A New Wood Roofing System: Marac's Barracks and Colonel Armand Rose Emy's Innovative System

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INTRODUCTION

After the contribution offered by architect Philibert de l'Orme (1514-1570), for two centuries nobody else dealt with the construction of timber roofing to cover civil buildings in a scientific and analytical way. It is only with the diffusion of the *Traitè de l'Art de la Charpenterie* written by the Colonel Emy (1771-1851) around the 1830s, that the reflection about timber buildings returned to represent one of the most important themes of the *Art of Building* **(fig. 1).** In particular, Emy investigated the possibilities exploiting the secrets of the art of wood cutting to reach valid, innovative, formal and technological solutions applicable to the covering of great-sized rooms. Today, this paper seeks to verify the modernity of Emy's construction system, which might justly be considered the first example of laminated timber engineering.

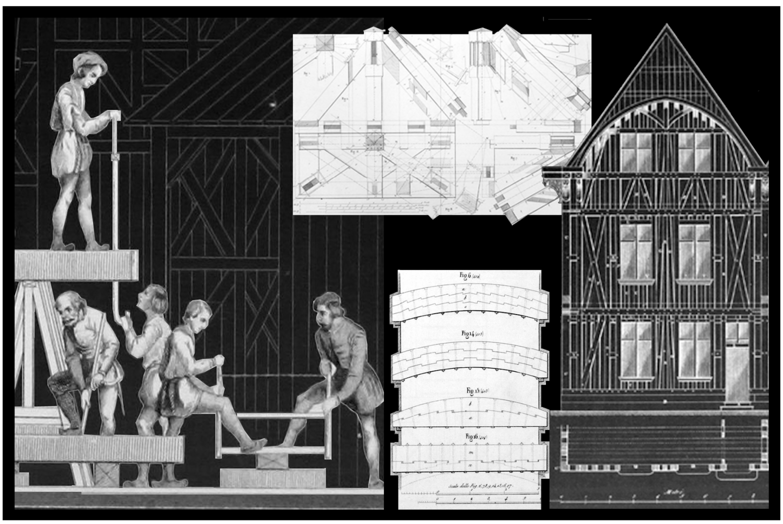

Figure 1. *Art of building* in wood. The role of carpentry. (Emy, 1856, pictures extracted from plates 10, 28, 39, 48)

CULTURAL AND SOCIAL CLIMATE

During the nineteenth century, in different countries, different intellectuals gathered information and knowledge on the *art of building in wood*. They wanted to write specific essays or manuals for large circulation and easy consultation. Although intellectuals deepened their knowledge of architecture's Classical theorists, the preferred focus was on the new *role of mechanics* in the construction, emulating what philosophers Diderot (1713-1784) and D'Alembert (1717-1783) had done in writing the definition of Carpentry in their *Encyclopédie, ou Dictionnaire raisonné des sciences, des artes at des métiers* (1751-1772).

In fact, using the strong, logical and rational formulations of the enlightenment thought and work organization, the 1800s intellectuals wanted to learn in detail the potentials of existing structural materials and their construction possibilities to contribute to the renewal and expansion of construction activities. Because of its intrinsic properties and its great availability (especially in some areas of the North Europe), wood became one of the more studied construction materials.

The writings were organized as manuals. Unlike ancient architectural essays, they did not have any solemn educational intent and they were often based on one theme. Instead, the numerous proposed texts aimed at giving concrete answers to daily construction problems and attaining perfect construction management. For the first time, handbooks showed an interest in the organization of working phases. Avoiding philosophical and ethic speculations on the *reasons to build*, the intellectuals gave precise definition of the wood workmanship procedures, picked up by observing carpenters' daily work. They proposed that good quality architecture could be realized through the assembly and repetition of small standardized pieces.

The sketches and architectural examples in essays had to solve problems relating to:

- maximum wood usage
- waste reduction in the workmanship and realization processes of architectonic elements
- manufacture assembling speed
- work site cleaning

In the treatises, the revolutionary use of scale drawing for the representation of parts and assembling techniques played a particularly important role.

Every construction element was described through the famous tables organized according to the orthogonal projection rules set out by the French mathematician Gaspard Monge (1746-1818). The whole construction was represented around three principal surfaces: horizontal, vertical and lateral. The use of perspective representation caused errors and was gradually abandoned. In this way, it was possible to understand immediately the dimensional relationships among the parts and to shape construction elements accordingly.

His method was so useful that the French Sciences Academy commissioned (as Emy writes in the preface of treatise, pp. 3-4) the draft of a new carpenter treatise by Professors Hassenfratz (1725-

1827) and Monge. It had to clearly show the stages relating to wood treatment and cutting as well as those relating construction assembly. Because of Monge's untimely death, this essay was not finished, but nevertheless its representation method came to be used by all the contemporary and subsequent building manuals. Thanks to new science, the complex stereotomic representations were turned into sketches which were equally effective, but simple and easy to understand. All carpenters were now privy to secrets of reading the *Stereotomic Art*.

Despite studies on the potentials of wood and availability of multiple architectural solutions, in all the essays the different character and symbolic value between wood and stone buildings was underlined (it is very interesting reading the engineer Breymann's desciption of these differences so clearly expressed in introduction of his work *Die Konstruktionen in Holz*, 1900).

Tinber construction was indissolubly tied to its decay caused by the wear and tear of time. A lot of these texts recommended the adoption of bricks or cut stone for monumental and eternal buildings while they considered wood a less precious material, suitable only for secondary and temporary construction. The stone and bricks elements formed structures by overlapping. In fact, they worked solely by gravity; in contrast the assembly of joints between wooded parts statically determined the structure's loadcarrying capacity. As a result the assembly of parts became the most important theme in essays on timber construction. The knot was conceived both as a lap joint among the parts and as a joint realized through the use of ropes. The particular kind of chosen joint was determined by the architectural solution **(fig. 2)**.

