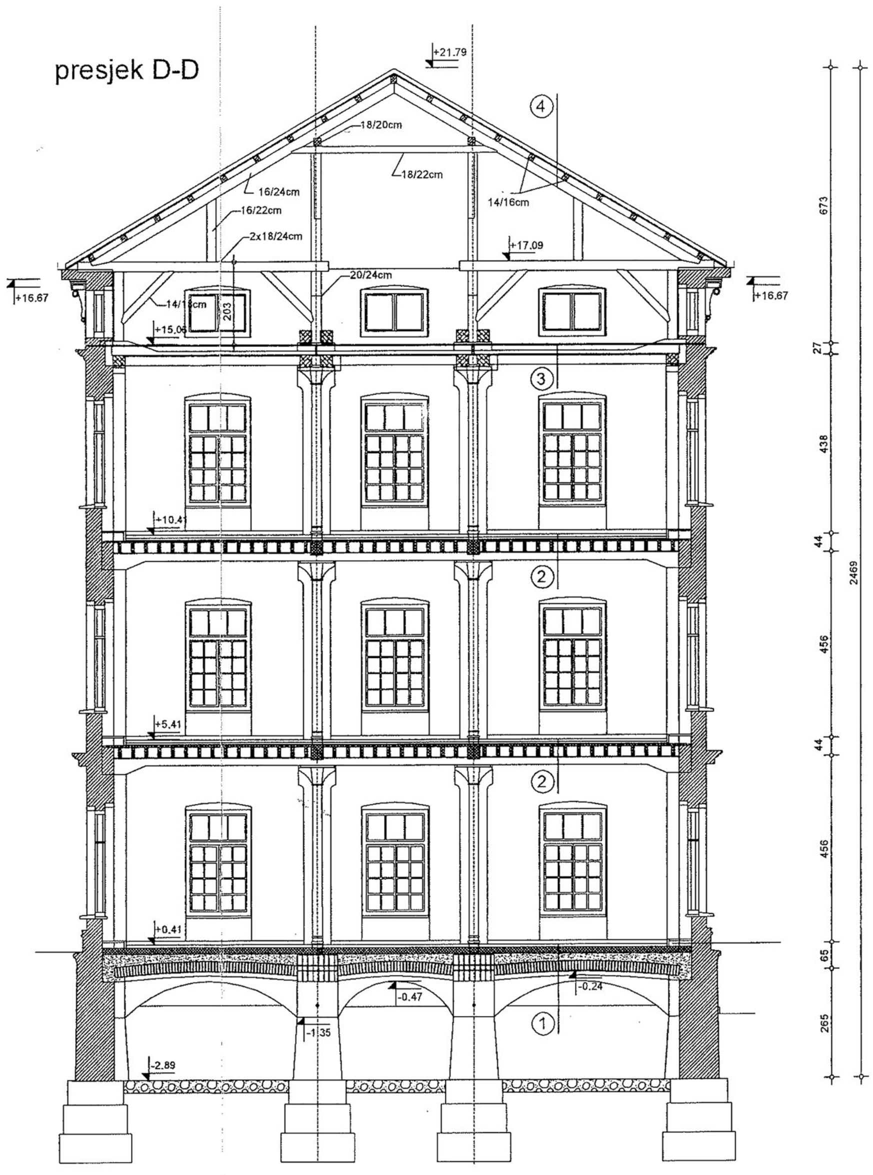

Figure 10. Tobacco Factory T-building, transverse section (AGA d.o.o. Rijeka, 2002). Reproduced with permission.

walls, whose upper edges (brims) are protruded, forming the eaves. In every principal truss, there are two such tensional members, wherein each connects the rafter, the central and the 'short upright chair'. Together with knee braces of the 'short upright chairs' and those positioned on central ones, the two additional stable frames were formed in the lower third of the attic's height, bolstering the impression of stability in the transverse direction. The additional vertical studs, positioned at the centre of collar-tie, support the rafters, reducing the stresses on their ends. Longitudinal stability of the roof is ensured by the two braced walls (*eg* system 'upright chairs' — middle purlins on 'arm' braces).

A traditional structural system like this one implies the use of carpentry techniques to connect structural members and make the joints, according to strict geometrical rules which enable the transfer of compression and shear forces over the contact surfaces. Tension forces were transferred by employing structural fasteners. The type of connection used, as well as the appearance and condition of the used materials, point to the originality of the existing load-bearing systems.[25]

In the zones of the hipped roof, similar load-bearing systems as a way of stabilisation were implemented. The hip rafters on their lower end lie over wall plates on the massive attic walls and are attached to collar-ties of a diagonal layout position. These two collar-ties are constitutive parts of the last pair of stabilisation frames in the lower third of attic heights. Apart from the diagonal layout position of the collar-ties, there are no other differences in comparison to the similar frames in the rest of the roof which were described previously. On the level of the upper ends of the hip rafters, a spatial stabilisation system was made, composed of arm braces — collar beams in a transverse direction, and arm braces — middle purlins in a longitudinal direction. The hip-jack rafters are extended over the massive attic wall at the gable. At the bottom zone, they lean on wall plates, while the collar beams support them on the upper zone (Figures 8 and 9). The roof covering was done the same way as in the rest of the attic, with sheathing boards as the substructure, leaning on secondary purlins above the rafters.

Subsequent Applications of the Same System: Eastern and Western Warehouses, the H-Building of the Tobacco Factory

Typologically and conceptually similar structural systems were used in some other buildings which were built within the factory complex by the end of the 19th century.[26] The buildings are on the whole not preserved today — both Eastern and Western Warehouses were demolished in 2006. The Tobacco Drying Facility has lost its original structure, but the structure has been completely preserved in the H-building.[27]

