Structural adaptations: The role of existing structures in adaptive reuse projects

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Case study: Adaptive reuse of abandoned industrial buildings in Oklahoma

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ABSTRACT: The present study explores intelligent urbanism, industrial preservation, retrofit technology, and adaptive reuse of the Sand Springs power plant in Tulsa, Oklahoma, USA. The power plant's existing building system was reviewed, analyzed, and evaluated to rehabilitate structures into a new proposed occupancy type that integrates within the urban fabric. The ultimate goal of this study is to develop a restoration plan to transform the abandoned Sand Springs power plant into dynamic commercial and co-working spaces. The proposed methodology focuses on creating a functional, vibrant, and safe usable space while preserving the original structure and building envelope.

1 INTRODUCTION

1.1 *Historical significance*

This research presents a case study on Oklahoma, a state located in the central region of the United States. Oklahoma has remarkable historic buildings that have remained vacant for many years. Unfortunately, some of these architectural buildings face demolition or continued vacancy, posing challenges to their surrounding neighborhoods. The present study investigates industrial preservation, retrofit technology, and adaptive reuse of the Sand Springs power plant in Tulsa, the second-most populous city in Oklahoma. The Sand Springs power plant, founded by Charles Page in 1911, is one of the historic industrial buildings and the first electric power source for the City of Sand Springs. Charles Page was a businessman and significant philanthropist in the early history of Tulsa, Oklahoma. He created jobs for many people, particularly for widows and orphans in need, drawing his own experience of losing his father at age eleven and being raised by his mother (Historic tour 8: Powerhouse 2002). The power plants led to an increase in the population of Sand Spring between 1910 and 1920 (CBRE 2019).

The power plant was the sole source of electricity for the industrial facilities in the city, as well as for residences and businesses in the area. It also provided power for the electric railway. In addition, the revenues from the power plant supported the Sand Springs Home and the Widows Colony (Iconions 2017). The building was expanded in 1919, 1925, and finally in 1935 (CBRE 2019). In 1923, the private sector began investing in the gas and electricity industries. The Public Service Company of Oklahoma purchased the plant in the 1960s and donated it to the city in 1995. In 1998, recognizing its historical significance in the establishment of Sand Springs, it was added to the National Historic Places (Smith 2019).

Based on the conducted field research, many community members do not want to see the historic building torn down; instead, they wish for it to be part of the town's growing revitalization. Some local businesspersons have expressed interest in developing a vibrant facility where people can gather for various purposes, such as a brewery, cultural mecca, Retail space, wedding venue, commercial space, etc. (Smith 2019).

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1.2 *Architectural significance*

The Sand Spring Powerhouse is a massive structure encompassing 2,950.5 square meters (31,759 square feet) on a 7527.2 square meters (1.86 acre) lot (Figs 1-2). The building is mainly red brick, with some sections featuring metal walls. Due to several additions, it has an irregular form, roughly 15.2 meters by 36.5 meters (50 feet by 120 feet). The building extends from west to east, ending with two three-story sections. The foundation is made of concrete or brick and the floors are concrete. There is a small basement on the south side. Over the years, some windows have been bricked up (Iconions 2017). The three-story section creates a dynamic volume with a gable roof on top. Excluding the load-bearing walls in the southwest part of the building, it has composite brick walls and steel columns with steel trusses that support the roof.

This case study aims to develop a toolkit for planning the adaptability of the power plant building, focusing on transforming abandoned and historic industrial structures in Oklahoma into dynamic residential, commercial, and co-working spaces. Furthermore, this study introduces an intervention methodology focused on transforming interior spaces while maintaining the integrity of the original structure and building envelope. Additionally, this research examines and assesses the current building system of the power plant to rehabilitate structures into a new proposed occupancy type that integrates within the urban landscape. The research intends to create harmonious spaces that foster sustainability and minimize ecological impact within the urban environment by integrating thoughtful design principles, renewable resources, and retrofitting techniques.

2 LITERATURE REVIEW

The construction industry has been one of the fastest-growing and evolving sectors in the United States (Business Wire 2020). Every Building is destined to age and outgrow its original functions. In a rapidly growing construction world, design is constantly being altered to meet new demands driven by technological and lifestyle changes. As a result, older facilities are often left in the wake of transition. While those sensitive to history may prefer to restore older structures to their former glory, the costs often make such plans unrealistic. An alternative concept is "adaptive reuse," a process of retrofitting old buildings for new uses, allowing structures to maintain their historical integrity while simultaneously meeting the modern needs of the occupants (Clark 2008). Instead of starting from afresh, adaptive reuse encourages innovative thinking to reflect on what currently exists and how it can be thoughtfully integrated into future expectations and ideas (Schmidt Associates 2018).

In today's economy, retrofitting an existing building compared to constructing a new one depends on its cultural significance, aesthetics, various project expenses, and other factors. It is considered one of the most sustainable approaches in the modern world. According to the United States Environmental Protection Agency (EPA), an energy-efficient new building takes about 65 years to save the energy lost in demolishing an existing building (Richard 2008). This is due to adding the carbon footprint throughout the building's life cycle of new construction.

Adaptive reuse of old buildings allows them to retain much of their character and aesthetics by incorporating these elements into the new framework (Smallwood 2012). In the United States, especially in the Northeast and the Midwest, loft housing is a prominent example. Former industrial areas, such as the meatpacking districts in New York City and Philadelphia, are now being transformed into residential neighborhoods through creative adaptive-reuse projects. Waterfronts that once harnessed the current of rivers and lakes to speed production are now significant selling points for homebuyers and renters (Clark 2008).

