# What potential does structural wood hold for reuse in urban housing in Liège? A study of timber frames from the *Ancien Régime* (14th to 18th centuries)

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**Abstract.** This study examined the reuse potential of historic timber frames in the city of Liège (Belgium), with the long-term ambition of developing a comprehensive regulatory framework to ensure the safe integration of these materials in new buildings. The methodology combined theoretical and practical parts. Concerning theorical part, a literature review on old timber frame structures, building practices in Liège and challenges of reusing materials was conducted with the objective to develop an identity card, a document compiling essential technical information of specific materials and offering guaranty to professionals' actors of their quality and suitability for use. The practical part, based on a technical inventory, focused on two case studies with the objective to collect and compile key technical data necessary for establishing a comprehensive identity card specific to old wooden components. A classification methodology was also proposed to determine the mechanical strength constraints of the studied elements. This bottom-up approach therefore enables the development of a standardized identity card format and the creation of statement sheets applicable to various old timber structures. The case studies reveal similarities with the technical inventory while highlighting local variations. The analysis shows that old timber frequently exhibits defects (knots, cracks, and insect damage), affecting its mechanical properties and classification for reuse. The classification methodology allowed certain rafters to be categorized as potential for reuse, while other elements require a more specific assessment. In conclusion, this innovative study has identified obstacles related to regulations, quality perception of reclaimed wood, while proposing concrete solutions to facilitate its integration into the circular economy. By adopting a multidisciplinary approach, combining archaeological methods to collect in situ data and identify traditional craftsmanship with perspectives from architecture and engineering sciences, it becomes possible to develop new tools and rethink existing reuse practices to give a second life to materials that would otherwise be lost.

## 1. Introduction

### *1.1. Context*

The construction sector, like many others, still follows a linear "take-make-dispose" model, which leads to significant consumption of resources and production of waste(1). This model assumes the infinite availability of resources and the unlimited ability to dispose of waste through landfills or thermal recovery. However, it is increasingly proving unsustainable for both economic growth and the well-being of future generations(2,3).

In response, transitioning to a circular economy has become a major challenge for the construction sector(2). This model aims to extend the life and value of materials through maintenance, reuse, refurbishment, remanufacturing, recycling, and composting, integrating them into a virtuous loop of resource management(4). To achieve this transition, it is crucial that all society actors become actively involved, as each holds significant levers and means of action.

Circularity is now central to European policies(5), including the European Green Deal introduced in 2019 and reinforced in 2024(6,7). In this context, concepts such as Urban Metabolism which focuses on the dependence of cities on the external resources they consume, transform, store and reject(8), and Urban Mining (9) which sees cities as material deposits, are shifting our perception of waste as a potential resource for the construction of new buildings.

For cities like Liège, where achieving carbon neutrality by 2050 will require large-scale renovation, transformation, and partial deconstruction of the existing building stock, the principles of Urban Mining are particularly relevant. Wooden components, especially those from pre-First World War buildings, which represent around 30% of Liège's stock (11), offer valuable opportunities for recovery and reuse, given their diversity, quality, and historic significance, particularly in buildings dating back to the *Ancien Régime*. This local dynamic fits into the broader framework of the Walloon Region's long-term renovation strategy(10), adopted in response to European climate objectives. The plan aims to improve the energy efficiency of the building stock by 2050, inevitably leading to extensive renovation and the selective dismantling of old and traditional structures, offering further opportunities to integrate circular economy principles into practice.

*1.2. Reuse, a long-established practice*

Although reuse may appear to be a complex practice to integrate into architectural design and construction today, it was an established practice and a part of building traditions until the end of the Second World War(12).

In historic and traditional buildings(13), materials retained a high use value due to their utility, and demolitions were often deconstructions enabling component reuse. Though driven more by practical and economic reasons(14) than environmental concerns(12), reuse was widespread, both through private salvaging and through active markets encouraged by urban policies. From the late 18th century, public works in European cities fostered large-scale reuse, illustrated by the municipal resale of materials from Brussels' Coudenberg Palace and city walls, or during Haussmann's renovations in Paris. Reuse also carried symbolic meaning, notably in Rome during the Middle Ages, the Renaissance and even up to the end of the 19th century, where religious buildings incorporated antique elements(15).