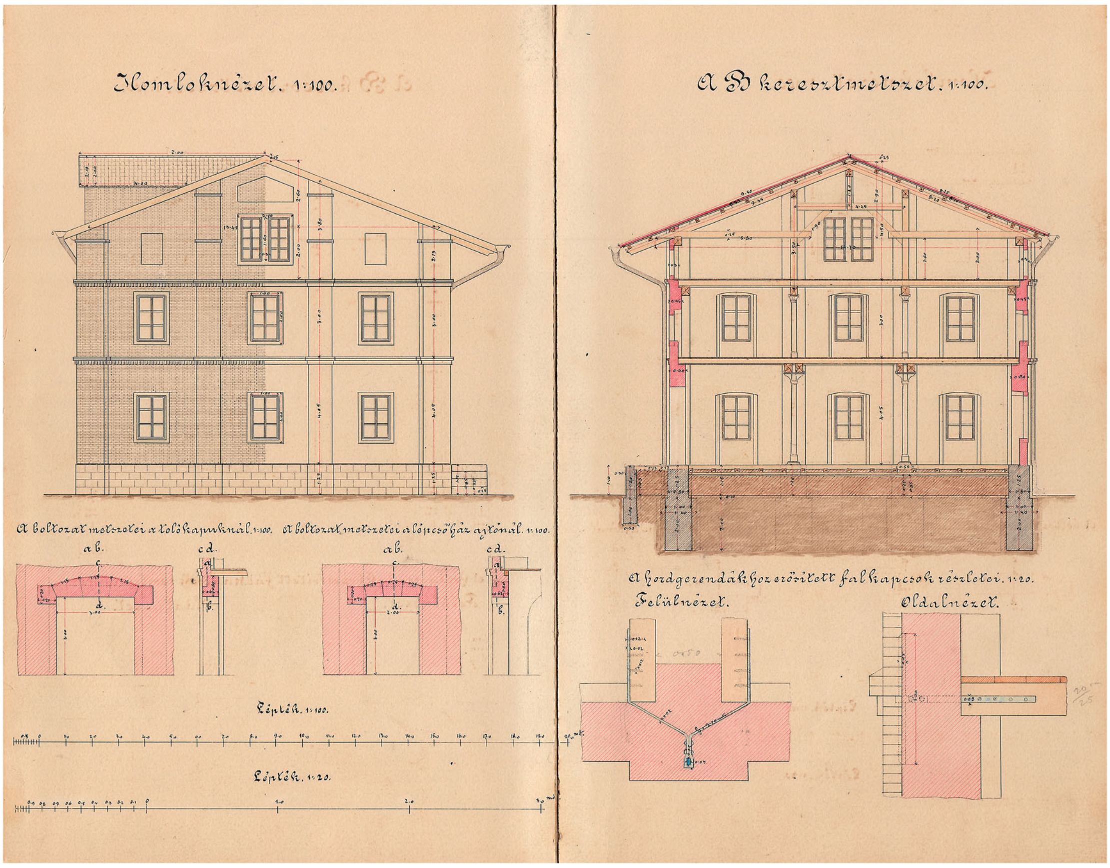

Figure 11. Western Warehouse, façade and transverse section. State Archives in Rijeka (HR-DARI), reproduced with permission.

According to the preserved location plan of the factory complex from 1875, the Eastern Warehouse was built between 1867 and 1875, the tobacco drying facility after that, and the western warehouse from 1882–3.[28] The archive plans are preserved fragmentarily but are sufficient to conclude that it is about the same constructive principle, which varies from building to building only in the dimensions of the elements. A gradual reduction of the ornamentation is also noticeable. The capitals of the pillars of the T-building are decorated with vegetative motifs; modest decoration with flower rosettes also existed on part of the tobacco drying facility, and probably in both warehouses, while in the last building, the H-building, it disappeared completely.[29]

The two-storey Eastern Warehouse with a useful attic was rectangular in plan and had the structure of massive perimeter walls and an internal skeleton. Two inner transverse walls stiffened and stabilised the building, and between them a staircase and ancillary spaces were settled. Two rows of columns were inserted inside the north (2 × 7) and south (2 × 8) wings (Figure 4).[30]

The Western Warehouse had similar characteristics but slightly different dimensions (smaller widths and greater lengths). The central staircase was smaller and the two identical wings had two interpolated rows of columns (2 × 7 in each wing). The columns in this warehouse were more slender, and the distances in the longitudinal direction slightly larger. The preserved cross-section shows a similar construction to that applied to the T-building (Figures 11 and 12).[31] Detailed plans of the transverse sections of T-building (Figure 10) and those of similar western warehouses (Figure 11 and 12) point to an inventive structural solution which enabled a simple installation and continuation of the iron columns on all storeys, connecting them in one unique system.

The columns of the skeleton of the second floor were of a similar structure to those on the lower floor, but with narrower capitals, adjusted to the single-section main girders of the timber ceiling structures which supported the 'upright chairs' in both longitudinal axes. The timber structures of the roofs were only slightly modified, but they basically kept the same system as in T-building. The warehouses had purlin roofs, and each was designed with a combination of double 'upright chairs' and a king post in the centre of the upper collar. The 'upright chairs' were braced only in the upper half, where the knee braces and the collar form a frame. Massive peripheral walls were raised up to half the height of the attic, and the rafters were executed with overhanging ends. Lower collar-ties connected the central 'chairs' and the rafters over the 'short chairs' which were placed along the attic walls to support the foot purlins. Collar-ties were constructed as interrupted members enabling free passage between the rows of 'chairs'. Longitudinal stability was ensured by braced walls, aligned in the axes of the middle purlins and the ridge purlin.

The H-Building — Typological Similarities and Specifics of the Roof Structure

As previously mentioned, the best-preserved structure of this typology is that of the H-building. The central staircase of the H-building was constructed in the period when the building was used by the army (1834–51), enabling simple communication between the eastern and western wing of the building.[32] After the repurposing as the Tobacco Factory, in its western part there was the factory for making pipe tobacco and in the eastern part there was the cigarette factory, while the two additional corridors were used for the transport of dried tobacco from the drying facility located in the north. The largest part of the H-shaped building was reconstructed in 1892.[33] In the eastern wing of the ground floor, and on the first and second floors, the inner structures were constructed as skeletal systems with cast-iron columns and longitudinal wooden main beams (Figure 13). A classically combined (stone and brick) structure with vaults was retained on the ground floor of the western wing and on the connecting part.[34]

The rows of the columns were axially spaced at about 5.10m (in western part) and 6.10m (in the eastern part), and the arrangement of the columns (up to 12 of them in each row) were relatively