Following the current trend of sustainable development, this study has identified an ideal candidate for adaptive reuse: Sand Springs power plant, Tulsa Oklahoma. The following sections elaborate on the power plant's urban context, unique architectural language, restoration strategies, and how it contributes to the enhanced development of existing urban fabric.

3 RESEARCH METHODOLOGY

This research focuses on three significant aspects: first, the analysis of the urban context and its relationship with the facility; second, the review of the existing structural system of the power plant; and third, the architectural design proposal, including the retrofitting techniques, to support new uses of the structure. This research investigates topics related to intelligent urbanism, industrial preservation, retrofit technology, and adaptive reuse.

3.1 *Urban analysis: Contextual study of power plant*

This study was conducted on two scales: regional and site. The regional study applied Sand Spring's GIS (Graphics Information System) data files to examine and analyze demographic, social, economic, and infrastructural information. This information was then graphically represented using the ArcGIS software. The site and its immediate context were studied through direct observation and mapping techniques (Fig. 2).

Figure 1. Sand Springs power plant (Photo by authors) Figure 2. Site context, graphical representation, Google Earth.

A contextual study reveals major restaurants, cafes, bars, grocery stores, public parks, schools, and entertainment facilities in the surrounding area. The primary concentration of these facilities is on the north side of Highway 412 and gradually extends towards the south side of the highway. As shown in the map in Figure 3, the rapid urbanization west of the power plant adds potential for development to the site.

The zoning map (Figure 3) shows Sand Springs' intention to preserve the character of selected areas within the city. The entire south part of Highway 412 was an industrial zone. However, a small portion of commercial zones in the area suggests the city authorities' intention for future development. The site is currently classified as an industrial zone; however, it can be converted into a commercial zone to accommodate the new use of the power plant by submitting the necessary documents to the city authorities.

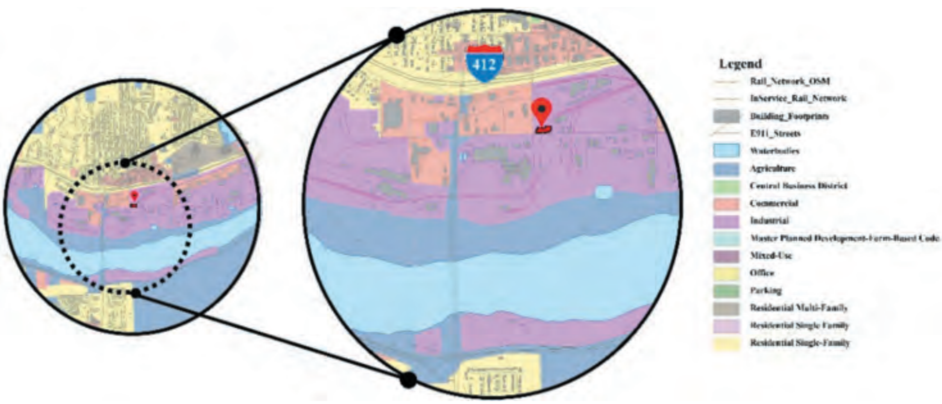

Figure 3. Zoning map, graphical representation, GIS - Sand Spring.

The site shown in Figure 4 has an urban walkability score of 18, a public transportation score of 5, and a bikeablility score of 32, all are on a scale of 1 to 100, with 1 being the lowest and 100 being the highest (Walkscore, n.d.). These scores suggest inadequate connectivity of the site with the surrounding context. However, the plant's proximity to new developments to the west and downtown Sand Springs to the north makes it appealing for a retail-based program, such as a hotel, restaurant, gym, or grocery store.

Figures 4 and 5 illustrate that the site suffers from poor public infrastructure with significant gaps in sidewalks, and very few funded trails, negatively affecting its walk and bike scores.

However, downtown to the north and new developments to the west are within walking distance. Therefore, improving the sidewalk conditions around the site and enhancing pedestrian connection to the north and west parts positively impact its revitalization.

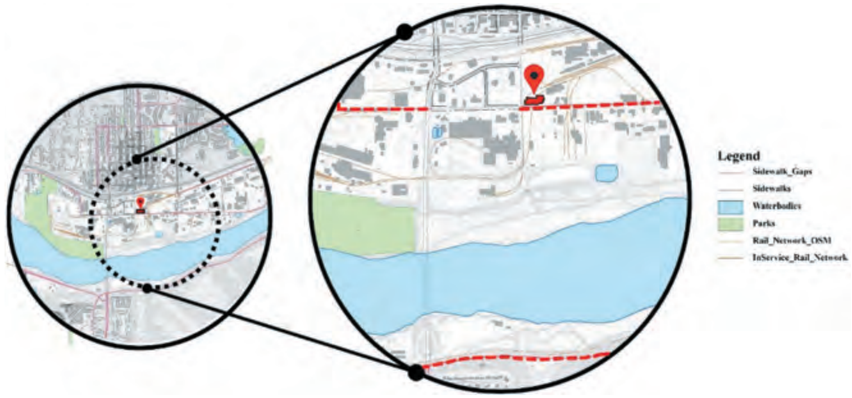

Figure 4. Public infrastructure-sidewalks, graphical representation, GIS - Sand Spring.

Figure 5. Trails, graphical representation, GIS - Sand Spring.

Figures 6 and 7 illustrate the available utility connections in the area. The sewer line map shows that the line running directly to the site is slightly smaller than the desirable size. Analysis of the sewer infrastructure network and size suggests that high-intensity uses, such as hotels or restaurants might overwhelm the system. However, the water line (Figure 7) that runs through the site is capable of supporting such uses.