However, from the mid-20th century onwards in industrialised countries, reuse declined due to changing mentalities, globalization, and the rise of non-reusable composite materials(1). Interest only resurfaced in the 21st century, as economic and environmental concerns grew, sparking a cultural shift toward reuse across Belgium, France, the Netherlands, and Great Britain from around 2005–2010(1). Today, replacing reuse into building professional practices meets many technical, economic, cultural and legal challenges(12,16). This lack of guarantees, such as technical documentation and CE approval, which now pose an obstacle to the reintegration of reused materials. Architects and contractors are often hesitant to use these materials, fearing that they will be held liable in the event of a problem(17,18).

### *1.3. Focus and aim of the study*

This study focuses on the reuse potential of old wooden frames from Liège, valued for their high technical, historical, and heritage quality. Their non-composite nature and primarily mechanical assemblies make them particularly suitable for deconstruction and reuse(1).

Liège's rich architectural heritage, particularly its half-timbered structures dating from the 15th to 18th centuries, with the oldest surviving timber frames outside churches dating back to the 14th century, sets it apart from other Belgian regions where this practice declined earlier(19). However, technical uncertainties, particularly regarding the structural performance of reclaimed wood, and regulatory constraints still hinder their reuse.

While it is often carried out informally, the establishment of a regulatory framework remains necessary. The Construction Products Regulation (CPR) requires a declaration of performance for all construction products, including reused materials, before they can be placed on the market(20). To meet this requirement, the identity card developed in this study proposes to define a set of performance criteria that are comparable, although not equivalent, to those expected for new materials. These criteria are established primarily through visual assessments, supplemented, where necessary, by targeted tests. This approach seeks to ensure both safe reuse and regulatory compliance, while offering a structured way to assess the reuse potential and future applications of historic timber elements.

### *1.4. Definition and objectives of the identity card*

The identity card of a building material compiles key information necessary for its reuse, maintenance, remanufacturing, or recycling. It details the material's composition, location in the building(21), and any modifications over its lifecycle, providing essential data for all stakeholders. The card also includes technical specifications and outlines relevant maintenance, disassembly, and repair procedures, whether planned or previously applied(22).