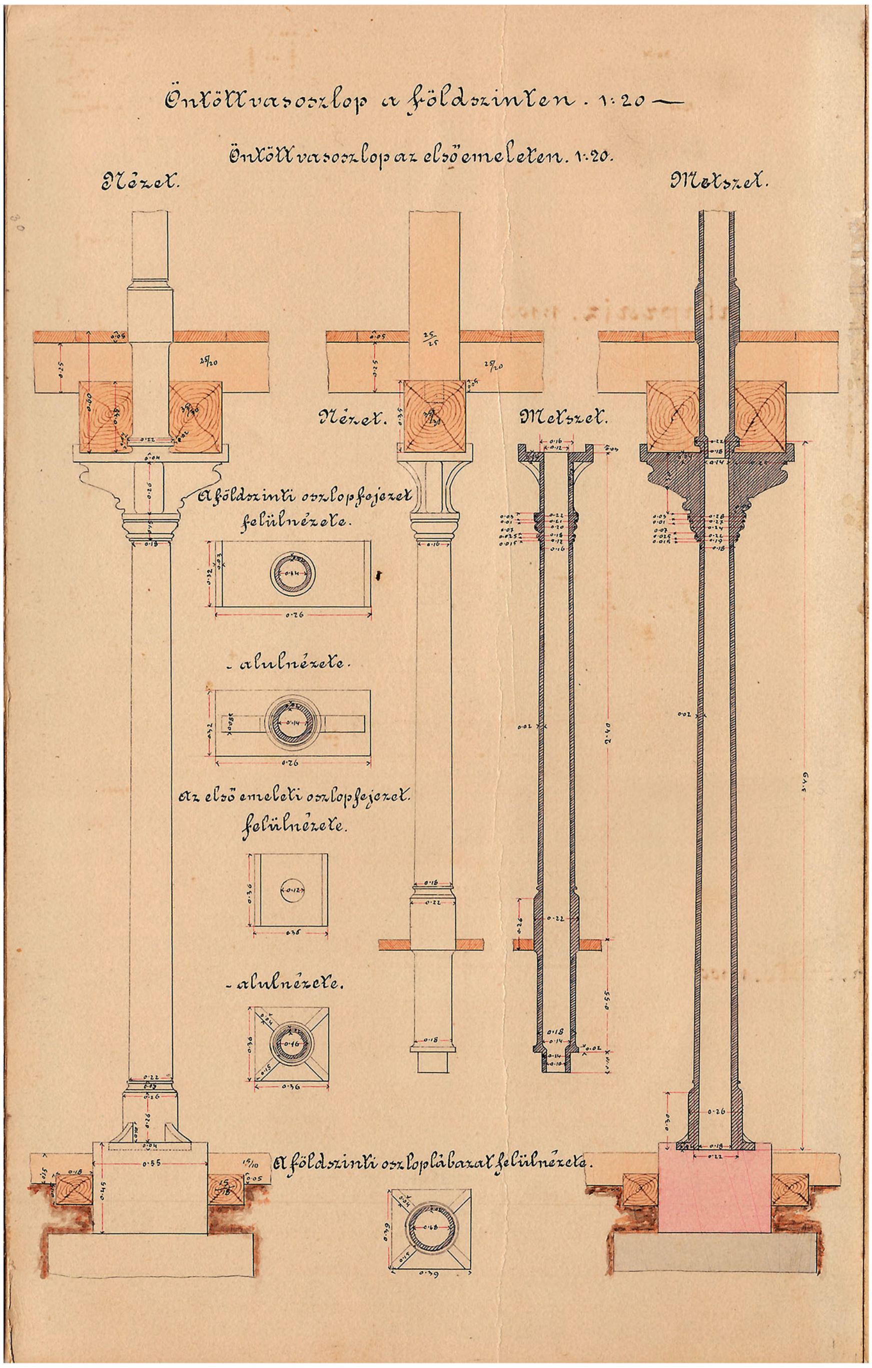

Figure 12. Western Warehouse, skeletal structure details. State Archives in Rijeka (HR-DARI), reproduced with permission.

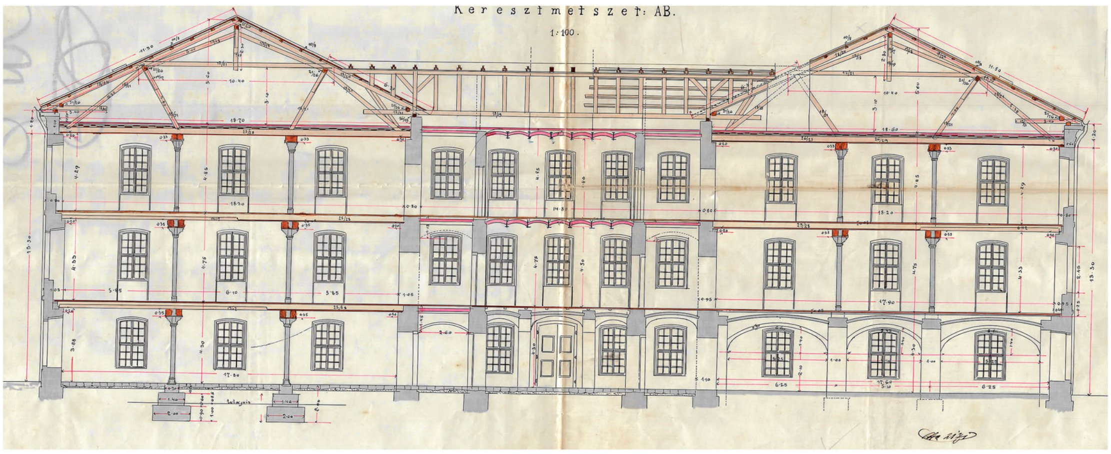

Figure 13. Tobacco Factory H-building, cross-section — reconstruction project from 1892, by Antal Hajnal, Jozsef Huszar and Jozsef Popp. State Archives in Rijeka (HR-DARI), reproduced with permission..

Figure 14. Tobacco Factory H-building, roof structure (Marko Franković, 2018).

regular, with longitudinal spacings of about 3.0m to 4.25m, and about 5.0m and 5.40m in the middle part. The hipped roof of the H-building has a particularly interesting timber structure which has been mostly well preserved and successfully serves its current use.[35] The roofs of both parts of the H-building (Figure 13) have the same purlin structures of an almost identical geometry. Their axial spans slightly exceed 19.0m, since the spacings of the attic walls are 18.7m (in eastern part) and 18.6m (in the western part). The massive attic walls are about 1.1m tall, having protruded head stones as parts of the decorative eaves. The height of each attic exceeds 5.60m, while the free height below the collar-tie is about 3.10m, measuring from the flooring level. This complex timber structure is a combination of a purlin-tie roof with double 'raking chairs' on the lower level and a king post truss on the upper level (Figures 14 and 15).[36] The used term 'raking chairs' refers to compression structural members within the principal truss of purlin-tie roof structures. As is otherwise typical for this typology, they are inclined at an angle to the rafters and support the middle purlins, and are constructed as braced struts (Figures 13 and 14).[37]