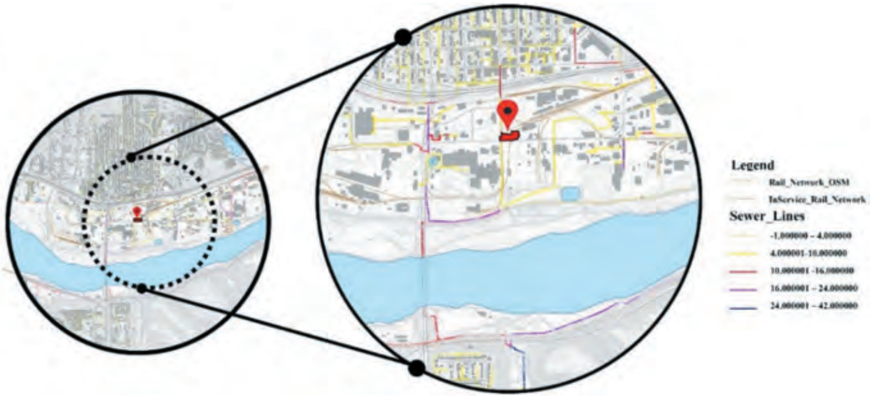

Figure 6. Utility connection- Sewer line, graphical representation, GIS - Sand Spring.

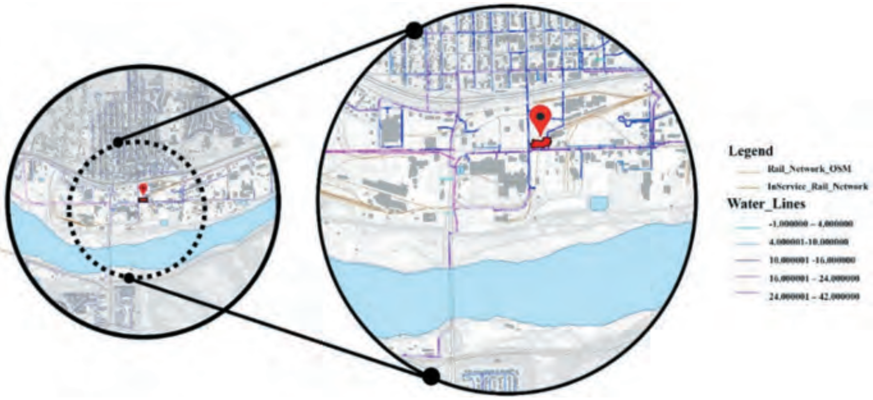

Figure 7. Utility connection- Water line, graphical representation, GIS - Sand Spring.

Considering the existing urban context and ongoing development in the Sand Springs area, the analysis identified restaurants and rentable small co-working spaces as the most viable options for the power plant's adaptive reuse. This approach will also fulfill the community's expectations about preserving the power plant's unique architectural style while redeveloping it.

3.2 *Structural systems*

Sands Springs building is structurally supported by wall footings and a steel structure frame consisting of various steel sections of columns, beams, trusses, and angles.

The project's floor plan was divided into three areas with similar sections sorted identically within each room or area (Figure 8).

Area 1 is structurally reinforced by circular hollow columns supporting 'I' girders holding a group of trusses (Figure 9a). Steel angles are placed at the top of the trusses at 45 cm (18 in.) c/c to brace the top cord of the trusses and fasten them to the metal roof. Area 2 is structurally supported by 'I' columns that hold a group of trusses and hollow rectangular beam sections on the roof. In addition, 81 cm (32 in.) brick columns support a 45 cm (18 in.) steel girder on either side that holds a crane system. The columns are spaced 6.1 meters (20 ft.) apart (Figure 9b). The structural frame of Area 3 indicates built-up 'I'- shaped columns supporting a group of roof trusses and steel angles, arranged into a gable roof structure (Figure 9c).

Figure 8. Sand Spring power plant- existing plan, graphical representation (Plan view by owner).

Figure 10 represents a three-dimensional model of the power plant representing Area 3 located on the northeast side of the building.

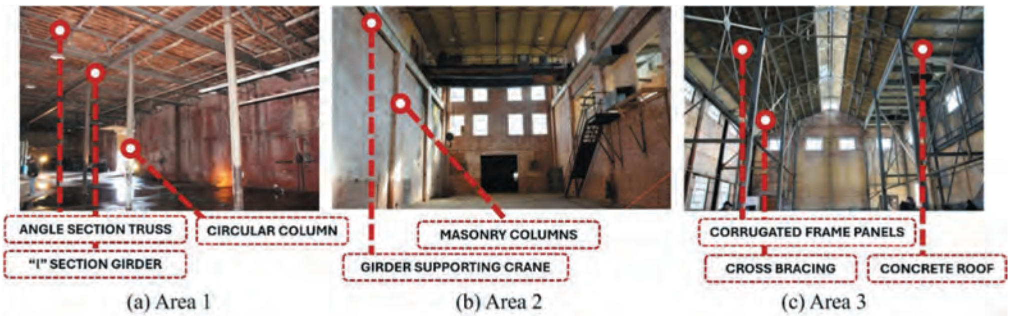

Figure 9. Structural systems, a) Area 1, b) Area 2, and c) Area 3 (Photos by authors).