## 2. Methodology

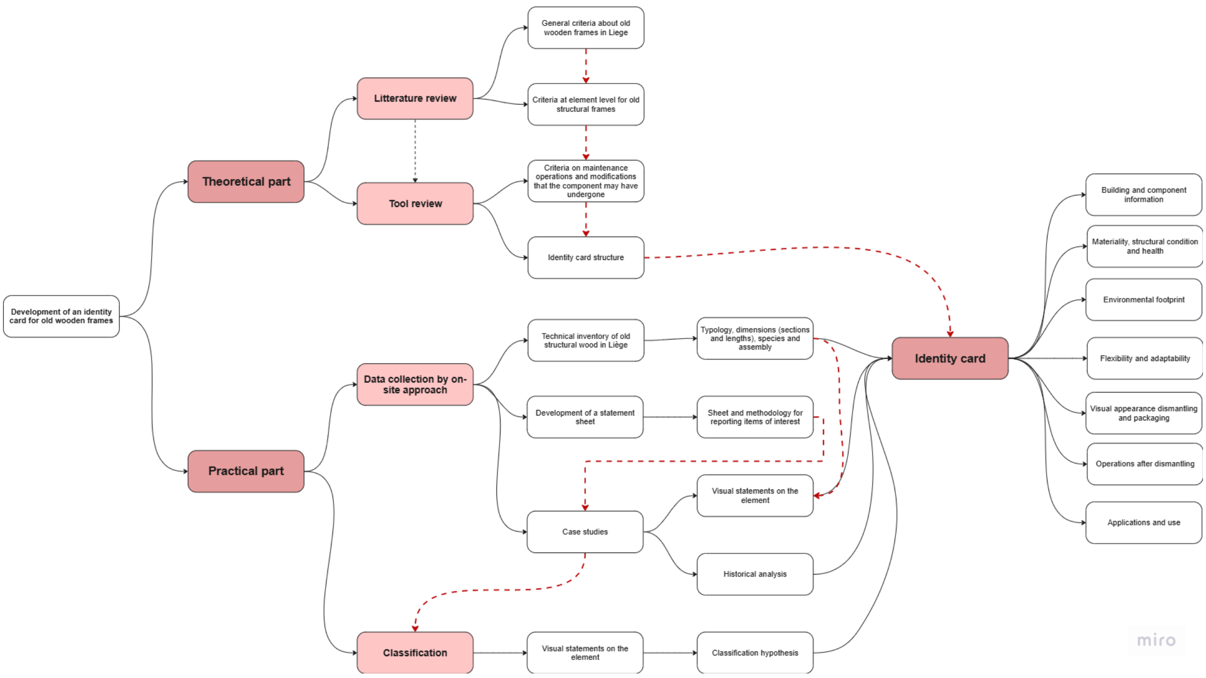



**Figure 1**. Flowchart of the methodological approach, created with Miro software. Source: O. Noël

The study's methodology encompassed both theoretical and practical parts, each contributing valuable quantitative and qualitative data. This data facilitated the development and structuring of the identity card, as well as the creation of the reuse framework (***Figure 1***).

*2.1. Theoretical part*

*(1) Literature review*

The objective of this review is to gather information on old wooden frames, including technical and historical knowledge of building practices in the city of Liège, with a particular focus on timbers used during the period of *Ancien Régime*, extending from the end of the Middle Ages until the revolution of 1789. It aims to identify technical and constructive key data such as component types, wood species, dimensions and cross-sections, positioning and stress distribution within structures, as well as assembly techniques (***Table 1*** and ***Table 2***).

Furthermore, a thorough review of scientific literature as well as regulatory and normative documentation was essential to deepen the understanding of circularity and reuse, along with the challenges they present, particularly those related to suitability for use and the uncertainty surrounding the technical properties of repurposed wooden elements. Those specific criteria and data collected contributed to structure a first draft of the identity card.

This first step summarizes the technical data available in the literature on old timber frames and their potential for reuse, while highlighting gaps in existing scientific knowledge.

**Table 1.** Criteria reported in the literature, general criteria

| General criteria | Specific criteria |
|---|---|
| House typologies | Houses on eaves and gabled houses |
| Roof typologies | Ridge roof and roof with eaves over eaves |
| Characteristics from the 15th to the 16th century | Saint-André cross, corbelling and carved brackets |
| Framework typologies | Truss rafters, truss and purlins, unbraced purlin and joining framework |

**Table 2.** Criteria reported in the literature, element criteria

| Element criteria | Specific criteria |
|---|---|
| Wood species | Oak and softwood |
| Wood cutting | Strand wood and sawn timber |
| Wood growth | Fast and slow |
| Tool marks (wood working) | Saw, axe and scissors |
| Shape of element | Straight and curved |
| Presence of knots | / |
| Marking | Assemblies |
| Sculpted wood | / |
| Wood finishing and treatment | / |
| Presence of metallic element | / |
| Assemblies | Half-wood, mortise and tenon, dowelled and nailed or screwed |
| Presence of humidity | / |
| Chemical substances | Heavy metals, asbestos and mineral oils |
| Biological substances | Fungi and wood-eating insects |

*"/": yes/no*

*(2) Tool review*

The essential information for the future reuse of old timber frames and components have been gathered based on two existing tools. The first one is the material passport developed by the Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) in Austria and Germany. This passport is comprehensive and includes essential information on resource usage, climate change impact, and the circularity of each component(23). The second is the materials sheets available on the Opalis platform, developed by Rotor as part of the Interreg - FCRBE project. The identity card created in this work offers a different contribution compared to the other two. It highlights not only the element's technical and mechanical suitability for reuse, but above all the maintenance operations and modifications it has undergone (***Table 3***).

