Cascading Potential for Recovered Wood from Heavy Timber Frame Typologies in Pre-Modern Dwelling Buildings in Madrid

Marina de Arana-Fernández[1] – Daniel F. Llana[1,2] – Bahareh Nasiri[3] – Guillermo Íñiguez-González [1,2]*

[1] Department of Foresty and Enviromental Engineering and Management, MONTES (School of Forest Engineering and Natural Resources), Universidad Politécnica de Madrid, Madrid, Spain
*m.aranafer@gmail.com**
danielfllana@gmail.com
guillermo.iniguez@upm.es
[2] Timber Construction Research Group, Universidad Politécnica de Madrid, Madrid, Spain
[3] Department of Bioproducts and Biosystems, Aalto University, Espoo, Finland
bahareh.nasiri@aalto.fi

Abstract

Wood is one of the premodern materials par excellence. It lost presence due to the appearance of steel and concrete in construction, however, now it is regaining importance for its structural performance, its capacity to fixate CO_2 and its low energy demand during manufacturing process.

In our current climate emergency, rethinking how resources are treated has become a need, and wood can be in the centre of the debate. The use of recovered timber in construction could be an important measure to widen the lifespan of this material. Cascading could help in the development of new economic models and potentiate environmental-friendly others like circular economy.

Premodern buildings could be a great source for reclaimed timber because the presence of timber in them is almost inevitable. A quantification of amount of recoverable timber that can be obtained from them is interesting in order to potentiate the reuse of the material.

Key words: Cascading, circular economy, corrala, dwelling typologies, Madrid cultural heritage, reclaimed timber, timber reuse

Introduction and state of the art

Timber has been used in construction since the ancient times. It is a highly versatile material, workable and resistant. It has gone through difficult times due to the appearance of modern materials such as steel and concrete, but nowadays it is regaining its former importance thanks to the evolution of timber engineering products, the prefabrication and for its great performing characteristics, resistance and sustainability.

In the present times, due to the climate change emergency that we are enduring where our ecosystems and resources are being affected (Lindner et al., 2010; Schröter et al., 2005), material reuse and recovery are necessary to achieve a sustainable and responsible economy and way of life. Timber presents itself as one possible solution, being the only construction material to fixate CO_2 (Wood, 1991) and it can be adapted to new needs without the use of large amounts of energy in the transformation process (Peck, 2001).

Circular economy is a key principle for reaching sustainable development goals (Sachs et al., 2019). This concept has highlighted sustainable use of resources, materials and energy due to increasing dependency on resources and increasing resource consumption (de Wit et al., 2018). Remarkably, around 40% of the resource consumption has been used in building and construction industry on a yearly basis (Bringezu et al., 2017). Thus, it is necessary to enhance the resource efficiency of materials in buildings through cascading concept, reusing the same piece or unit several times (Sirkin & Houten, 1994). Timber is the perfect example for it as it could help to achieve this compromise with the planet thanks to its renewability and reusability.

The spread of the use of recovered timber could be one of the challenges of this century. Studies are being held in order to determine the potential for cascading of timber and how can it be obtained from building demolitions (Fraanje, 1997; Höglmeier et al., 2013; Sakaguchi et al., 2016, 2017). As a result of those studies, cascading wood from buildings is a possible and influential course of action, though several choices, such as ecological taxation of resources, prohibition to dumping waste wood on site, regulation enabling the use of recovered wood in buildings and reliable data, showing the quantity and quality of available recovered wood, need to favour cascading.

Although there is currently an abundance of forests, the resources of the planet are finite, and it is our duty to rethink how we use them in a more efficient, responsible and circular way.

Re-examining how we have built our cities, the constructive systems and the pre-modern materials used, could be a good start to understand the cascading potential for recovered wood.

Firstly, cities are fundamentally made of anonymous constructions, which are the true originators of a good urban tissue, and their use is mainly dwelling. These buildings are rarely the most notorious constructions of a city, but they are the most common, the less protected by cultural heritage laws and the most likely to suffer a change of use or rehabilitation.

Secondly, studying the pre-existent constructive systems and typologies could deepen the understanding of the aforementioned buildings. A very common dwelling typology in Mediterranean cultures is the house with a courtyard. This typology has evolved since the ancient Mesopotamians, the Greeks and the Romans to our days, and it has been progressively adapted to the times, the culture and the urban tissue. There is an endemic type of courtyard house in Madrid mainly built between the 16th and 19th centuries that is very present in the city centre, called “corrala” (Santa Cruz Astorqui, 2012).