The complexity of the roof structure is here heightened by presence of a king post. This vertical tensile member supports the ridge purlin, providing the additional support at the centre of a collar-tie, and the principal braces, connected to a king post, having a less steep slope than the rafters.[38] The collar-tie of a double cross-section is a constituent member of each structural level, denoting at the same time a transversal boundary line between these two with its position above the mid-purlins. This tensile member connects the rafters within each principal truss. There are three equally spaced secondary trusses between two adjacent principal trusses whose longitudinal arrangement follows the rhythm of the iron columns on the lower floors. The principal and common rafters are 11.7m long and have the same cross-sections. They support the secondary purlins which carry the sarking boards as a base for the roof cover. An axial spacing of the middle purlins determines the collar-tie length (10.4m) and the central position of the king post. The inclined middle purlins above the braced 'raking chairs' and the ridge purlin above the king post support the rafters along the entire roof, participating in the formation of longitudinal braced walls as well. These three longitudinal members have the same cross-section as the foot purlins which lean over the short collar-ties, supporting the ending parts of the rafters. Since the lower ends of the 'raking chairs' are positioned above the iron skeletal columns, their maximal transverse spacing is about 6.10m. In conjunction with principal braces, they support the middle purlins. The principal braces have the counter-inclination which is less than the slope of the chairs, contributing to the transverse stability and stiffness of the entire roof. This system significantly unburdens the ceiling structure and the skeletal structure of the floor below as well, since the principal braces transfer a portion of the vertical loads onto the peripheral walls and redistribute the horizontal forces along the ceiling joists. The short collar-ties, which are about 3.4m long and are supported by wall plates above the longitudinal attic walls, transfer the horizontal forces from the rafters onto the principal braces and additionally bolster the impression of stability. On the upper level of the purlin roof structure, the king post truss also represents a stable system with principal braces whose slope is milder than the rafters' slope. They are eccentrically joined to a king post and directly supported by the middle purlins at the bottom end.

The hip rafters were supported by middle purlins and purlins parallel to the gable of the building. Together with the 'raking chairs' and four principal braces, two of which are diagonal in layout (in the corners of the building), and the other two that are placed on the gables, they form a stable structural system. Both the hip-jack and common rafters are centrically connected on the hip rafters. The longitudinal and transverse stabilisations here are ensured by arm braces. They are joined eccentrically to purlins and raking chairs, as in any longitudinal braced wall of the main roof structure as well. Since the roof structure represents a traditional system of those times, most of the carpentry joints were made in a way that is much more detailed and already described for the roof structure of the T-building.[39]

Development of the System: Port Warehouses 8 and 11, Tobacco Drying Facility

In 1888, two warehouses in the port of Rijeka were designed using a similar system. The warehouse designer is not known

Figure 15. Tobacco Factory H-building, roof details (Marko Franković, 2018).

but, as with the earlier warehouses, they can be attributed to Francesco Placsek, at that time the most active engineer of the Technical Department of the Maritime Gubernatorial Administration. Warehouses 8 and 11 were located at the start of Rudolf's pier (currently known as Orlando's Pier), adjacent to the engine room for the hydraulic plant. They were identical, 22.5m wide and 66m long, with masonry peripheral walls. Within the span of 19.35m, in the basement and ground floor, a metal skeletal structure with three rows of columns and girders is interpolated. Unlike the Tobacco Factory where timber beams were used in skeletal structures, here they were replaced with metal, most likely iron girders.[40]

The ceiling of the ground floor had a full metal structure whose secondary I-beams were placed above the transverse girders of the skeleton. In the ceiling structure of the basement, which bore the largest load, a more sophisticated system was applied, with secondary I-beams of longitudinal direction combined with shallow segmental vaults (probably made of concrete). Similar ceiling structures were applied to the Royal Hungarian Customs House which 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. Ceiling structures with segmental concrete vaults and iron girders were first constructed in Rijeka Port warehouse No. 4 in 1881.[41]

The open roof structure was the purlin-tie system with triple 'upright chairs' that were raised from the first-floor level, supporting the purlins. These unbraced and tall vertical struts were positioned above the metal columns. In the longitudinal direction, three braced walls (*ie* purlins on arm braces) provided the stability of the roof. In the transverse section, two collar-ties enabled the connection between the principal rafters and all three struts. Below the lower collar-tie, a metal tie was installed to additionally stiffen the system and ensure stability for the peripheral massive walls, preventing them from overturning.[42]

Although it has four storeys, the drying facility of the Tobacco Factory is, due to its lower ceiling heights, the same height as the T-building. In the first phase, in the 1880s, the northern part of the building was built, according to the designs of the Hungarian architect Karol Kunter, with four floors (ground floor and three upper floors), and in 1899 the southern part was added and the fourth floor was built over the entire building, according to the designs of architect Miksa Schiffer (Figure 16).[43] This new part of