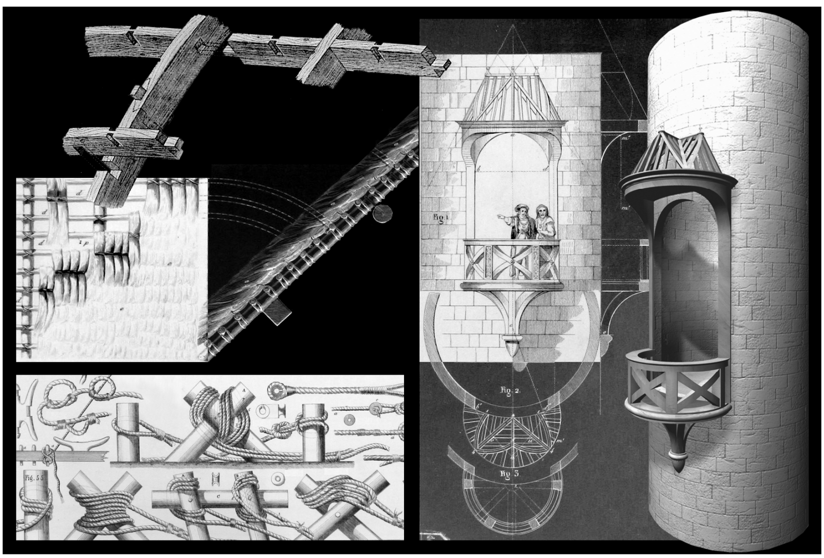

Figure 2. The knot: union realized through ropes and lap joint. An application: wooden *guitare*. (Emy, 1856, reference plates: 40, 80, 105, 152)

In fact, the wooden joint or knot originated endless formal solutions derived from the type of construction (civil, manufacturing, development building) and the place, the time and the culture that produced it. The joint or knot became the fulcrum of wood construction: the place where forces came together and at the same time sorted themselves out **(fig. 3)**.

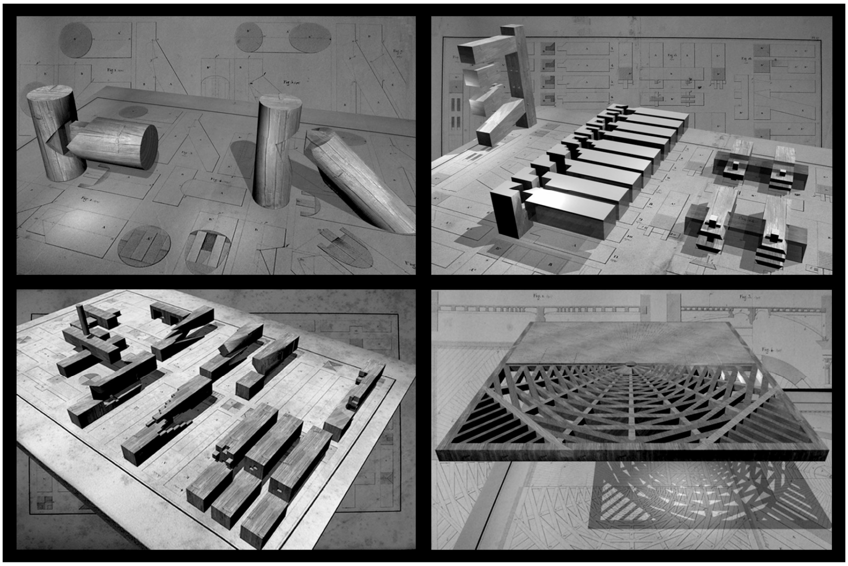

Figure 3. Three-dimensional plans of some meaningful joints. An application: wooden beam floor in the manner of Serlio. (Emy, 1856, reference plates: 16, 17, 19, 35)

Many intellectuals of the time underlined how very different cultures, Europeans and Asians, achieved similar technological solutions with varying degrees of complexity (as written in the fifth book of *Traité théorique et pratique de l'art de bâtir* by Jean Baptiste Rondelet, 1802 and the first part of *Traitè de la Charpenterie* by Hassenfrantz, 1804). The buildings were dismantled and analyzed according to its most important joints: the foundations; the elevation and the roof covering. The construction was born of small joints that had a greater or lesser character of seriality. When they were properly assembled, they worked as a continuous structure. While rationalizing woodworking techniques, analyzing contemporary buildings, re-interpreting assembly techniques and describing traditional joints, Emy also experimented and developed new construction methodologies. Particularly, he looked into the opportunities available for joining thin shaped plates to produce rectilinear and curvilinear beams.

ARMAND ROSE EMY AND "TRAITE' DE LA ART DE LA CHARPENTERIE"

Armand Rose Emy's essay is one of the most interesting points of reference in the French and European cultural debate on timber construction during the 1800s. Emy suggested a new wood coverage system inspired by the inventions of de l’Orme, architect and counsellor to the Court of King Henry II who wrote in 1561 *Le nouvelles inventions pour bien bastir et a petit fraiz*. Recognizing his valid and modern intents, Emy tried a new and different method of thin wood plates joints (Volume II of Treaty, pag. 161-84). Like de L’Orme’s systeem it too used small and economic wood pieces to cover great spans. From the frontispiece, we know Emy was Colonel of the Official Genius of the Real Order of the Legion of Honor; Professor of Fortification in the Military Real School of Saint-Cyr; member of the Real Academy of Ancient Literature, Sciences and Arts of the Rochelle; member of the Regal Society of Agriculture and the Arts of the department of Seine et Oisè **(fig. 4)**.