Finally, vernacular residential constructions are linked to a city’s DNA and it is important to maintain them in order to keep the essence of our cities. As the pre-modern buildings that they are, all of them have timber in its structure. The quantification of these structures, determining the species used and the general amount of timber saved, could lead to a change of paradigm and foster new behaviours towards rehabilitation, construction and reuse of materials.

Traditional typologies and timber constructive systems in residential buildings in Spain

In Spain, as well as in many other countries, timber constructive systems have evolved from the primigenial log shelters, to more intricated systems as heavy timber frames and light timber frames. Recently, due to the appearance of new timber-derived products, an important development in new constructive systems has taken place. The recent appearance of these new ways of construction has changed the paradigm for timber buildings.

In Spain, as it happened in other countries, the appearance of new materials such as concrete and steel has put timber in a second place, and almost since the beginning of the 20th century timber construction began to lose presence in the Spanish construction paradigm.

The Spanish Civil War (1936-1939) supposed a turning point in the industrial use of timber (Zapata Blanco, 1998). Timber´s use in construction was relegated to the countryside and northern areas of the country, where forests are more present. Thus, the main “source” of recoverable structural timber is premodern architecture; considering premodern constructions those buildings that were built with neither concrete nor steel in their structures.

The main timber constructive system in Spain before the Civil War is heavy timber frame. Timber is present in the horizontal and roofing structures and, in some typologies, in the vertical structure too, either laced in the walls or as isolated supports.

In the following scheme (Fig. 01), the main dwelling typologies, materials and constructive systems have been studied to define the most common residential timber buildings and main examples of premodern architecture with timber structures.