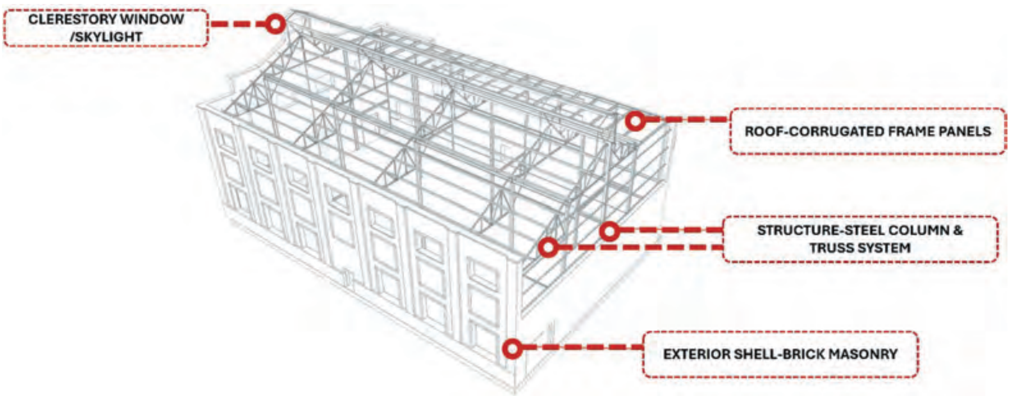

Figure 10. Area 3 - structural frame (3-D frame by Authors).

3.3 *Architectural proposal*

After analyzing the urban context and reviewing the existing structural system of the power plant, an architectural design has been proposed. Restaurants and rentable small co-working spaces are considered the most efficient urban functionalities for the adaptive reuse of the power plant. This approach meets the community's expectations of preserving the power plant's unique architectural style while redeveloping it. Skylights and reopening of existing windows allow for cross ventilation and natural light into the interior. The light interior color, indoor plantation, and lighting add new life to the unused building. The proposed raw flooring in the south block adds richness to the rustic building and can be converted into a more relaxed area. Additionally, to connect with the local community, transforming half of a large unused outdoor space into a garden and a dining courtyard for the restaurant is proposed to fulfill the client's desire. Figure 11 shows the rendered interior perspective images of Area 3 in the existing and proposed conditions used as co-working spaces.

Figure 11. Rendered interior perspective of Area 3, a) before and b) after proposed architectural design (By authors).

As shown in Figure 11b, old containers are used to create a mezzanine level in the northeast block of the building. This area provides a certain degree of privacy for the office spaces while creating opportunities for social interaction at the ground level. Due to the addition of the mezzanine level, it is recommended that the structural frame system be re-evaluated to ensure the structure's strength.

4 BENEFITS OF ADAPTIVE REUSE

There are several benefits of repurposing an old power plant rather than demolishing it and constructing a new building:

- Cost-effective solution: Maintaining the existing building frame and renovating the interior is significantly more affordable than constructing a new building from scratch (CAEDC 2018). The proposed co-working space will allow small businesses to move into a prime downtown location without incurring high costs. Additionally, the attached restaurant greatly benefits the workers by minimizing their trips outside of the building for meals.
- Environmentally friendly: Redevelopment involves repurposing an existing structure, which means less building waste and debris during demolition. Repurposing also avoids the embodied carbon of new construction and landfill impacts. Additionally, restoration is a great way to incorporate new energy-efficient technologies into an older structure (CAEDC 2018).
- Community engagement: Reusing abandoned buildings in neglected urban centers provides new possibilities while retaining some of the city's historical value. Moreover, it creates

opportunities for other small businesses and revitalizes these areas, giving them new, vibrant identities that help them thrive (CAEDC 2018).

5 CONCLUSION

In conclusion, this research highlights the importance of preserving the historic power plant building in Tulsa, Oklahoma and supporting its adaptive reuse. Following an analysis of the urban context and a review of the existing structural system of the power plant, an architectural design has been proposed. The design suggests that restaurants and rentable small co-working spaces are the most efficient urban functionalities for the adaptive reuse of the power plant. This approach aligns with the community's expectations of preserving the power plant's unique architectural style while redeveloping it. By highlighting architectural features such as exposed brickwork and the steel framework, this modern adaptation breathes new social and economic life into the building's forgotten historical significance. The preservation of existing materials, adaptive reuse, and community sensitivity are crucial in transforming this turn-of-the-century power plant into a vibrant mixed-use commercial neighborhood.

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Timber-based retrofitting of unreinforced masonry: An experimental approach to repair and reuse

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ABSTRACT: Across the Northeastern United States and Eastern Canada, steel and concrete systems are frequently used to retrofit unreinforced masonry buildings. In most cases, these systems are designed to supplant existing brick walls and create auxiliary or substitute loadbearing systems for vertical and lateral loads. Such efforts are materially intensive, architecturally invasive and economically costly, making them unsuitable for workaday (non-heritage) buildings that are frequently left vacant or underutilized. Taking an alternative approach to retrofitting, the authors present research focused on existing masonry structures of modest character, which are materially valuable but unlikely to be retrofitted. These anonymous structures account for a large quantity of the material and energy embodied in current building stocks, and extending their service life has substantial benefits from carbon emissions and urban regeneration to urban heritage and housing supply.

1 INTRODUCTION

A widespread shortage of housing continues to plague many North American cities, and in recent years the situation has grown especially severe in Canada. Rental and ownership costs have risen substantially, leaving many citizens in financially precarious circumstances and contributing to increased rates of homelessness. The root causes of this crisis go well beyond building design, but efforts to reduce costs and expedite construction are a critical component of rising costs and shortages. For this reason, attention has been given to new and innovative methods of assembly that have potential to lower costs and expedite construction. However, the renovation and re-use of existing buildings may also have potential to expand housing supply and reduce costs. By capitalizing on investments made decades ago in material and energy, the repair and upgrade of existing buildings presents an enormous opportunity to assist in the housing crisis while helping to limit the greenhouse gas emissions associated with construction.