Figure 4. Frontispiece of Emy’s treatise in Italian and French versions.

We would therefore expect his work to be a mixture of careful study of the technologies and possibilities attained by new scientific discoveries and direct experience of the engineering and construction of roads and military shelters. A clearness of analysis, the continuous and constant comparison with the building norms and particularly with the wood workmanship practice can be seen in the *Traitè de l’Art de la Charpenterie*. In this work, Emy clearly showed his great love and knowledge of wood, his intellectual vivacity, and his acumen for the observation of the manual production processes of his time. In the preface, he affirmed:

> […] the Frezier observation on stones cutting is equally applicable to lumber cutting. Carpentry is quite different from what it appears at first sight, that is the manual job of a craftsman who cuts the lumber in pieces putting together them one on top of another. Mainly carpentry is the art that lays down the laws of construction; it is the art that

calculates the arrangements and the necessary strength of squared tree trunks to erect wood buildings. First of all, carpentry must fix the building's form; then, it must evaluate the execution process and finally it must establish the plan of the job that a skilled worker must to use. Carpenters are not the only ones expected to know this art, […] both the architects and the engineers must be very knowledgeable in it, down to the smallest details […]

(Emy, 1856, Volume I, p. 3)

The treatise comprised three volumes. In the first and second one, Emy illustrated theoretically the merits and application of wood in the architecture and construction of civil buildings; in the third volume, he used drawings to explain and clarify the first two. All the volumes were published in Paris, but in different dates: the first theoretical volume in 1837; the second theoretical volume and the one of drawings were printed together, in 1841. The conceptual apparatus was organized in fifty-three chapters, as follows:

VOLUME I

I.	Tools used to work lumber
II.	Lumber
III.	Cutting, squaring and preparation of lumber
IV.	Lumber's transportation
V.	Bending
VI.	Lumber's maintenance
VII.	The best lumber for carpentry jobs
VIII.	Lumber's conjunction
IX.	Execution of carpentry work
X.	Lumber walls
XI.	Scaffoldings
XII.	Coverage
XIII.	Roofs
XIV.	Detail drawings

VOLUME II

XV.	Framework erection
XVI.	Curved surfaces and roofs
XVII.	Curved surfaces and roofs, continued
XVIII.	Flashings
XIX.	Rectilinear surfaces and roofs
XX.	Openings in roofs and vaults
XXI.	St. Andrew's crosses used in curved surfaces

XXII.	[Particular roofs known in French as] ‘*guitares*’ and ‘trompes’ used to protect doors and windows openings
XXIII.	Various roofs system in wood
XXIV.	Heavily loaded roofs
XXV.	Wood buildings in the Middle Ages
XXVI.	Frame trusses and pendants
XXVII.	Planks on edge systems
XXVIII.	Lacaze’s system
XXIX.	Flat plank wood roofs
XXX.	Centerings made with planks called *madrievi,* curved about the width
XXXI.	Laves’ system
XXXII.	Domes, pinnacles, steeples and wood rammers
XXXIII.	Iron use in wood buildings
XXXIV.	Iron use in joining wood framework
XXXV.	Wood staircases
XXXVI.	Cribs
XXXVII.	Wood scaffolding
XXXVIII.	Fixed wood scaffolding
XXXIX.	Mobile and hanging wood scaffolding
XL.	Knots descriptions
XLI.	Use of roped knots
XLII.	Wood works erection
XLIII.	Ropes, stages, foundations and repairs
XLIV.	Scaffolds and centrings for vault construction
XLV.	Hydraulic works, dikes, sluices and foundations carpentry
XLVI.	Naval carpentry
XLVII.	Machinery carpentry
IIL.	Experiences and calculations related to wood strength
IL.	Movements
L.	Additional constructions
LI.	Skills
LII.	Calculation of cubic wood measurement essentials to build
LIII.	Wood strength

Immediately the essay spread throughout Europe. The consulted Italian translation, made by Engineer Antonio Romano and Professor Engineer Gustavo Bucchia, dates back to 1856 (all the present quotations in this paper refer exclusively to Emy’s Essay in this Italian version).

Published in Venice and entitled *Il Trattato dell’Arte del Carpentiere*, today a copy of this work is preserved in Central Engineering Library of Padua University. In his introduction, Eng. Bucchia underlines that "in the cradle of Art and great talents [Italy], nobody has ever assembled a collection of knowledge and architectural inventions on the workmanship and carpentry of wood." (1856, Translator Introduction, pp. 1-2). He considered Emy's study on wood absolutely complete, worthy of popularization and indispensable for educating modern architects and engineers.

Avoiding the *captatio benevolentiae* typical of many Architecture Essays, Emy identified the audience of his work as "anyone who wants to achieve new formal and technological architectural definitions, by learning the secrets of the art of wood cutting" (1856, p. 5), claiming that the correct management and construction of a building were based on a clear difference between the roles of the master builder carpenter and the designer. The first one had to know the *Art of Tracing*: he had to draw on the wood the pieces to be cut and in particular he had to know how to represent and to cut their joints; the second one, either architect or engineer, had to know the material and its characteristics because he had to be able to find specific solutions for new construction problems. Knowing all wood's peculiarities, the designer could arrive to determinate an invention on the building system. In this way, even Emy invented a new beam system using thin plates, to cover barracks at Marac. A good planner should not have to "call for the help of a carpenter master builder to complete the building project and to assure its stability" (Emy, 1856, Volume I, p. 5).