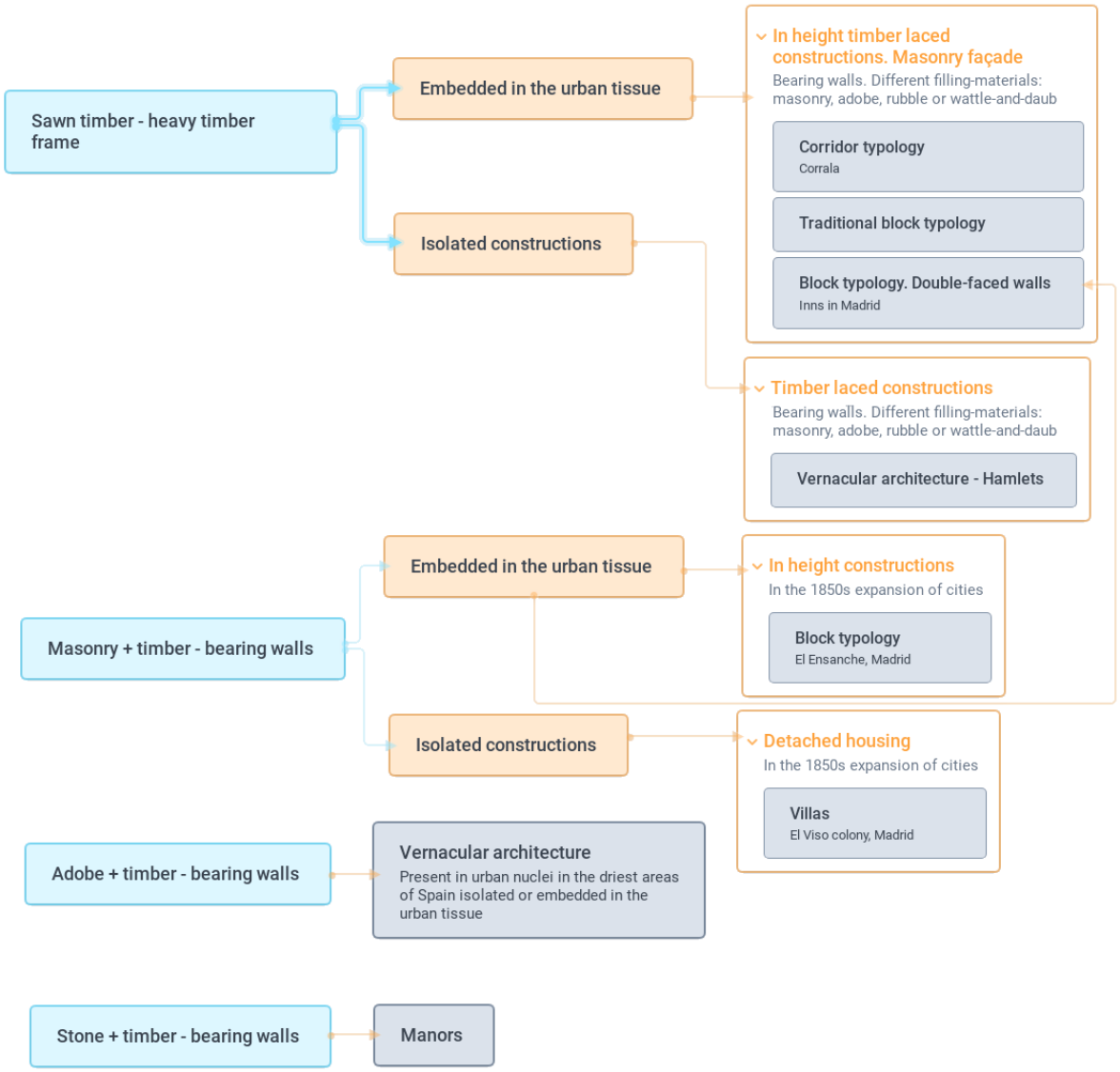


Fig. 01. Traditional typologies scheme.

Recovered timber has an enormous potential as constructive material, either as sawn timber or transformed into a timber-derived product. Analysing the state of the built heritage, a deeper understanding of the existing structures could be achieved. It could lead, for instance, to more curated demolition practices that could benefit both the conservation of built heritage and the reuse of the timber obtained from it (Nunes et al., 2019). If the obtained pieces are in good conditions (not damaged by water or attacked by termites or fungi), they could be placed into similar buildings that use pieces of approximately the same dimensions.

In this process of reusing the timber obtained from existing buildings, a new category has been stablished. Depending on the amount and quality of the material (i.e. dimension of the cross-

section, length, species and condition of the pieces) that can be obtained from the existing timber buildings, they will be considered as either “sources” or “drainers” of timber. The sources will be those buildings from which reusable timber can be obtained, and drainers will be those in which timber is needed in order to be rehabilitated.

Again, demolition practices are of vital importance because with more curated systems (e.g. manual demolition), more material may be recovered for potential reuse. With better demolition practices, all buildings are potential sources for recovered wood, excepting the ones protected by cultural heritage laws.

For the present study, a vernacular dwelling typology has been chosen; the Madrilenian “corrala”. It has been selected in order to analyse the potential of an existent building to be source of recoverable timber. The state of the timber of demolished buildings is interesting to be defined to determine its potential for cascading (Sakaguchi et al., 2016) and to quantify the amount of timber in the built heritage of Spain.

Pre-modern Madrid. The “corrala”

The “corrala” belongs to the corridor typology. It is a common type of building in Madrid’s centre because it was an abundant typology and many of those buildings have arrived at our days mainly untouched. In Madrid’s Centro district, there are 3,221 dwelling buildings built prior to 1900 (EMVS – Empresa Municipal de Vivienda y Suelo), 286 of which are “corralas” (Santa Cruz Astorqui, 2012). They represent the clearest example of vernacular residential architecture in the city.

This typology has been in use since the 16th century until the first decades of the 20th century, and in the meantime has not substantially evolved. Originally, it was a simple house and when the city began to grow and the need of dwelling was a pressing matter, these houses began to suffer transformations to lodge all the people coming to the city. They began to grow in height and depth, inhabiting the spaces that were previously destined for the courtyards, and ended by tilting the urban tissue (Fig. 02). Most of them have arrived to our days as 4-storey buildings. The expansive use of the typology took place between the 17th and 19th centuries.