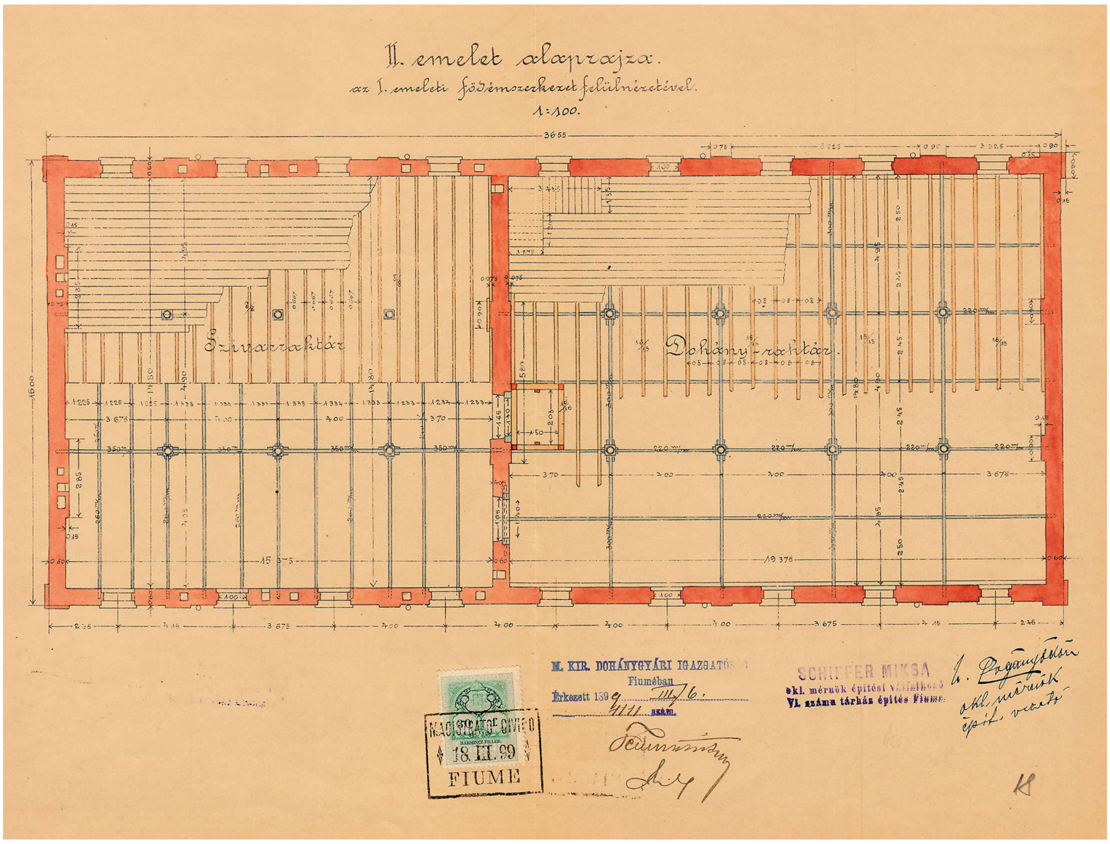

Figure 16. Tobacco drying facility, plan of the second floor — old (right) and new (left) part of the building. State Archives in Rijeka (HR-DARI), reproduced with permission.

the building was built in the second industrial age when metal structures prevailed over wooden and combined ones.

In both parts of the building, the internal structural systems were designed as complete metal skeletons; however, the ceiling structures of each part were significantly different. The whole building had an interesting external aesthetic, too. It was the only one within the entire complex whose interior skeleton extended to the brickwork façades, since the massive outer walls, 16.0m wide and 36.55m long, were decorated with lesenes (brick pilaster strips). The structure of the entire building is unique in many ways, so it is a bit surprising that only a few researchers have studied it. Although in one of the few studies conducted it was suggested that steel I-girders were introduced into the skeletons of the new part, there is no real evidence for this since the original structure no longer exists.[44] It is also possible (and perhaps more likely) that I-profiles of wrought iron were the ones actually embedded there, like those in the old part of the building.

The two rows of cast-iron columns were spaced at 4.5m in every part of the building. Since the new part of the drying

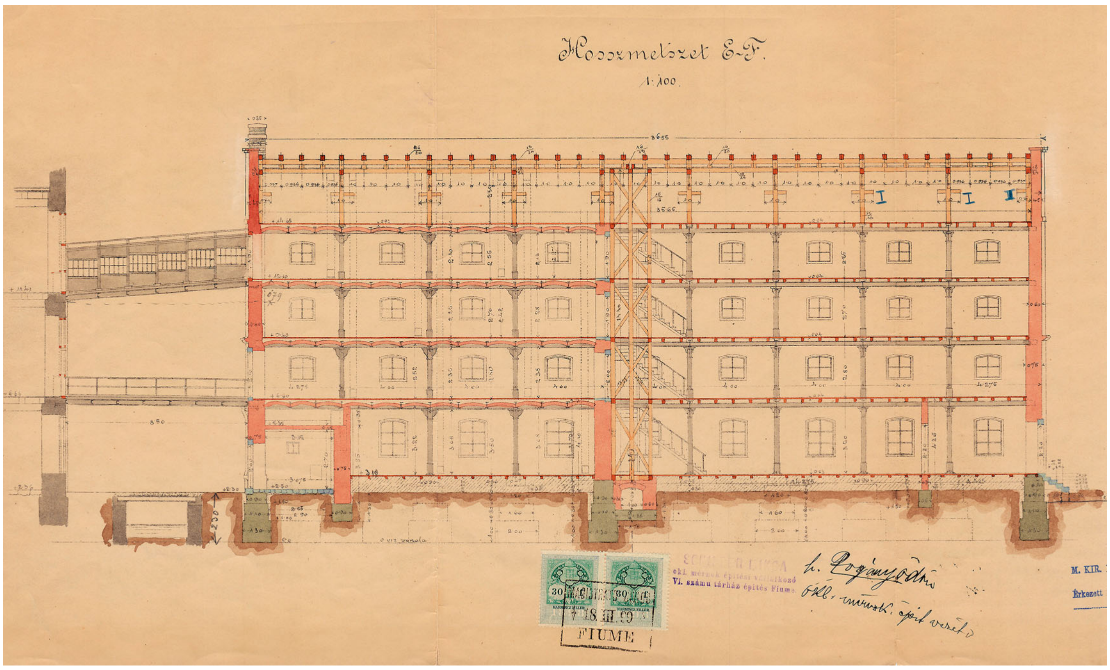

Figure 17. Tobacco drying facility, longitudinal section through old (right) and new (left) part of the building. State Archives in Rijeka (HR-DARI), reproduced with permission.

Figure 18. Tobacco drying facility, detail of column (Marko Franković, 2019).

facility was 4.0m shorter than the old one, it was a logical choice to copy the arrangement of the iron columns in the two rows keeping the spacings the same, and to only change the number of columns. Therefore, the grid of 2×4 columns remained in the old part, and in the southern part of the building it was transformed into 2×3.

The iron columns were of a circular hollow section, with capitals devoid of any ornaments.[45] At the same time, the four protruding plates were constitutive parts of the extensions above the capitals, enabling the installation of metal I-girders of the cross layout (Figures 17 and 18). In the old part of the building, the longitudinal I-girders had a depth of 220mm, while the transverse I-girders of the skeletons were 80mm deeper. Between these latter, the longitudinal ceiling I-girders were placed (one in each field), serving as supports of the transverse wooden ceiling beams which were uniformly arranged at spacings of 0.8m, carrying the plank flooring.

The ceiling structures in the new part of the building were examples of what was at the time thought of as a 'fireproof' system. The longitudinal I-girders of the skeleton had a depth of 350mm, while the transverse girders were 90mm smaller in depth than the longitudinal ones. Longitudinal girders supported segmental brick vaults (jack arches), where the two transverse I-girders were placed between the two adjacent transverse girders of the skeleton. Plank flooring was attached to wooden 'sleepers' which were laid on the bricks.