**Table 3.** Criteria reported in the tool review, maintenance and operation criteria

| Maintenance and operations criteria | Specific criteria |
|---|---|
| Dismantling risks | Impaired mechanical performance, impaired visual appearance, health risk and safety risk |
| Ease of dismantling | Weight, volume, fragility and handling |
| Handling equipment required | / |
| Easily accessible site | / |
| Sufficient space | / |
| Dismantling time | // |
| Warehousing/storage | // |
| Environmental footprint | Manufacture, material origin, energy required for transport, level of processing, life of the material, reuse potential and recycling potential |
| Operations after dismantling | Removal of components, cleaning, drying, classification, preservative treatment, resizing, planning and repair |

*"/»: yes/no; "//»: data to be completed*

*2.2. Practical part*

*i) Development of the identity card*

Based on the results of the theorical part, a first structure of the material identity card was developed. It was then refined and completed using data collected from on-site studies.

*(1) Data collection by on-site approach*

This next step aims to collect data, based on an on-site approach and the analysis of two study cases. Two documents have been used for the analysis: a statement sheet and the first draft of the identity card.

The study relied firstly on the development of the statement sheet, which is divided into two parts. The first part presents the overall analysis, including historical elements, graphic surveys and species of the structure. The second part aims to determine the reuse potential of the elements studied. A series of data were visually collected following the method developed by Poncelet and Vrijders, from the Belgian research centre Buildwise(16). The objective was to refine and validate the first draft of the identity card and then complete it with the collected data. Due to the lack of iconographic documentation, digital technologies like photogrammetry were used to support the analysis.

The data collection was initially carried out through a technical inventory which was compiled by gathering available data from scientific literature, such as archaeological excavation reports, dendrochronological reports, published studies, university statements and research carried out by specialists in this field, such as Houbrechts(19). The work was used to gain access to timber frame and half-timbered structures statements to obtain information such as typology, the dimensions of the parts or elements (sections and lengths), the type of species and the assembly elements. The next step was to compare these data to identify recurring or non-recurring elements, in particular dimensions, assemblies, health, structural and visual condition. This comparison and observation will lay the foundations for the following stages(16). Thanks to this inventory, data was collected and could be compared with the data stated in the case studies.

The first case study is a house in Liège, the Donceel hotel, whose oldest wood frames dates from the early 16th century. It has a remarkable wooden roof structure, but a complex one that has been successively modified from the 16th to the 20th century (***Figure 2***).

The second case study is a group of two buildings in Liège, on Place Émile Dupont, the remains of a cloistered building belonging to the Benedictine abbey of Saint-Jacques. Although the façades were rebuilt in the 19th and 20th centuries, these buildings still retain an ancient structure dating back to the 14th century, which has been modified over the centuries (***Figure 2***). These case studies reflect the building typologies and construction methods of the *Ancien Régime* and are particularly well preserved.

**Figure 2.** (a) Framework of the Donceel hotel. (b) Framework of Place Emile Dupont 9-10. Source: O. Noël

In these two case studies, on the study focuses on the validation of technical and constructive data gathered in the theoretical section and the completion of the initial draft of the identity card, making it more comprehensive and relevant for other wood structures, such as half-timber houses, and for a broader geographical context in the Mosan region.

The condition of old timber structures was assessed primarily through visual inspection, based on Buildwise's method(16). Case study analysis supplemented the technical and constructive criteria from the literature to strengthen the identity card.

*(2) Classification rules for old structural timber*

This step aims to assess the structural and technical properties of old wooden frame and to facilitate its reuse in new construction projects. It has set up and tested a visual and on-site classification method, which is essential to ensure the suitability of materials for reuse, particularly for specific requirements such as mechanical strength.

To carry out this analysis, precise data on the structural and technical properties of structural timber needed to be collected. This process included documenting the size and location of singularities, cutting characteristics and deterioration of the elements, in accordance with NBN EN 1310(24). These singularities are then compared with the criteria of NBN EN 975–1(25), which provides a visual classification methodology for assessing wood quality.