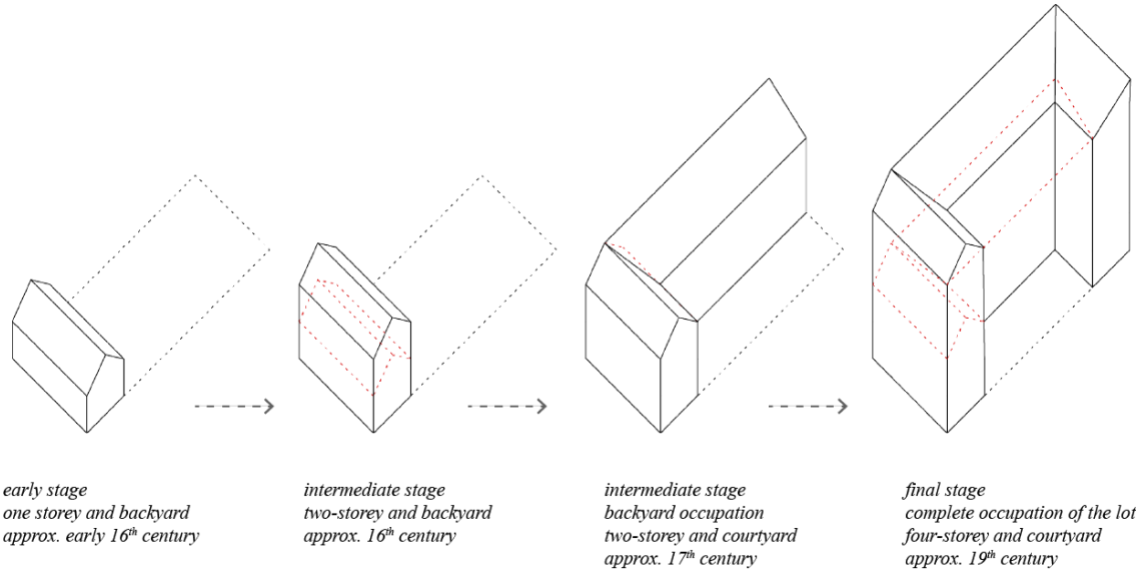
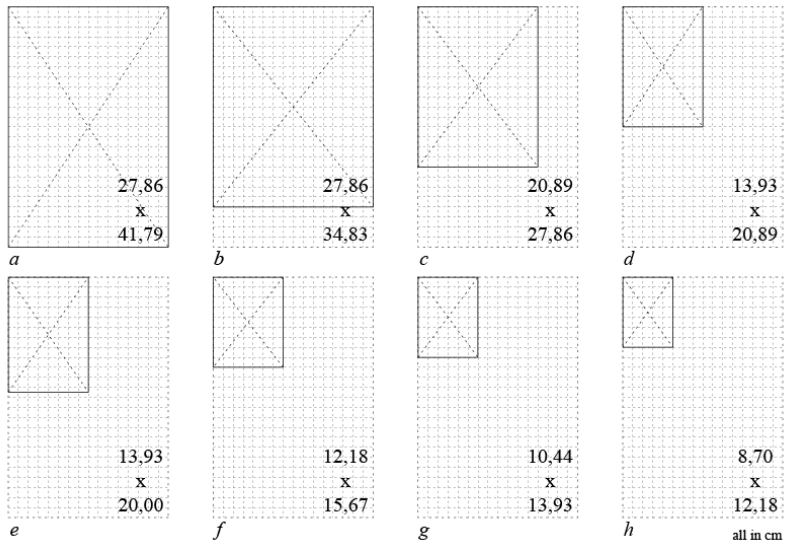


Fig. 02. Development of a "corrala" from the beginning to the complete occupation of the urban lot.

The constructive system, heavy timber frame with timber-laced walls, remained the same during all the years that the typology was in use. All the supporting structure is timber made with pieces of different cross-sections depending on the part of the building that they are placed. The cross-sections were defined by the urbanistic laws of the moment, "Ordenanzas de Madrid" by Ardemans (1719), and were anthropomorphic measurements (e.g. elbows, hands, feet, fingers) (Fig. 03).



a. "Elbow beam" of undetermined length
b. "Foot-and-quarter beam" of undetermined length
c. "Foot beam" of undetermined length
d. "Hand beam" of lengths varying from 6,50 to 3,34 m.
e. "Eleven-and-a-half-finger joist" of lengths varying from 5,00 to 2,78 m.
f. "Nine-finger joist" of length of 4,45 m
g. "Half-a-foot joist" of undetermined length
h. "Seven-finger joist" of lengths varying from

Fig. 03. Cross-sections established by Teodoro de Ardemans, 1719.