The following paper describes an ongoing campaign to design and experimentally validate new strategies for retrofitting non-residential masonry buildings to create new housing in cities across Eastern Canada. Funded in part by the Canada Mortgage and Housing Association (CMHC)

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and led by specialists in architecture, building science, structural design and computational analysis, the project focuses on buildings that are underutilized or vacant due to changes in use, location and lack of compliance with current codes. As such, the work has broad applicability to cities not only in Canada but also in the United States where a substantial amount of the building stock includes unreinforced masonry. Extending the working life of these buildings for even a few decades could potentially increase the number of housing units in urban areas and support a wider effort to improve the quality and affordability of housing.

The project focuses primarily on the provinces of Québec and Ontario, where more than 60% of the Canadian population resides (22% in Quebec, 39% in Ontario; Statistics Canada, 2019). Metropolitan regions in this area such as Montreal, Ottawa, Toronto and Québec City are among the densest urban agglomerations in the nation and contain some of the it's oldest building stock (Abo-El-Ezz, et al., 2017). Many of these structures have remained in active use, and continue to receive regular repair and maintenance, but thousands of others have become underutilized and now sit partially or fully vacant. In Montréal alone, more than 3000 city-owned buildings are currently unoccupied and waiting for demolition or refurbishment (Davis et al., 2023). This inventory includes a large number of unreinforced masonry (URM) buildings, built with stone or clay-brick walls that contain little or no supplemental steel or iron. Despite their apparent longevity, these structures are uniquely vulnerable to natural hazards like earthquakes, floods and differential settlement, (Canadian Academies, 2019) problems which are exacerbated by the elastic properties of local subgrade soils present across the region (Motazedian, 2010). Along the Ottawa and St. Lawrence river valleys, these risks are especially concerning given the threat of moderate seismic activity (Bruneau, 1994) and changing patterns of seasonal precipitation (Bush, 2019).

1.1 *Repair, Reconsidered*

Most existing URM buildings were erected before the introduction of robust national seismic provisions (1960) and are generally considered to be no-code or low-code structures (Mitchell, 2010). However, this broad category encompasses a wide range of buildings with varying degrees of architectural and historical significance. The finest examples are often recognized, protected and restored, but many workaday structures persist in a state of ambiguity. Low-rise buildings for industry and commerce often sit vacant due to economic changes and shifting demographics, but demolishing or re-purposing such structures can be difficult due to preservation measures and code restrictions.

The National Building Code of Canada (NBCC 2020), for instance, requires that buildings subject to major renovation and/or changes of use be brought into compliance with contemporary standards of structural and energy performance (CCBFC, 2024). Partly for this reason, current practices for the conversion of non-residential URM buildings require a large investment of labor and material. Typical approaches use steel or concrete to construct a new frame within the existing masonry shell to create a new loadbearing system. This new frame manages lateral and sometimes vertical loads, while the masonry facade is preserved for historical or aesthetic value.

From a technical perspective, this is less a matter of repair than of reconstruction. Setting aside concerns of historical authenticity or *façadism*, the practice erecting a new building inside an existing shell poses substantial economic challenges. It is only viable in cases where the value of the land or building is very high and is rarely feasible for sites or structures of modest value, where return on investment is limited.

Given this situation, it is reasonable to ask if alternate paths might be available? Life-safety remains paramount, but it needn't be confused with the structural longevity. While new buildings should be designed to resist and recover from environmental damage, this is not necessarily the case for structures that have existed for a century or more. In such cases, it is possible to consider repair as an interim solution that provides occupants with an acceptable level of safety, but does not insure the building will remain in perpetuity. The American Society of Civil Engineers recognizes multiple categories for structural performance, including S-3 (ASCE 41-23) which defines safety in relation to a post-calamity state in which a structure has damaged components but retains a margin against the onset of partial or total collapse.

Framed in this way, it may be possible to extend the useful life of URM buildings and ensure the safety of occupants while accepting that they may not be recoverable after a seismic event or substantial settlement condition.

The Canadian Commission on Building and Fire Codes has already recognized that current frameworks limit the number of renovations undertaken in Canada and is seeking to make building renovation a priority for the 2020-2025 development of the National Building Code of Canada. Following the guidelines set out by their report, the repair and alteration of buildings should prioritize affordability, life safety and sustainability. Rather than supplanting existing systems with a new structural frame, the work here proposes to capitalize on the vertical load-bearing capacity of URM walls and supplement these with a low-stiffness system of reinforcement that increases in-plane lateral resistance and controls the mode of failure under lateral loading. If this alternative approach can be installed at a lower cost than other solutions, it has the potential to be applied to a broad range of buildings and contribute substantially to urban housing supply.

2 RESEARCH FRAMEWORK AND EXPERIMENTAL CAMPAIGN

Given the complexity of this problem, the development of a low-cost, carbon conscious system for retrofitting URM structures must address a host of technical and practical concerns from structural performance and architectural detailing to installation and hygrothermal behavior in a range of climate conditions. To address these issues holistically, a project team with expertise in these areas designed a campaign for experimental testing and simulation aimed at developing a holistic design approach. The following pages present an overview of the development and testing of the system, while detailed assessments and numerical results are presented in additional forums.