Emy's treatise did not include an explanation of Monge's representation methods but it made use of orthogonal projections. He drew every element, from the wood plank to the theatres coverage, using real dimensions and proportions. Emy did not use the perspective view, which he judged more apt for a picturesque representation. Cutaway axonometric views clarified the assembly method.
Emy stated:

> […] now descriptive geometry teaching is so popular in every technical school that we believe there does not exist a carpenter today who does not know its principles and use. To those people who do not know these principles yet, we advise to inquire into them before reading this work […] as we also recommend the study of the elements of mechanics to young carpenters, since it can be useful to them […]
>
> (Emy, 1856, Volume I, p. 4).

Every sketch was drawn to metric scale. So the carpenter could know the relative scale of the parts. In fact, with only the use of a compass, it was possible to immediately calculate and compare the dimension of objects. Survey operations became faster and easier. Those particular characters of Emy's treatise underline his different way to consider the building. He was not interested in the stereotomy problem as military engineer Amédée François Frézier (1682-1773) writing in 1739 the *Traité de stereotomie à l'usage de l'architecture*. Emy wanted to provide a handbook in which there were good architectural examples to encourage the correct use of wood.

Unlike many contemporary treatises (for example, *Travailles primitif de charpenterie. Plans, coupes et façade de plusieurs constructions*, written by A. Krafft and published in 1805 in Paris in which at least twenty reconstructions of models of primitive residence, huts and rustic houses were present), in his treatise Emy only wanted to show *the present state of the art*. He chose among contemporary architecture "the construction that is built today with much elegance, solidity and courage." (Emy, 1856, Volume I, p. 8).

Emy compared wood architectures from Europe with that of other populations he defined "civilized", as Chinese, Indian and Russian. He recognized that these cultures had made great progresses on “the path of the art of wood building ". (Emy, 1856, Volume I, p. 9). He underlined the great similes existing between Swiss and Russian constructions. He verified that the ways to build in wood led to similar architectural forms and joints production. Emy did not dwell on the description of buildings by "wild populations and our black colonies" (Emy, 1856, Volume I, p. 9). He praised however their ability to erect huts by fastening wood parts with ropes or leather strips and to build walls by weaving tropical plants branches and leaves.
He affirmed:

> […] They [the wild populations] seldom use iron dowels to make their joints more solid. These joints are generally soaked in tar which holds them together, compact and solid. Tar keeps also wood characters. The huts, built in this way, have an admirable stability. The builders are so skilful when they use highly flexible lumber so that in the zones prone to hurricanes, constructions fold up to the winds violence, without breaking […]
>
> (Emy, 1856, Volume I, p. 9)

The analysis of the construction techniques of other populations induced Emy to consider new technological and structural possibilities offered by the use of iron in stone and wood construction. He observed that the wood use in civil construction was restricted more and more to the construction of roofs and bridges. He analysed with great attention a treatise called *Beiträge zum praktischen Wasserbau und zur Maschienenlehre* written by Engineer Carl Friedrich von Wiebeking (1762-1842) in 1792. Wiebeking had introduced in his text a lot of his ideas and studies on the solidity and the elasticity of the different wood types, on the bending of the beams, and on the possibility of holding together thin plates by bandaging them with some metallic stirrups to present waste of wood. Emy admired Wiebeking’s ideas and described his most important bridges in Volume II of Treatise, in the thirty-eighth chapter **(fig. 5)**.

The use of great spans in construction and bridges contributed to loss of entire century-old forests. Emy proposed "saving lumber and replacing the use of long-span wood members through new methods" (Emy, 1856, Volume I, p.14), as de l’Orme had done.

CONCEIVING AN INVENTION: EMY AND DE L’ORME

Emy was strongly convinced that by knowing the most important wood architectures and technological shrewdness adopted by great ancient masters, one would be able to reach innovative solutions for original constructions. For this reason, he described de l’Orme’s innovative system in the twenty-seventh chapter (p.161-184), entitled *Planks on edge system*.

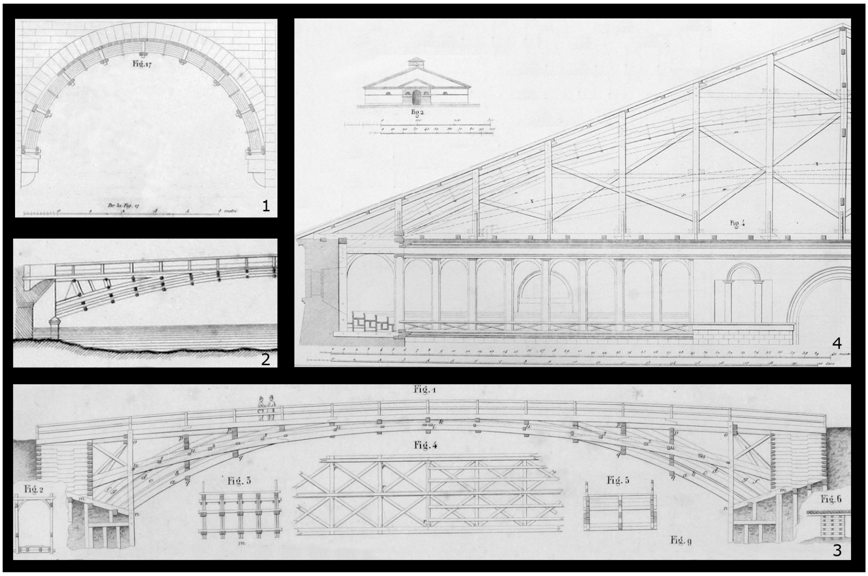

Figure 5. Meaningful examples of buildings realized with curved plates in wood.
1. Melun's Fruit Bridge; 2. Wiebeking's Bemberga Bridge; 3. Wiebeking's Sharding Bridge;
4. Krafft's Imperial physical exercise room (Emy, 1856, reference plates: 93, 137, 141)

Emy stated that Philibert de l'Orme's beautiful discovery had been completely forgotten for two centuries. After the death of this famous architect, no planking was realized using his system. But now thanks to construction of the dome over the grain market in Paris by architects Legrand and Molino, people could again appreciate this way of building. Emy affirmed it was possible that Philibert de l'Orme invented this kind of wood planking by looking to ancient construction, especially the vault that his contemporary Serlio had discovered while restoring the building of the Tournelleses.