As a vernacular typology being built in the urban tissue, the building adapted itself to the space available, not following any particular urban guidelines. The typical "corrala" has generally one facade front and is developed in depth. It is built between party walls and has the courtyard as common feature, although it can vary in extension and position within the lot. The surface considered for the archetypical "corrala" illustrated in Fig. 04, is of 260 sqm. per storey, and four-storey height.

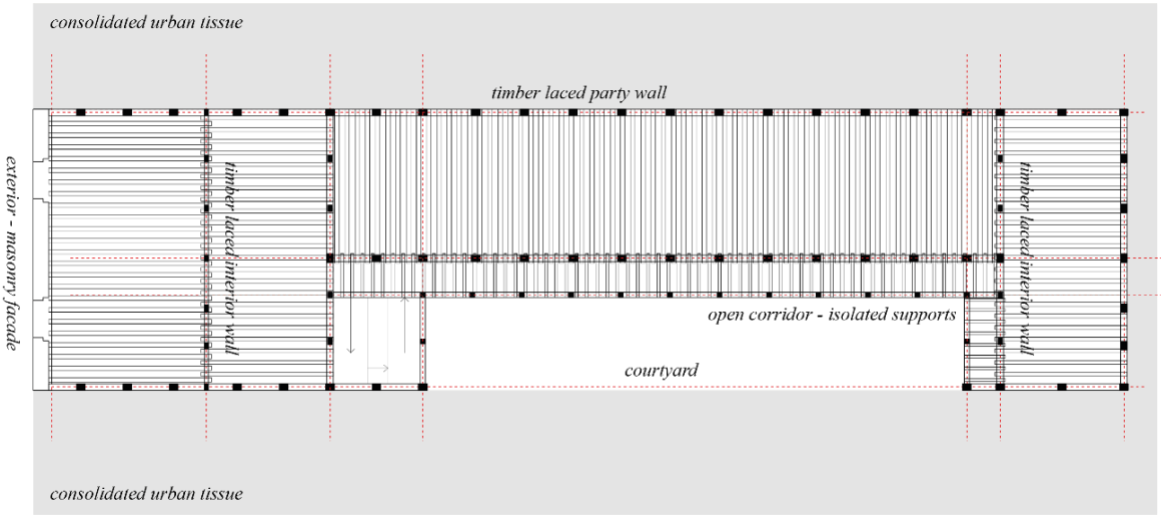


Fig. 04. Plan of an archetypical "corrala".

Until the 19th century, the totality of the supporting structure of the dwelling buildings was timber made. After the 19th century, facades begun to be masonry-made instead of timber laced and the corridor supports could be made of cast iron.

The vertical structure, with exceptions in the facade (those built after the 18th century), is composed by timber-laced walls (Aroca Hemández-Ros & González-Redondo, 2000). Timber laced structures are mentioned in texts from the 12th century (Langenbach, 2009), and its use is spread around the globe. The laced wall is composed by vertical and horizontal timber elements that support the upper floors (Fig. 05).