Mechanical performance was assessed by matching visual classes to mechanical strength classes in accordance with standard EN 338(26), which defines the permissible technical stresses of oak according to its classification. Structural elements were classified based on the obtained results, allowing for the determination of their suitability for various structural applications.

## 3. Results and discussion

The study emphasized various criteria originally identified in the literature, enabling the compilation of technical, typological, constructive, pathological, and logistical factors. However, the literature on roof structure and frameworks provides limited technical details regarding wood sections and dimensions (*Erreur ! Source du renvoi introuvable.*). Both theoretical and practical parts of the study analysis have thus helped to bridge this gap by providing precise and complementary data. However, it should be noted that, based on these two case studies, it is not yet possible to assess whether there are any recurring patterns regarding timber characteristics. In order to gather sufficient and representative data, the corpus of case studies would need to be significantly expanded. This research therefore represents a first step, primarily aimed at testing and validating the proposed methodology.

During the practical phase of the study, several factors were identified, although the process was sometimes hampered by the limited visibility and accessibility of certain elements within the case studies. Firstly, the data collected through the technical inventory and the case studies revealed significant similarities in the dimensions of the structural elements, while also highlighting some variations. These discrepancies could suggest local adaptations or evolutions in construction techniques over time. Secondly, observations from the case studies confirmed the presence of typical characteristics, such as knots (***Figure 3a***), drying cracks (***Figure 3b***), and damage caused by micro-organisms, particularly wood-eating insects (***Figure 3c***). These factors can directly impact the mechanical properties of the wood and influence its classification (***Table 4***). It is worth noting that oak, when well-preserved, is generally resistant to insect attacks; although minor superficial galleries may occasionally be found in the sapwood, the softest part of the wood, these do not compromise the overall structural integrity. Lastly, some uncertainties remain regarding certain factors, especially the precise identification of wood species. In these cases, assumptions have been made based on the typological characteristics and estimated dating of the timber, although definitive confirmation was not always possible.

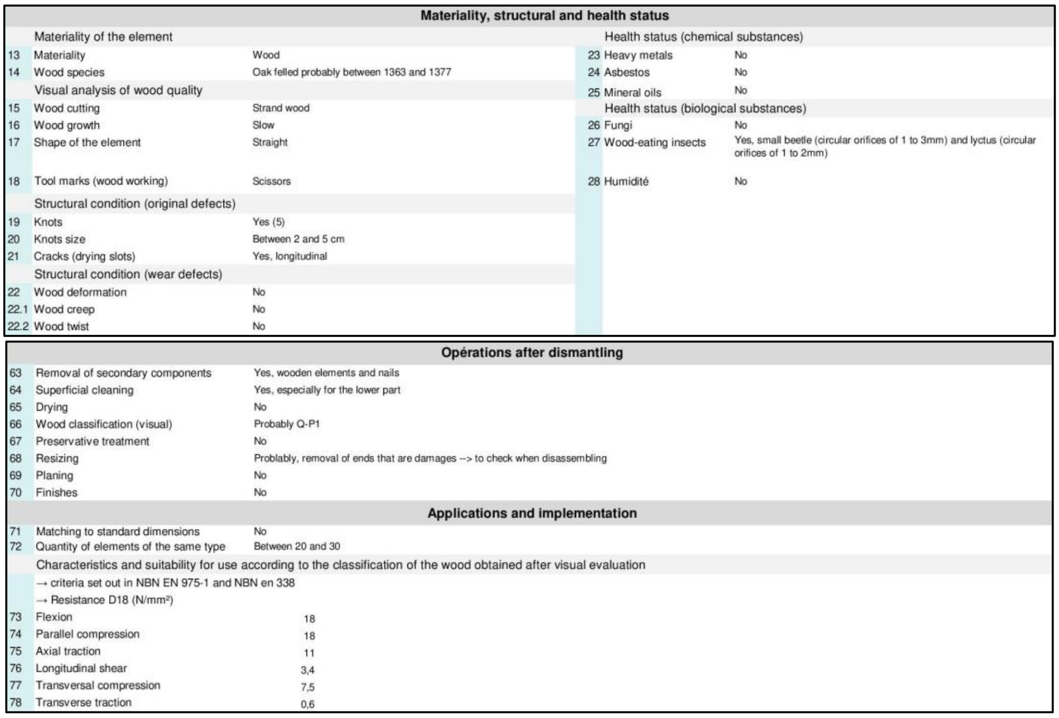
**Figure 3.** (a) Knots on a rafter from Place Emile Dupont. (b) Drying crack on a tie beam from Place Emile Dupont. (c) Wood-eating insect holes from Donceel hotel. Source: O. Noël