2.1 *Characterization of Existing Buildings*

Given the age and variability of construction systems in the early 20th century, it was necessary to first establish baseline criteria and material properties for URM buildings within the project framework mentioned above. To this end, the team worked with the City of Montreal to locate a building to serve as a viable test case for the material, architectural, structural and urban conditions. After evaluation of multiple sites, the team selected a structure built for industrial purposes and now used intermittently by the City of Montreal for offices and storage. Located at 3558 Saint Patrick Street, near the Lachine Canal, the building sits in a developing area of the city, alongside similar buildings with comparable brick construction. The largest of these nearby buildings have been subject to extensive renovation and converted to offices and housing, but many structures of smaller size remain vacant or partially in use.

Analysis was initiated by characterizing the spatial and material composition of the building. Using a stationary drill and carbide coring bit, samples were extracted from the masonry walls of the structure and bricks were removed from the interior of lower floors then transported to the lab for analysis. A total of 58 characterization tests were then carried out on masonry, bricks and mortar to evaluate their strength, composition and structural characteristics. An additional 45 tests were conducted on timber extracted from the building frame.

To evaluate the exterior walls, openings and principle structural features, an extensive laser scanning operation was carried out on both the interior and exterior. A Leica Laser Scanner (RTC360 LT) was used to scan visible surfaces and generate a high-resolution point cloud model, which captured the geometry of the building in millimeter-level precision. In addition to these scans, photographic surveys were used to generate photogrammetric models of the interior of the building and document notable conditions including pocketed beams and structural connections between the heavy timber framing and masonry walls.

By comparing these overlapping datasets, field measures and visual assessments could be confirmed and verified. However, some notable challenges arose in the synthesis of information. Although laser scanning was able to produce a highly detailed study of the walls and interior, materials differences were not always legible, and structural features such as beams and walls were sometimes indistinguishable from furnishings such as lockers and cabinets. While useful as a reference, the point cloud models were supplemented with conventional 3d

NURBS models that incorporated critical points and reference dimensions from the high-resolution scans while simplifying some features and removing some inaccuracies from scans.

Figures 1, 2, 3. An existing building at 3558 Saint Patrick Street, Montreal, was selected as a case-study and used to collect detailed information on material and construction systems.

Figures 4, 5, 6. Preliminary test configurations at McGill University's Structural Laboratory.

2.2 *Structural Testing and Simulation*

Structural tests were initiated at McGill University with the construction of six identical URM walls measuring 1.2 x 1.2 x 0.2 m. Extending from data gained from samples of the Saint Patrick Street building, each wall was erected by two professional masons and cured for a minimum of 28 days while being controlled for humidity and temperature. To approximate the physical properties of the existing bricks, the team selected Glen-Gery solid handmade clay bricks for construction of the test walls, however matching the properties of the original lime mortar proved more challenging, since any newly mixed mortar would lack the 100 years of environmental exposure that characterized the test sample. To overcome this problem the team sought to develop an approximation of the existing sample using a cementitious mortar (Type-O), which was weakened by the introduction of additional sand at a mix of 15%.

Of the six walls, two were selected as control specimens, two were fitted with wooden panels and two were fitted with wood panels and surface-mounted steel rods. Each specimen was then evaluated in using the standard ASTM E519 structural test, which is intended to simulate the effect of earthquake or settlement through by applying a compressive load on the diagonal from a steel show at the wall corners. The setup departs slightly from the test standard in order to avoid rotating the walls to 45° angle specified in the test protocol.

Typically, this sort of diagonal tension failure yields the minimal drift capacity and is characterized by a sudden force drop upon reaching ultimate lateral load. In real terms, this is the sort of failure that provides little warning before a catastrophic collapse, leaving insufficient time for occupants to evacuate (Dizhur et al., 2013). Notably, all walls to which the retrofit had been applied demonstrated progressive sliding failure and avoided the explosive disintegration that was observed in un-retrofitted specimens. This delay in abrupt lateral resistance was a welcome and desirable outcome with respect to building evacuation scenarios and it illustrated the potential of the system to support life-safety goals per ASCE 41-17.

Following the laboratory tests, a parallel series of simulations were carried out using computational models and Distinct Element Method (DEM) analyses in the commercial platform 3DEC. This modelling strategy falls into the category of discontinuum-based analysis in that it represents the masonry composite as a system of discrete blocks that interact along their boundaries. The forces between the separate blocks are predicted following a point-contact hypothesis, in which three orthogonal springs are defined (one in the normal and two in the shear direction) at each point contact. By testing variables through iterative changes, the simulated analyses were developed to align with the laboratory tests. In this way, the team could begin to scale up the simulation to the larger geometric configurations (façade and eventually building) while retaining core material and structural characteristics from the destructive experiments.

Figures 4, 5, 6. 3DEC Models for Distinct Element Method (DEM) simulation and analysis.

2.3 *Hygrothermal Analysis*

In addition to improving structural performance, the retrofit system is intended to concurrently improve thermal capacity (per the National Energy Code of Canada for Buildings). To comply with current standards, the system is designed to bring existing brick walls up to a thermal resistance of 0.045 W/m^2K (+/- R22). In the cold regions of Eastern Canada this is no simple task as brick buildings with interior insulation are notoriously prone to moisture damage, which often results from condensation in wall assemblies.