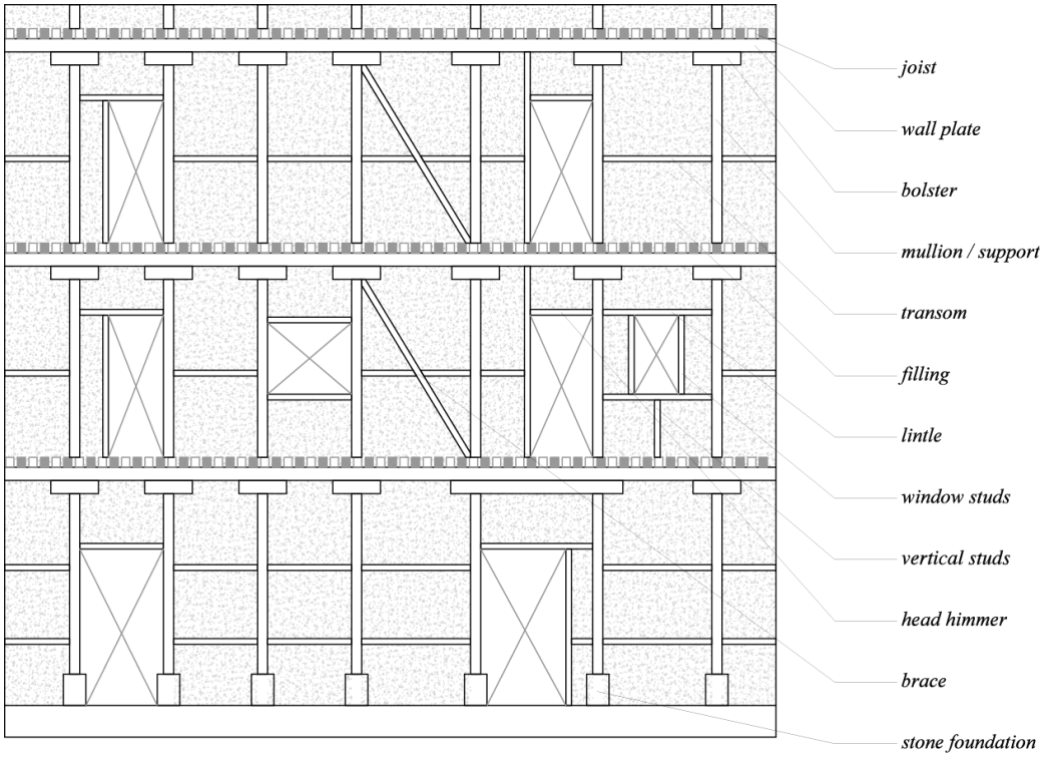


Fig. 05. Composition of a laced wall in a “corrala”.

The filling between the supports could be either masonry, adobe or wattle-and-daub. For the “corralas” built after the fire of the Main Square in Madrid in 1790, masonry filling began to be the most used because it avoided the spread of the potential fires (Villanueva, 1790).

In the “corrala” the horizontal structure, composed by beams and joists, is also timber-made. Being the constructive system the heavy timber frame, the joints between pieces are usually mortise and tenon, and no steel is present.

The roofing structure is usually composed by ridgepole trusses with a simple design. Due to the lack of high loadings and the cheap construction, they usually lack the bottom chord (Fig. 06).

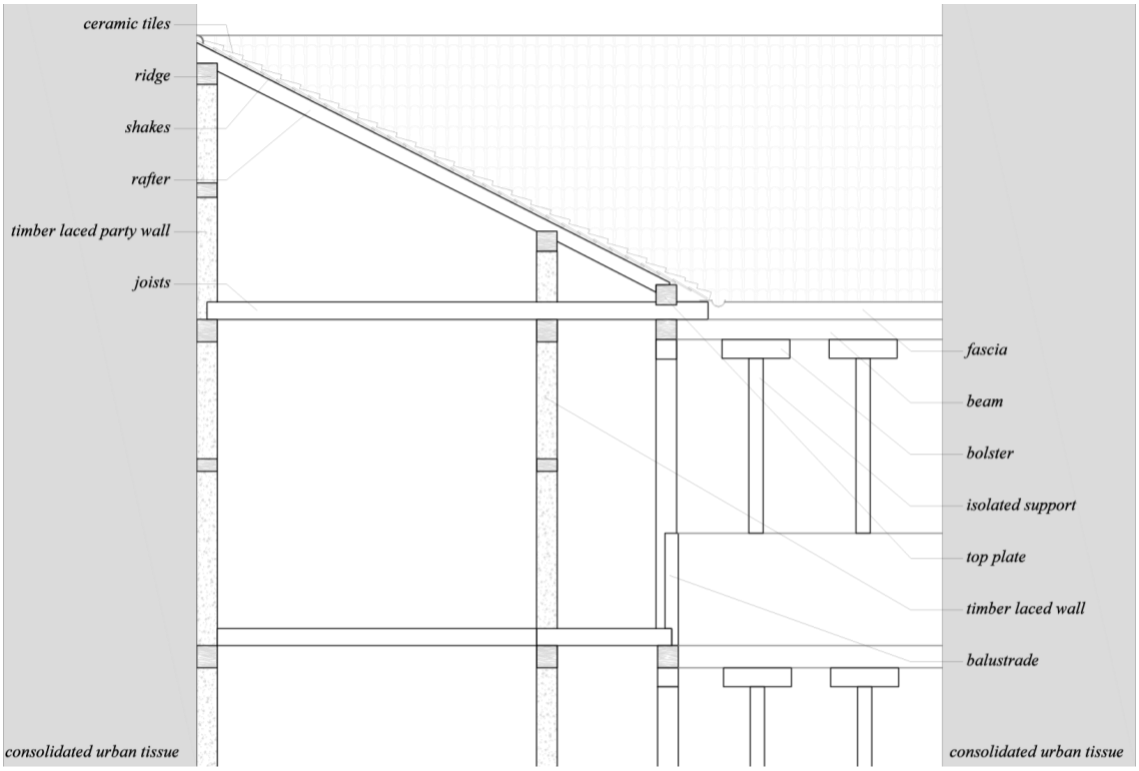


Fig. 06. Transverse section.