According the Colonel, de l'Orme's invention consisted not only of the use of shaped planks on edge, but in their union and in the really clever use of hemicycles bonded by cross beams and pins. Neither nails nor iron were used in this clever construction method. In fact, de l'Orme, conscious of waste produced by the use of forest trees, proposed a new way to use them for the construction of roofs. First of all, he recommended squaring and dividing the log in many thin plates. Then, he suggested cutting every plank into small and equally sized semi-circular pieces, to subsequently assemble them. The semi-arches realization also allowed the use of smaller trees. Their joints were fixed using cross beams opportunely inserted and kept in tension by wood pegs. **(fig. 6)**

Recognizing the value of de l'Orme's idea, verifying the tangible savings both in the use of wood and in the construction process, the speed of execution, the use of non-skilled labour, Emy undertook to find a new system to cover even greater spans.

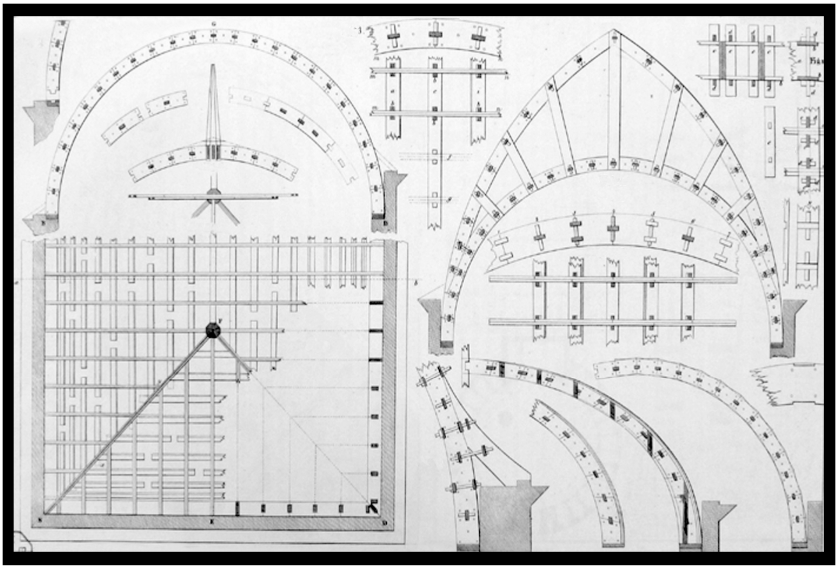

Figure 6. Plan, sections and details of de l’Orme’s system (Emy, 1856, reference plate: 102)

In the twenty-ninth chapter of Volume II (pp. 189-94), Emy described the roof construction of civil architecture, in which the builders tried to attempt to create flat wood with bottom planking. They however did not succeed in calculating exactly the strength of these thin plates and quantifying their lifespan. According to Emy, their attention was set more onto the economy and the lightness of the construction systems. Also it was his opinion that any cut of wood necessary to make the joint was inherently weak. In his construction system, Emy proposed the use of flat thin wood elements, fastened by metal plates, stirrups and bolts. He thought that the combination of iron and wood, as a good alternative among the construction systems entirely realized in either wood or iron, could offer a lot new possibilities to the “Art of Carpentry”. In this way, it was possible to realize buildings that were at the same time light, less expensive and had a good aesthetic quality. His experience allowed him to show that, for barracks of the same surface area, roofs realized in iron costed four or five times more than wood ones. According to Emy, both materials had a similar lifespan. The only advantage offered by exclusive use of iron was in its incombustibility. Because of its high cost, Emy recommended using iron only in the places where wood was lacking or its import was too onerous. In the subsequent treatises, de l’Orme and Emy’s systems were often compared and referenced. Breymann described Emy’s invention in this manner:

> […] Instead of putting, as in de l’Orme system, the short and same-sized planks on edge, one after the other, Emy overlaps planks (that have the same width and thickness, but different length) one on the top of another according to their length. In this way, the maximum lenght of the log is better used. Generally the assembly is simple; it is necessary only to alternate the planks joints, so that in a same section they never find two; and all

> planks need to be connected with iron plates, stirrups and bolts. The planks of the Emy system bend one by one on special centring used as a model; after the whole arch has taken the established form, the screws are arranged for shutting. […]
>
> (G.A. Breymann, 1927, pg.187)

THE INVENTION IN ACTION: THE NEW WOOD ROOFING SYSTEM IN THE BARRACKS AT MARAC

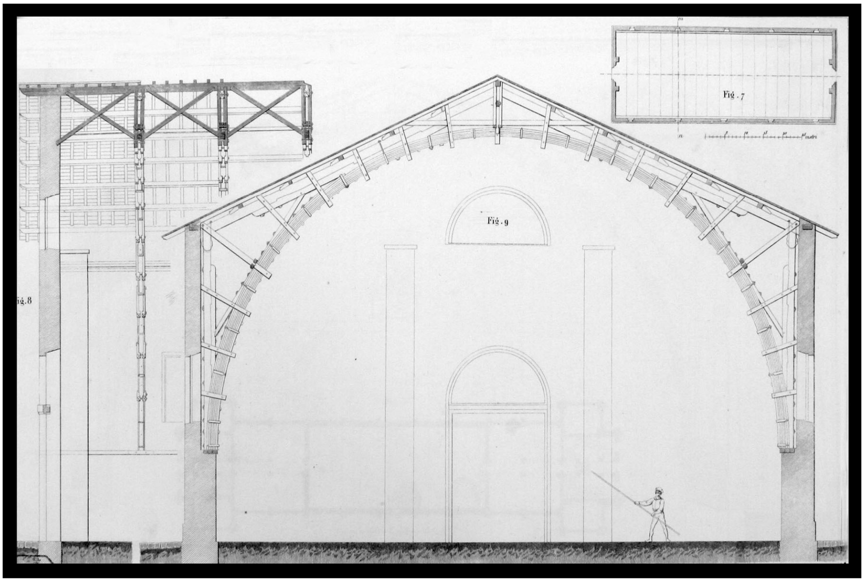

Figure 7. Plan, cross and longitudinal sections of Marac's barrack (Emy, 1856, reference plate: 102)