To address this concern, preliminary tests of the retrofit were designed to limit moisture intrusion through the exterior of the wall using a hydrophobic coating (siloxane) and distance moisture sensitive materials from the interior surface of the brick wall. After the installation of anchors, but prior to the application of the structural panel, a layer of 25 mm (1”) mineral wool insulation is applied to the surface of the brick wall and then held in place by the structural panel. Wood fiberboard is then installed directly against the plywood/timber panel and air sealed with caulk and tape. Two additional layers of fiberboard are applied, each layer 38 mm (1.5”) thick with a thermal resistance of 0.713 m2·K/W (4.05 ft2·°F·h/BTU). As the wood framing is also 38 mm (1.5”) thick, the first layer of wood fiberboard is inserted into the triangular cavities created by the frame and installed to be coplanar with the wood framing. The second layer of wood fiberboard is installed over both the wood framing and first layer of wood fiberboard to reduce thermal bridging. 12 mm (1/2 in.) thick gypsum wall board is installed over the wood fiberboard as the interior surface. The unreinforced original masonry wall is estimated to have a total thermal resistance value of 0.3667 m2·K/W (2.0822 ft2·°F·h/BTU). The retrofitted wall assembly with wood reinforcement, 76.2 mm of wood fiberboard insulation, and gypsum wall board is estimated to have a total thermal resistance of 1.8667 m2·K/W (10.6028 ft2·°F·h/BTU).

These thermal resistance values were determined through physical testing with a guarded hot box (ASTM C1363) and simulated modelling using THERM 7.8. The physical and modelled results demonstrated that the retrofit with two layers of fiberboard insulation improves the thermal resistance of the assembly by over 400%. Further design, analysis, and testing is now underway, with an ambition to achieve an assembly thermal resistance of ca. 4.0 m2·K/W (22.7 ft2·°F·h/BTU) and meet moisture performance criteria (ASHRAE standard 160-2021).

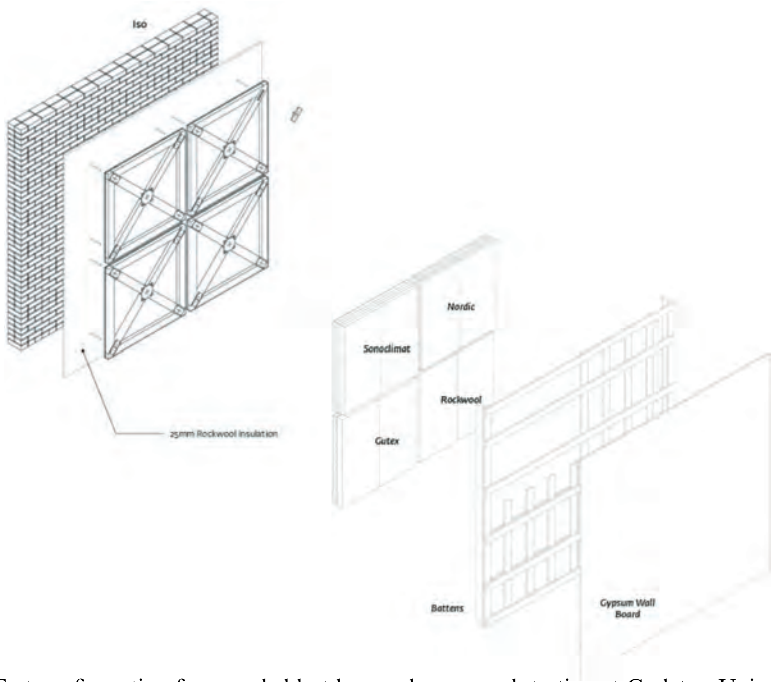


Figure 7. Test configuration for guarded hot box and spray rack testing at Carleton University. Drawing by Philip Tidwell.

Physical testing this retrofit assembly is now underway at Carleton University's Centre for Advanced Building Envelope Research (CABER). This includes an extended exposure at -25°C conditions using a guarded hot box apparatus and simulations of wind-driven rain using a pressurized spray rack. Four panel assemblies are being tested to gauge the performance of a multi-panel retrofit and to test different insulation products with varying environmental credentials.

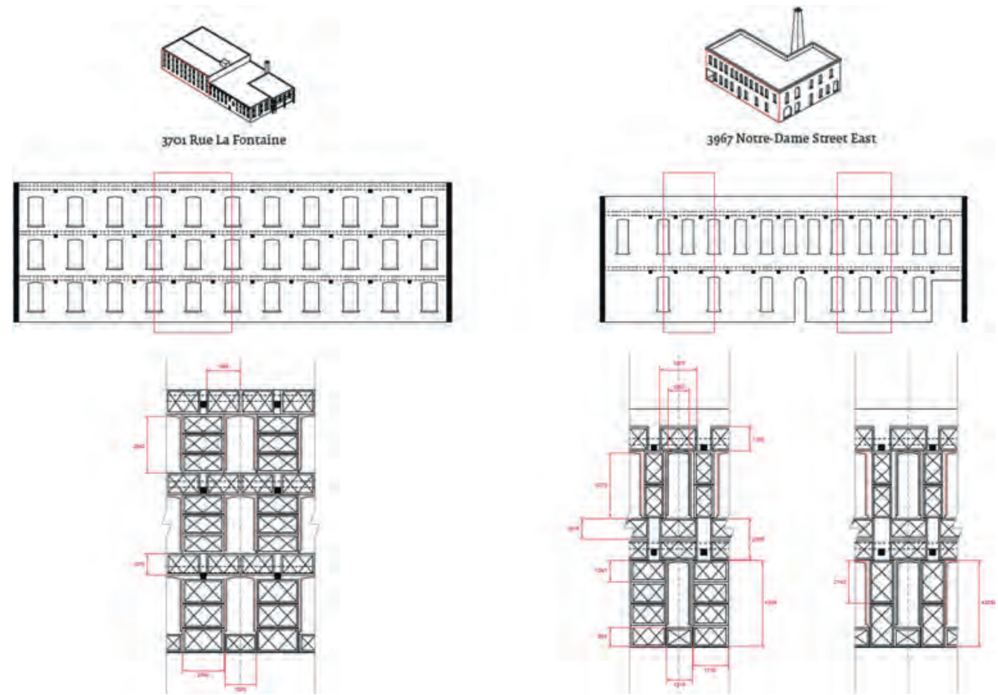
To explore and test the designs to meet a variety of highly populated Canadian cities, computer simulations have been used to examine the performance of the retrofits during the weather conditions predicted in cities such as Toronto (Zone 5), Ottawa, Montreal (both Zone 6), Quebec City, Edmonton, and Winnipeg (all three Zone 7A). Hygrothermal analysis is performed using WUFI Pro 6 under the ASHRAE Standard 160 Criteria for Moisture-Control Design Analysis in Buildings.