Conclusion

Although the application of theory in structural engineering in the early the 19th century was inspired by wooden structures, the real driving force of the innovations in the technical and engineering science was the usage of iron and the development of iron structures.[46] The introduction of iron was at first slow because of its high price, but, thanks to the innovations which enabled mass production, iron became a standard material for load-bearing structures, with obvious advantages in relation to other materials. During the first industrial age, it was rarely used on its own; nevertheless, numerous examples of combined skeletal structures with wooden beams and iron columns were constructed. In that way, not only efficient but also economical structural systems were designed since the advantages of both materials were used to the maximum. Some of these structures, which have been preserved to this day, represent non-typical, innovative engineering solutions, adaptable and adjustable. Since they prove that architectural values are not only a product of artistic intentions but also represent rational responses to newly formed needs, induced by industrial progress and structural advancements, it is important that they are valued, preserved and protected for future generations.

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Notes

1. Rudolf Bićanić, 'Važnost Rijeke u ekonomskom životu Hrvatske', in *Rijeka zbornik*, ed. Jakša Ravlić (Zagreb: Matica Hrvatska, 1953), 153–80; Danilo Klen, ed., *Povijest Rijeke* (Rijeka: SO Općine Rijeka and Izdavački centar Rijeka, 1988), 134–6; Milica Trkulja, 'Rijeka — središte manufakturne proizvodnje', in *Temelji moderne Rijeke*, ed. Ervin Dubrović (Rijeka: Muzej grada Rijeke, 2006), 43–66.
2. Described in detail in Nana Palinić and Adriana Bjelanović, 'Structures of the Proto-industrial and Early Industrial Age in Rijeka, Croatia', *Industrial Archaeology Review* 43, no. 1 (2021): 1–18.
3. J. Ehlbeck and M. Kromer, 'Carpentry joints, Lecture C12', in *Timber Engineering STEP I. Centrum Hout*, eds H.J. Blass *et al.* (Almere, 1995), C12/1–C12/7.
4. David T. Yeomans, 'Early Carpenters Manuals, 1592–1820 (Chapter 8)', in *Development of Timber as a Structural Material, Studies of the History of Civil Engineering (Vol. 8)*, ed. David T. Yeomans (London: Routledge, 2017), 13–33; Stefan M. Holzer, 'Structural Iron Elements in German Timber Roofs (1600–1800)', *Construction History* 23 (2008): 33–57, http://www.jstor.org/stable/41613927 (accessed 8 July 2019).
5. T.M. Charlton, 'Innovation in Structural Theory in the Nineteenth Century', *Construction History* 3 (1987): 55–60, https://www.jstor.org/stable/41613634 (accessed 9 March 2022).
6. John Gloag and Derek Lawley Bridgwater, *A History of Cast Iron in Architecture* (London: G. Allen and Unwin, 1948); R.J.M. Sutherland, ed., *Structural Iron 1750–1850: Studies of the History of Civil Engineering*, vol. 9 (London: Routledge, 1998).
7. State Archives in Rijeka (HR-DARI), City Council Rijeka (22), H 40/1882: Rapporto quindicinale 16.–31.03. 1884, nr. 2722; Nana Palinić, *Riječka kazališta — Nastanak, kontinuitet i značenje kazališnih zgrada i scenskih prostora u razvitku urbane strukture grada* (Rijeka: Državni arhiv u Rijeci and Sveučilište u Rijeci, Građevinski fakultet u Rijeci, 2016), 230.
8. Nana Palinić and Adriana Bjelanović, 'Wooden Structures in the Historic Port of Rijeka', *Građevinar* 68 (2016): 10, 803; Antun Herljević, 'Ravna Gora', http://library.foi.hr (accessed 15 November 2019); Rudolf Bićanić, *Doba manufakture u Hrvatskoj i Slavoniji* (Zagreb: JAZU, 1951), 219.
9. The timber roofing was estimated to have cost 2,303 fiorines, and the iron roof was to cost between 3,720 and 4,500 fiorines. State Archives in Rijeka (HR-DARI), Management of the Rijeka City Theatre (DS 60), box 9, nr. 1509 (1854); Palinić, *Riječka kazališta — Nastanak, kontinuitet i značenje kazališnih zgrada i scenskih prostora u razvitku urbane strukture grada*, 107.
10. In 1862, the mill was sold to the holding company Stabilimento commerciale di Fiume. After a fire which almost completely destroyed the main and ancillary buildings, the president of the holding company Iginio Scarpa bought it and built a new building in the same place. In the historical sources, there are conflicting accounts and it is not entirely clear whether the existing building was rebuilt or a new one was constructed. If it were a case of reconstruction, then it had to be extensive, and it is more correct to talk about a new building. HR-DARI, Technical Offices of the City of Rijeka (57), 89.
11. In the layout, the tubular columns of greater dimensions were shown in the middle section, and smaller ones in the lateral wings — *ie* the columns in the wings are shown as larger than the middle columns. This is an obvious mistake, which is illogical and does not correspond with the layout.
12. Here it refers to a purlin-tie roof which is characteristic for Central Europe, and it is not common in Northern, Western and Southern Europe. In German literature it is known as 'Pfettendach mit doppelte stehendem Stuhl'. The literal translation of this original term would mean 'purlin roof with double upright chair', also used in some construction dictionaries, and is common in Croatia where the Central European carpentry tradition is adopted mostly thanks to historical circumstances. In this context, a 'chair' marks a structural compression element.
13. It is difficult to conclude from Figure 2 whether the common rafters or sheathing boards as a base for roof covering are shown.
14. The queen post roof here refers to the structural system which is copied from Austria and German-speaking territories (originally, 'Pfettendach mit doppelte Hängewerk / Trapez Hängewerk'), wherein the principal rafters are supported by middle purlins, and double suspended posts are braced by principal braces and connected by a straining beam. It differs from the homonymous system (*eg* queen post truss, so-called 'Palladio truss') characteristic for the Mediterranean region and England. HR-DARI 57, box 89; Slobodan Ilić, *Klasični drveni krovovi*, 5th ed. (Belgrade: Građevinska knjiga, 1999); Karl Lehrmann, *Holz im Holzbau* (Vienna: Rudolf Bormann Industrie and Fachverlag, 1960); Simona Valeriani, 'The Roofs of Wren and Jones: A Seventeenth-Century Migration of Technical Knowledge from Italy to England', Working paper on *The Nature of Evidence: How Well Do 'Facts' Travel?, 14/06* (London: School of Economics and Political Science, Department of Economic History, 2006), 1–39, http://eprints.lse.ac.uk/22534/1/1406Valeriani.pdf (accessed 18 May 2019).
15. On the town map of 1862, the building was not drawn in, but it can be seen on the town map of 1870 and in all subsequent plans. HR-DARI 57, box 106.
16. Olga Magaš, 'Kako nastaviti povijesni kontinuitet prve šećerane u Austro-Ugarskoj monarhiji', *Građevinski fakultet Sveučilišta u Rijeci — Zbornik radova* X (1994): 155–7; Olga Magaš, 'Industrijska arhitektura / Industrial Architecture', in *Arhitektura historicizma u Rijeci / Architecture of Historicism in Rijeka*, ed. Daina Glavočić (Rijeka: Museum of Modern and Contemporary Art, 2001), 422–4; Saša Dmitrović, 'Mala povijest duhana u Rijeci', *Sušačka revija* 18/19 (1997): 66.
17. The original plans have not been preserved, and the sparse archive material dates from 1897, when the ground-floor staircase was reconstructed. Olga Magaš states that this plan is in the private collection of the 'Rikard Benčić' factory. Some authors presuppose that the designers were Jozsef Huszar, Jozsef Popp and Antal Haynal.