Emy's new wood roofing system first appeared in theoretical form in a pamphlet called *Description d'un nouveau system d'archs pour les grands charpentes,* published in Paris in 1823. A few years later, Emy used the whole thirtieth chapter of treatise, *Centerings and arches made with planks called madrievi, curved about the width* to describe his system (pp. 195-214). First of all, he explained his invention; then, he reported his practical experience made both in the handling of barracks at Marac and Libourne (two villages in France); finally, he compared his system to trusses generally used to cover civil buildings and de l'Orme's one underlining the advantages of his method. The history of the invention of curved *madrievi* arches began in 1819. The Military Genius entrusted colonel Emy with the design of the roofing for the barrack at Libourne, for which the foundations and walls had existed since 1764. He proposed using de l'Orme's system to cover the 21 meter wide by 48 meter long classroom, judging this method to be better suited to ensure a good aesthetic result and discreet savings. Not approving of the waste inherent in the proposed system, Emy took it upon himself to find a different architectural solution. In his treatise he affirmed that he wanted to plan a roofing system in which the full length of lumber was used. He aimed to achieve same solidity and elegance of de l'Orme's method with less timber. This innovative idea was not immediately accepted for the Libourne barracks and he had to wait for another chance to be able to propose his revolutionary system. Finally in 1825, he got to design the roofing system for the barracks at Marac, near Bayonne **(fig.7)**. It comprised a roof for a classroom 20 metres wide by 57 metres long.

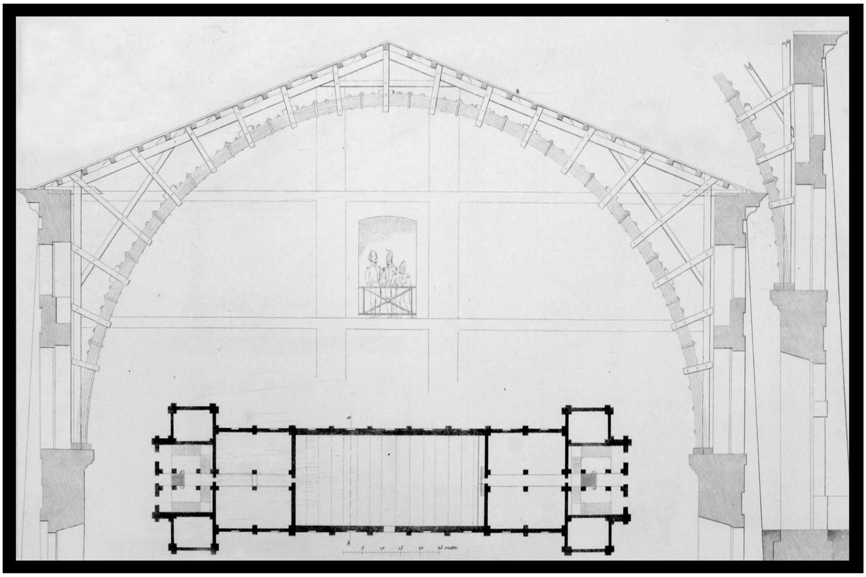

Figure 8. Plan, cross and longitudinal sections of Liborne's barrack (Emy, 1856, reference plate: 109)

The success of the this roofing system also ensured the use of the same method at Libourne in 1826 **(fig.8)**. The fame of these two projects contributed to diffusion and application of this method in many French barracks. Spatially, the structure was composed of a double system formed by semicircular arches and struts. The repetition of the arches contributed to the definition of inside space that seemed turned into a barrel: in fact the space between the ground and the arches was free due to the lack of chains. Instead the series of struts supported the layers of the plain external roof . Technologically, the construction system was much more complex. Every truss of the roof was composed of multiple elements: one semi-circular arch and two struts, two vertical supporting legs, two *razzas* (particular kind of wood chains that jointed struts and supporting legs) and many *ascialloni* (horizontal and radial crossbars of wood) **(fig.9, fig.10).** The arch was the most important element of every truss. Its correct construction was essential to the structural integrity of the roof. Every semi-circular arch was formed by overlapping longitudinally a varying number of curved thin plates (called *madrievi*). For example: near the arch impost ashlars, the thin wood plates were eight in number; in proximity of king post, they were three. Every thin plate had a maximum length of 13 metres; a fixed width of 13 centimetres and fixed thickness of 55 millimetres. Spatially, two *madrievi* and a half, arranged in succession, were enough to complete the hall span. No thin plate had more than three joints; generally there were two. Emy suggested staggering the joints among overlapped thin plates and driving wood pins to make their joints stronger. The *ascialloni* had a very important role. One of these, small sized, horizontal and tangent to the arch behaved as a chain the struts. The others, radially located along the arch, prevented the thin plates sliding as they were fitted into quarters of wood. At the same time, the radial *ascialloni* fastened the plates to the struts tangent the arch, supporting the external roof covering. The triangular union formed by the *razzas*, the vertical supporting legs and the struts stabilized the entire roof system creating a self-supporting grid. The connection of the trusses stiffened the system through a series of St. Andrew’s crosses arranged transversally to the arch. Iron sheets, brackets and bolts, prepared at regular intervals, contributed to the stronger joining of the thin plates **(fig.11)**.