Thanks to photogrammetry, applied in the case study of Place Emile Dupont, it was possible to accurately redraw and measure the singularities of a structural element. This allowed the classification method to be tested on a rafter that exhibited numerous defects and specific features, including multiple knots, cracks, and traces of xylophagous insect activity. The identification and assessment of these characteristics were carried out in accordance with standard NBN EN 1310. Based on these observations and by referring to standard NBN EN 975-1, the rafter was classified as Q-P2. According to the correspondence table between visual grading and mechanical strength classes defined by standard EN 338, timber graded Q-P2 falls into mechanical strength class D18, meaning it retains sufficient mechanical properties to be reused in its original structural function. The assumption is that other rafters could be classified in the same way. However, for the rafters in the Donceel hotel case study, a different classification may be necessary due to their very specific condition, such as reused timber used with deformation and twisting and the presence of many knots. Purlins, stirrups and beams, which are subject to higher loads, must achieve at least strength class D 24.

**Table 4.** Criteria for analysis of structural timber components in the two case studies

| Criteria | Donceel hotel | Place Emile Dupont |
|---|---|---|
| Nature, treatment and dimensions | 16th century, oak, high quality wood, axe and saw marks and satisfactory strength | 14th century, timber frame with rafters forming trusses, oak, high quality wood, chiselling mark, satisfactory strength |
| Health condition | No chemical substances, no fungi, wood-boring insect holes (furniture beetles and lyctus) and no recent damp | No chemical substances, no fungi, wood-boring insect holes (furniture beetles and lyctus) and no recent damp |
| Structural condition | Knots, longitudinal cracks at knots and deformations: creep | Knots, longitudinal cracks at knots and deformations: creep |
| Assemblies and connections | Mortise and tenon and half-timber | Mortise and tenon, half dovetail and whistle end with wooden pegs |
| Comparison with technical inventory | Rafters: similar dimensions but smaller values; post: value from the lower range of the inventory; purlin: similar in width but less high and headers: narrower | Rafters: similar but much wider; centres: similar but wider and armrests: similar but wider |
| Structural classification | D18 and D24 | D18 and D24 |

The development of the identity card was made possible thanks to the methodological rigor applied, combined with the statement sheet designed for this study. However, its creation faced challenges, as most reference materials focused on modern construction products, which lack, and do not require, the historical, origin, and manufacturing details essential for older materials.



| Materiality, structural and health status | | | | | |
|---|---|---|---|---|---|
| | Materiality of the element | | | Health status (chemical substances) | |
| 13 | Materiality | Wood | 23 | Heavy metals | No |
| 14 | Wood species | Oak felled probably between 1363 and 1377 | 24 | Asbestos | No |
| | Visual analysis of wood quality | | 25 | Mineral oils | No |
| 15 | Wood cutting | Strand wood | | Health status (biological substances) | |
| 16 | Wood growth | Slow | 26 | Fungi | No |
| 17 | Shape of the element | Straight | 27 | Wood-eating insects | Yes, small beetle (circular orifices of 1 to 3mm) and lyctus (circular orifices of 1 to 2mm) |
| 18 | Tool marks (wood working) | Scissors | 28 | Humidité | No |
| | Structural condition (original defects) | | | | |
| 19 | Knots | Yes (5) | | | |
| 20 | Knots size | Between 2 and 5 cm | | | |
| 21 | Cracks (drying slots) | Yes, longitudinal | | | |
| | Structural condition (wear defects) | | | | |
| 22 | Wood deformation | No | | | |
| 22.1 | Wood creep | No | | | |
| 22.2 | Wood twist | No | | | |