    Magaš, 'Kako nastaviti povijesni kontinuitet prve šećerane u Austro-Ugarskoj monarhiji', 176; Krasanka Majer and Petar Puhmajer, *Palača šećerane u Rijeci / The Sugar Refinery in Rijeka* (Rijeka: Grad Rijeka and Hrvatski restauratorski zavod, 2008), 54.
18. See also Figures 10, 11 and 12 for more detailed plans of the transverse sections and structural system.
19. *Architectural Survey of the T-building* (Rijeka: AGA d.o.o., 2002); Tin Strizić and Filip Franolić, *Kompleks Rafinerije šećera — Tvornice duhana — Tvornice Rikard Benčić*, seminar work (Rijeka: Faculty of Civil Engineering Rijeka, 2012), 1–27.
20. This repurpose imposed greater loads on the ceiling structures and the condition of the structure, damaged by the differential settlement of structural masonry walls built on alluvial soil, required the strengthening of the structure. Remediation on a larger scale was done in 1949: the pillars of the ground-floor ceiling were strengthened with steel ties, the wooden ceiling structures of the ground floor and first floor were replaced with a prefabricated reinforced concrete structure of ribbed ceiling, and the second floor was strengthened with reinforced concrete girders. The ribbed ceilings were stiffened with compressive unreinforced concrete slabs above which a layer of unreinforced cement screed (15mm thick), terrazzo tiles and floor coverings (20–170mm thick) were laid. Below the lathes in the factory, to protect the flooring from damage and liquid spills, industrial flooring was laid, and beneath the ceiling of the ground floor, asbestos-cement sheeting was placed. Cast-iron columns, which had leaned due to settlement, were returned to an upright position, and their supports were adapted in accordance with the changes of the ceiling structures. (To achieve the continuity of the columns by the height of the building the original joints were concreted.) The ceiling structure between the ground floor and the basement was strengthened with reinforced-concrete slabs over the original cross-vaults. The slabs were constructed of lean-mix concrete and finely grained material which the funnels above the two-way reinforced vault were filled in with, and in the foundations of the stone columns additional ties were built in. Cast-iron columns from the ground floor were supported by the stone pillars of the basement. Along the exterior masonry walls of the second floor, beneath the ending posts of roof structures, additional brick columns were constructed. The transverse cross-section (Figure 10) is the result of the architectural survey of the existing condition, the source from which the rest of the data about the arrangement and spacings of original structural elements were taken. Most significant are those about the exterior outline of the main building (15.26 × 61.37m), axial spacings between columns from 3.82m and 3.17m, and their distances of 5.04m to the outer longitudinal masonry wall (Figure 4). The spacings between the transverse ceiling wooden beams of the attic were of about 800mm. The secondary wooden structures of ceilings of lower storeys were probably originally made of boards, which were arranged on double-smaller spacings. The changes to the original structure can be seen on other layouts. See Strizić and Franolić, *Kompleks Rafinerije šećera — Tvornice duhana — Tvornice Rikard Benčić*, 9-10.
21. See refs 15 and 23.
22. The plans of the original structure of the roof with a visible cross-section have not been preserved, and the archive layouts from 1883 for the building of the western tobacco warehouse, which no longer exists, point to the particular similarity of the load-bearing systems of these two trusses.
23. The secondary beams have taken over the traditional role of rafters as a base for the roof covering, the asbestos-cement plates, in their existing condition. These beams are placed above the rafters, at spacings which do not exceed 1.0m.
24. Since the struts might be set directly onto the capitals of iron columns, they fill the empty space between constituent parts of longitudinal main beams.
25. Knee braces are joined to all struts using traditional carpentry connections, such as notches and/or notches combined with tenons, secured by an iron bolt. Connecting the knee braces to the collar-tie is realised as a bridle ('fork') joint, reshaping the end of the compressive member into a tenon (whose thickness was about one-third of the gross width of the cross-section), while the widths of each part of the double cross-section of the collar-tie were weakened by side grooves. The inclined surface enables tenon joint fitting and the transfer of the forces over the contact area, and the connection is ensured by a bolt which can also take over the forces. In a similar manner, additional vertical studs were connected to a collar-tie. The connections between these studs and rafters, due to their equal width, are probably made as a notch with a tenon joint, secured by an iron bolt, or in a similar way the collar beams were joined to the rafters. Mortise and

tenon joints were probably used to connect the central vertical struts with the collar beam, and cross-lap joints (with shallow steps, typical for cogged joints) were the common choice where middle purlins laid over collar beams. The connections of 'arm' braces to middle purlins and central vertical struts are made in an eccentric manner, perhaps as stepped mortise and tenon joints or, more likely, as an angled lap or angled half-dovetail lap joint, secured with an iron bolt. The rafters are probably mutually connected by either fork (bridle) or end-lap joint, as a simpler one, where a secured iron bolt was used against the loads which tend to separate the rafters. A traditional birdsmouth joint must have been used to connect the rafters to the wall plates, where an iron bolt is commonly used to receive the horizontal force in a rafter-to-collar-tie connection. Collar beam-to-rafter connections could have been made as mortise and tenon joints, angled lap or angled half-dovetail lap joints. It should be noted that only a few of the described joints were really visible. For others, presumptions about possible joint types were made in accordance with the carpentry techniques relevant to the time of construction and the engineering practices of the time.