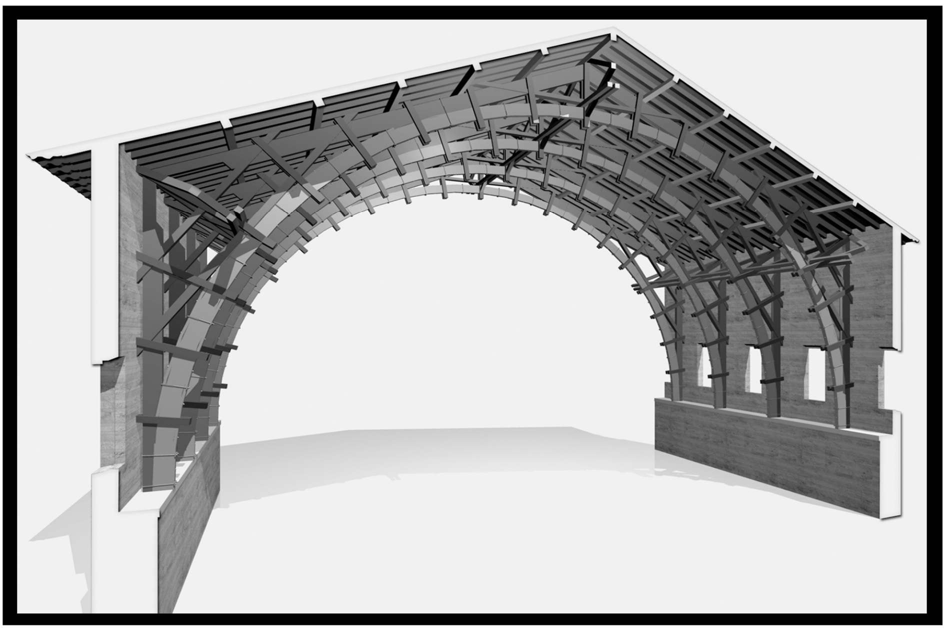

Figure 9. Three-dimensional plan of Marac’s barrack

In that period, many other architects and engineers proposed and used roofing systems similar to Emy’s one. For example, Krafft used big arches formed by overlapped and curved boards to cover the physical exercise room of the Imperial Palace in Moscow **(fig. 5)**. This solution was awkward because the dimension of each thin plate was too great and their uncontrolled bending produced an excessive movement in the perimeter walls.

Figure 10. External and internal photographs of Marac's barrack (Bonnel, 1960)

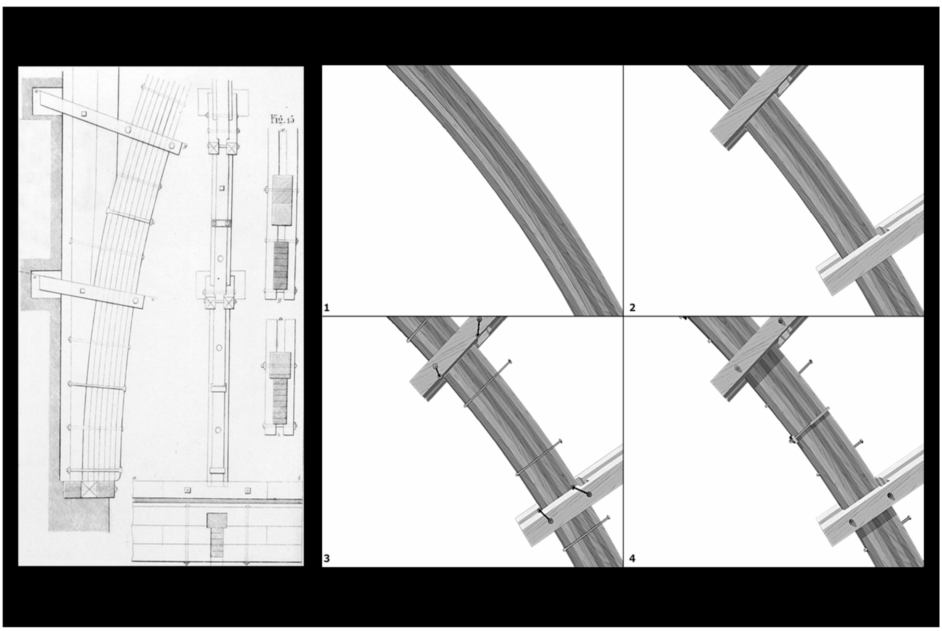

Figure 11. Detailes: joint on wall (Breymann, 1927, reference plate: 37) and assembling system of arch

The Melun's arch realized in the Fruits bridge **(fig.5)** was differed from Emy's one in two ways: firstly the distance to be spanned (approximately 7 metres) and secondly, the procedures adopted to curve the wood. The wood plates were softened with the steam produced by the combustion of manure. The bending of the thin wood plates, generally explained in the fifth chapter of Volume I (pp. 165-179), represented one of the most delicate problems to be faced for realizing any type of coverage. Because of static and formal advantages, curved wood was often used both in naval and civil carpentry. The carpenters obtained the lumber by bending it in very different ways: they could use heat and steam, or live flames, or the immersion in hot water or hot sand, or high-pressure vapour jets. Each of these methods presented some disadvantages, generally tied to the natural strength reduction of the wood or to the shrinking and splitting of the wood. However, Emy considered the following two methods as being the absolute worse: the growing or the cutting of trees with the purpose of attaining a semicircular shape. In these cases, the work of wood fibres was seriously compromised. He also provided a detailed description of methods used for bending plates adopted for the project at Marac. Before being bent, the thin plates were softened with vapour producing machinery. This first setting occurred away from the building yard.