| Opérations after dismantling | | |
|---|---|---|
| 63 | Removal of secondary components | Yes, wooden elements and nails |
| 64 | Superficial cleaning | Yes, especially for the lower part |
| 65 | Drying | No |
| 66 | Wood classification (visual) | Probably Q-P1 |
| 67 | Preservative treatment | No |
| 68 | Resizing | Problably, removal of ends that are damages --> to check when disassembling |
| 69 | Planing | No |
| 70 | Finishes | No |
| **Applications and implementation** | | |
| 71 | Matching to standard dimensions | No |
| 72 | Quantity of elements of the same type | Between 20 and 30 |
| | Characteristics and suitability for use according to the classification of the wood obtained after visual evaluation | |
| | → criteria set out in NBN EN 975-1 and NBN en 338 | |
| | → Resistance D18 ($N/mm^2$) | |
| 73 | Flexion | 18 |
| 74 | Parallel compression | 18 |
| 75 | Axial traction | 11 |
| 76 | Longitudinal shear | 3,4 |
| 77 | Transversal compression | 7,5 |
| 78 | Transverse traction | 0,6 |

**Figure 4.** (a) Detail from the identity card: technical, structural, and sanitary characteristics of a rafter, Place Emile Dupont. (b) Detail on material conformity and performance. Source: O. Noël

The structure of the identity card was therefore adapted to reflect these specific characteristics, which are crucial for reuse. Following a progressive and systematic approach, the identity card moves from general building information to detailed technical data, including material composition, structural and sanitary condition, and visual characteristics (***Figure 4a***). It also incorporates key evaluation criteria such as environmental footprint, flexibility, adaptability, post-dismantling considerations, and mechanical properties, ensuring a complete and reliable evaluation (***Figure 4b***).

## 4. Conclusion and outlook

### *4.1. Conclusion*

This study has highlighted the potential of old structural timber found in the urban dwellings of Liège, particularly within roof frameworks dating from the *Ancien Régime*. Through a building archaeology approach, it was possible to better understand past construction practices and identify these heritage resources as valuable opportunities for reuse within a circular economy. Nevertheless, integrating reclaimed timber into modern construction raises challenges, particularly regarding compliance with current standards, quality perception, and economic viability. To address these, the study proposed a methodology supported by clear documentation tools, such as an identity card, to ensure traceability and facilitate reuse.

Today, the reuse of timber is gaining significant momentum in Brussels and Wallonia, with specialized actors such as Batiterre and Woodpark actively structuring the market. Alongside initiatives led by organizations like Rotor, Circonflexe, and Retrival, the growing ecosystem around reuse highlights both the relevance of this research and the need to deepen knowledge on reclaimed timber. This study underlines not only the existence of a valuable material stock but also the emergence of a real market for reused wood, supporting both heritage conservation and sustainable construction practices.

### *4.2. Outlook*

The preliminary studies conducted on these two case studies will be further developed within the framework of a doctoral thesis. The aim is to expand the research to include 19th-century structural timber in Liège, a material more likely to have undergone transformations over time, yet still retaining significant quality and value. Enlarging the corpus will help gather broader data and refine the classification methodology. One key perspective is to develop an on-site assessment tool capable of visually evaluating the technical performance of timber elements and identifying when additional tests are necessary to confirm their suitability for specific reuse applications. Integrating an estimation of the available timber volumes in Liège would also be a valuable step toward better structuring the reuse sector. Moreover, the identity card system could be extended to other types of materials, facilitating broader reuse integration in the construction industry. Such documentation would help address concerns about the compliance of reclaimed materials by offering clear and transparent traceability. Finally, beyond technical evaluation, the reuse of materials also highlights their cultural and heritage value, ensuring the preservation and transmission of historical craftsmanship while contributing to modern sustainability goals.

## 5. Acknowledgements

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