The species used for this type of building are mainly Scots Pine (*Pinus Sylvesris* L.*)* (Santa Cruz Astorqui, 2012) and European Black Pine (*Pinus nigra* A.) because they are the most common and accessible species of timber due to the proximity of the forests to the city.

The interest of the present work is to analyse the volumes of timber that could be recovered from the pre-existing buildings. The data obtained from this analysis would help to determine the cascading potential that these buildings, and in particular the “corrala”, have for the timber in their structures.

In order to achieve this, and with the description and characterisation of the archetypical “corrala”, the general volume calculations have been made dividing the structure in: vertical structure, horizontal structure, roofing and shakes (Table 01).

Table 01. Volumes and sections of the timber structures present in the "corrala"

Location in the building	*Volume of timber in m^3*	*Average section of the pieces in cm*
Vertical structure	*38.00*	*20.89x27.86*
Horizontal structure	*102.00*	*13.93x20.00*
Roofing	*15.40*	*13.93x20.89*
Shakes (roof + flooring)	*17.80*	*Thickness = 2.00*
Total (without shakes)	*155.40*	-

The laced walls (mullions, wall plates) and isolated supports were considered in the calculations of the vertical structure. In the horizontal structure, joists and bolsters. In the roofing, the trusses. The shakes were not considered in the general figure due to the fact that they are not structural pieces and the possibilities to reuse them are lower than with the structural pieces because of its use and location in the building.

Previous studies consider that the amount of recovered wood from buildings that could be reused as bearing structures is a 26%. If the timber could be transformed into other pieces, the reusable amount would be a 45% (Höglmeier et al., 2013). If the results obtained from the "corrala" are merged with this data, from the raw 155.40 m^3, 40.40 m^3 would be reusable as supporting structures and 69.90 m^3, would be the total of timber reusable to be transformed into other products.

As it has been described, there is timber in all the parts of the structure. The geometry of the pieces, their lengths, sections and timber quality, makes them an interesting source for recovered timber.

Conclusions: the potentials for cascading

Timber is present in all the elements of the structure of the "corrala" with different sections and lengths. The reusability of the timber is very high because the joinery between the pieces is mainly steel-free; the pieces are usually joint by tight ropes and mortise and tenon. The fact that almost all the elements of the structure can be reused allows the categorization of these buildings as "sources" of recoverable timber.

The potential of timber to be transformed and reused into other structures is immense. Those pieces could be either used to rehabilitate similar buildings protected by heritage laws that need the same kind of timber or transformed into new timber products that would also have great performance although they were made with recovered timber.

Cascading should be put into practice with the timber recovered from constructions by transforming high quality timber into smaller pieces such as joists. After its service life it could be transformed into boards, then into chips, and so on until it is no longer reusable.

These results should encourage on the one hand, a revision and completion of the current regulation of reclaimed timber to establish the parameters in which timber is reclaimed and further uses of it. On the other hand, the deconstruction of buildings instead of the demolition in order to enhance the possibilities for timber to be reused once the life of the building has come to an end.

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Biography

De Arana-Fernández, Marina

Expertise: Architecture, forestry, construction, cultural heritage

Biography - Marina de Arana-Fernández

2010 - 2016. Degree in Architecture by Universidad Politécnica de Madrid

2016 - 2017. Master in Architecture by Universidad Politécnica de Madrid

2017 - 2018. Architect in Geneva, Switzerland

2018 - 2019. Master in Rehabilitation of Cultural Heritage by Università degli Studi RomaTre

2019. Stage as an Architect in Parco Archeologico di Pompei, Italy

2019 - present. PhD in Wood and Cork Technology Research Group by Universidad Politécnica de Madrid

2020 - present. Researcher Associate in Timber Construction Research Group of the Universidad Politécnica de Madrid, Spain. Topic: Reuse and recycle of timber from demolition in structural products and design for the deconstruction in the future (InFutUReWood European project).

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