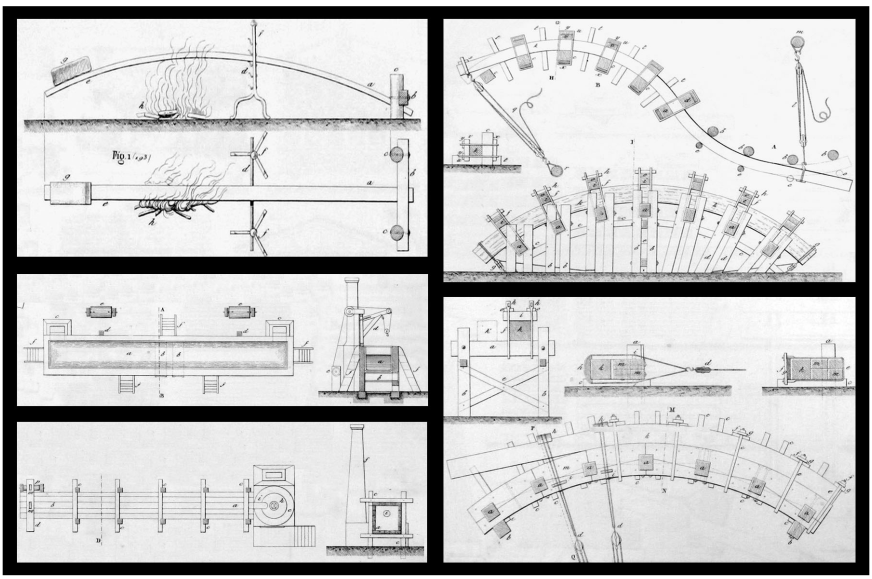

Figure 12. Different ways to bend thin wood plates (Emy, 1856, reference plate: 22)

The thin plates were then transported to the building yard and placed with care on the continuous surface of suitable centring, made especially to the span of the barrack at Marac **(fig.12).** The bending and the subsequent air-drying of the lumber occurred therefore before the laying of the roof. The thin plates forming the thickness of each arch were bent together. Then they were fastened with wood pins and metallic stirrups. In this way the assembly process of arch was carried out on the ground. When each arch was ready and seasoned, the entire truss was assembled. Using special winch and scaffolds of wood, located around the perimeter of the building, all trusses were then lifted and correctly positioned in the masonry walls.

CONCLUSIONS

Emy used the roof at Marac as an experimental laboratory to verify the validity of his invention. The objectives pursued were two:

- the construction of a self-bearing roofing system that did not produce an outward thrust
- a system of arches and struts able to hold up a heavy roof covering without loss of elegance and simplicity

He wrote:

> […] up to there nobody has purposed or built yet long spanning light-weight arches, made only with long and thin wood elements, whose flexibility allowed an easy and ready bending without the use of fire […]. Its rigidity, suitably controlled, has the property of maintain the form of the main frame and to remove the inclined push so that it is no applied to the walls […]
>
> (Emy, 1856, Volume II, p. 196-98)

The great resistance and lightness of this new way of building arches along the possibility of realizing architecture of *worthy decorum* were sure advantages of these coverage.

> […] My system arrangements can indefinitely be varied in number, in form and capacity. These arches strength can be increased according to the need, without changing the system, without harming to the elegance, neither to the audacity of the building, only with the thin plates addition in arches development […]
>
> (Emy, 1856, Volume II, p. 211)

The facility of assembly which resulted in the use of non-skilled labour, material savings, the speed of construction and the cleaning of the work yard were the most interesting advantages of his system. Emy stated:

> […] the execution of my system of arches is so simple that the ability of an ordinary carpenter (not a master builder) is sufficient for its realization. The required work is much easier than in de l'Orme's assembly method. In fact the thin plats are all straight pieces. […] The process of construction and erection is so simple that a dozen workers, of which two

bystanders are labourers, were sufficient for the construction and laying-in work of two trusses per week, in the barracks at Marac and Libourne […]

(Emy, 1856, Volume II, p. 213)

To summarize the advantages of Emy's invention, a comparative table **(table 1)** is reported below:

Table 1. comparative analyse

Roofing	Internal dimension of building			Trusses number	Trusses span	Load	
	width meter	length meter	building lot square meter			1 truss Kg/linear meter	Stringer between Struts Kg/linear meter
Marac Barrack	20	57	1140	48	3	8800	400
Libourne Barrack	21	48	1008	14	5,20	3775	417
According to de l'Orme system	20	57	1140	82	0,70	1555	67,6
Usual roofing system	20	57	1140	13	4,07	12535	397

The greatness of Emy's work, the precision and the correctness of his studies and the validity of his invention led Emy to realise many barracks using this roofing system. Photographs show that the Marac barracks was in existence until the 1960s **(fig. 10)**. Today, he must to be remembered for another reason. Although in 1907, it was Otto Hetzer who filed in different European countries the patent for the realization of curved beams (formed by thin glued plates in wood), it is Emy who should arguably be seen as the true father of this technique, as can be seen by his the first careful reflections and experimentation using this type of construction. In fact, studying the Wiebeking's bridge realized at Bemberga, Emy had even evaluated the possibility of introducing the blood-albumen glue between the thin plates to strengthen his semi-circular arch. He had realised however that organic glues, then in use, represented a great weakness in the building system (as he wrote in the note number 2, the thirty- eighth chapter, Volume II, p.410). In fact, their corruptibility could result in the failure of the whole planking system. Because of this, he had preferred to rely on the strength of iron to reinforce the joints.

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