26. This specific construction was first analysed by Olga Magaš. Magaš, 'Kako nastaviti povijesni kontinuitet prve šećerane u Austro-Ugarskoj monarhiji', 145–77.
27. It should be noted that structural system of the Tobacco Drying Facility, the building which was an integral part of factory complex, significantly differed from structures of other buildings mention here and is described later in more detail.
28. Magaš presupposes that it was in the 1880s. Magaš, 'Kako nastaviti povijesni kontinuitet prve šećerane u Austro-Ugarskoj monarhiji', 156; HR-DARI 57, box 115, nr. 14/3/1875; HR-DARI 57, box 119, nr. 29/3/1882.
29. Magaš, 'Kako nastaviti povijesni kontinuitet prve šećerane u Austro-Ugarskoj monarhiji', 155; Magaš, 'Industrijska arhitektura', 420–7.
30. See ref. 25.
31. Magaš, 'Kako nastaviti povijesni kontinuitet prve šećerane u Austro-Ugarskoj monarhiji', 155; Magaš 'Industrijska arhitektura', 424.
32. In the plants of the ex Sugar Refinery the 52nd Regiment of Archduke Francis Charles was stationed. The administration building was probably used by military command. See Krasanka Majer and Petar Puhmajer, *Palača šećerane u Rijeci*, 69.
33. Magaš, 'Kako nastaviti povijesni kontinuitet prve šećerane u Austro-Ugarskoj monarhiji', 156; Magaš, 'Industrijska arhitektura', 426–7.
34. See ref. 2. Likewise, central parts of the ceiling structures of the first and second floors in the connecting part of the H-building were constructed as so-called 'Prussian vaults' (shallow brick vaults with iron I-girders) as it is shown in Figure 13. State Archives in Rijeka (HR-DARI) 57, box 131, nr. 45/2 (1892).
35. There are traces of deterioration to the wooden material due to moisture migration from peripheral masonry walls, and in the zone around the chimneys as well. The change of colour is particularly visible (*eg* white colour), which points to technically damaged wood of the lower collar ties and the dimensional changes, especially visible in these cross-sections. In certain principal rafter joints, discontinuity is noticeable, as well as the notable longitudinal cracks along some parts of the chairs. The visible deforming of the upper collar ties has been most probably caused by creeping.
36. This complex structural system (a combination of purlin-tie and king post truss) originates from German-speaking construction practice and it is usually used for large spans. See Ilić, *Klasični drveni krovovi*, 229, 232.
37. This refers to the structural system which is characteristic for German-speaking territories, and is also common for Croatian's traditional roofs, thanks to the legacy of the Austro-Hungarian monarchy. The literal Croatian translation of the original name, '*Bockpfettendach mit Kniestock*', would be 'fan-shaped chairs with knee braces'. See Lehrmann, *Holz im Holzbau*, 130. See also Ilić, *Klasični drveni krovovi*, 229, 232.
38. This type of structural system is also characteristic of German traditional construction (originally, '*Pfettendach mit einfachen Hängewerk*'), despite its Romanic roots. See Lehrmann, *Holz im Holzbau*, 132. See also Ilić, *Klasični drveni krovovi*, 267, 268.
39. Bridle and birdsmouth joints were used in rafter-to-rafter and rafter-to-purlin connections, and notch with tenon joints to connect principal braces and 'raking chairs' to the ceiling joist. Mortise and tenon joints were probably used to connect principal braces to either the middle purlin or king post, and lap joints were suitable to eccentrically connect arm braces. Iron bolts were used either to transfer tension forces or to ensure carpentry connections in which the compression or shear forces were transferred over contact surfaces. To connect short collar-ties to the principal braces, grooves were made on the inner side of each part of its double cross-section, forming an inclined surface along the tie depth. It enabled these two structural members to fit into each other. Moreover, the connection is secured by an iron bolt, which also transfers any possible compression forces that may occur. In the middle of the collar tie length, the king post was positioned, slightly prolonged below the lower edge of the collar tie. The widths of each part of the double collar tie are locally weakened in this connection by cutting along the section depth, and the load-bearing iron bolt accepts the tension force from the king post. The collar-tie-to-rafter connections were made in a similar way.
40. The warehouses were built 11 years before the newer part of the tobacco drying facility.
41. The first such ceiling structure, built in 1862 by William Fairbairn, was an eight-storey warehouse at a sugar refinery in Dublin, where it consisted of wrought-iron I-profiles between which in the sheet metal formwork were shallow segmental concrete vaults. See R. Byroms, 'William Fairbairn — Experimental Engineer and Millbuilder' (doctoral thesis, University of Huddersfield, 2015), 255. See also Palinić and Bjelanović, 'Structures of the Proto-industrial and Early Industrial Age in Rijeka, Croatia', 17; Palinić and Bjelanović, 'Wooden Structures in the Historic Port of Rijeka', 805; Varaldo and Zuccotti, 'Armirani beton', in *Enciklopedija moderne arhitekture*, ed. Milorad Radonić (Belgrade: Izdavačko preduzeće Građevinska knjiga, 1970), 36.
42. Palinić and Bjelanović, 'Wooden Structures in the Historic Port of Rijeka', 804.
43. The plans of the first phase of the building have not been preserved. Magaš, 'Kako nastaviti povijesni kontinuitet prve šećerane u Austro-Ugarskoj monarhiji', 156; Majer and Puhmajer, *Palača šećerane u Rijeci*, 54.
44. Magaš, 'Kako nastaviti povijesni kontinuitet prve šećerane u Austro-Ugarskoj monarhiji', 155; Magaš, 'Industrijska arhitektura ', 424–6.
45. The heights of the storeys differ and they are: 3.0m in the ground floor, 2.27m on the first and second floor, 2.12m on the third, and 2.22m on the fourth floor. It is similar with inner and outer diameters of the columns, so they are: 240mm and 280mm in the ground floor, 210mm and 270mm on the first floor, 180mm and 220mm on the second floor, 160mm and 180mm on the third floor, and 100mm and 130mm on the fourth floor. Data refer to Figure 16. and Figure 17. State Archives in Rijeka (HR-DARI), 57, box 140 nr. 14/11 (1899).
46. L. Vandenabeele, I. Bertels and I. Wouters, 'Designing Timber Trusses in Belgium during the Age of Iron Engineering', in *Structural Analysis of Historical Constructions — Anamnesis, Diagnosis, Therapy, Controls*, ed. K. Van Balen and E. Verstrynge (London: Taylor & Francis, 2016), 615–20. See also ref. 5.

Acknowledgements

The authors would like to thank the University of Rijeka for the financial support of the scientific projects: Improvement of Design Models for the Condition Assessment of Structures and Materials, Structures and Techniques to Control the Physical Influences of Historical Architecture in Kvarner Region, which cover this research.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

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