3 SCALING THE SYSTEM

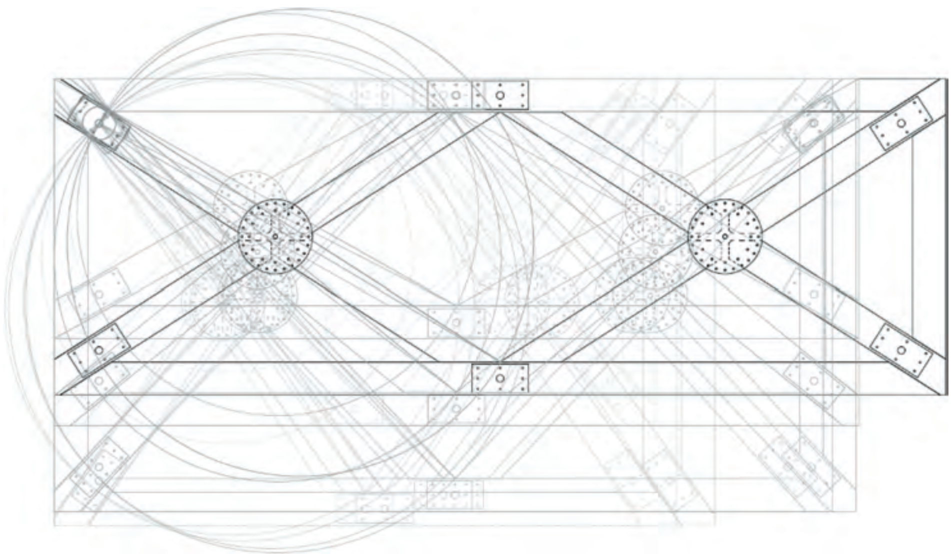
The panel is idealized as a rectangular module with a maximum dimension of 1.2 x 2.4 m, but application of the system at scale demands that it be adaptable to a wide range of building geometries and façade conditions. To evaluate the challenges in fitting panels to buildings with varying heights, window patterns and opening sizes the team selected four additional case study buildings in the city of Montreal to test the potential of the system.

3.1 *Facade Geometry and Panel Distribution*

For any given building, retrofitting must be designed to maximize coverage of the existing URM walls while minimizing the number of panel sizes that need to be produced and installed. To achieve this goal, the design team developed a strategy in which a building is subdivided into structural bays and analyzed geometrically in terms of key dimensional parameters. By establishing axes and measures, any given façade can be discretized and optimized for structural performance and panel repetition. To do this, a reference axis is established by



Figures 8. Subdivision and discretization of panel on facades of differing types. Drawing by Yifan Xie. offset a 100mm gap.



Figures 9. Overlay of panel types illustrating variations in size and consistency of geometry. Drawing by Yifan Zie.

the centerline of windows, then horizontal panels are placed over the spandrel at a maximum possible width. Finally, vertical panels are placed vertically in each pier and subdivided as necessary to negotiate spacing.

The maximum size of any panel is limited to 1.2 x 2.4 m (a standard plywood sheet), but the method of distribution produces a wide range of rectangles. To make these variations consistent in terms of fabrication and structural behavior, another parametric definition is used to define the geometry of any given panel size. In this definition, the position of all anchors is maintained at a constant 120 mm from corners and additional anchors at the center or bisected center of the panel.

4 CONCLUSIONS AND FURTHER RESEARCH

Preliminary investigations into this novel method of light-timber retrofitting of unreinforced masonry (URM) buildings have been fruitful and yielded many encouraging results. Both numerical and experimental validation demonstrate that potential exists for a low-cost system that can effectively prevent catastrophic failures during seismic events, without wholesale replacement of the building structure. Experimental results show a significant increase in structural performance compared to un-retrofitted walls, and an ability to meet life-safety goals per ASCE 41-17. Structural modeling further validates the retrofitting approach, with good agreement between the Distinct Element Method (DEM) models and the experimental findings for both retrofitted and un-retrofitted masonry walls. In terms of thermal performance, the use of wood fibreboard insulation panels in the retrofit is shown to substantially improve the overall thermal resistance of the URM walls. Both physical testing and simulation modeling confirm the effectiveness of thermal retrofit, with a notable increase in thermal resistance.

Ongoing research and testing will aim to further optimize the retrofit design and confront the evident challenges of applying the system at building scale. These findings contribute valuable insights to the field of conservation and re-use with potential for widespread implementation that may improve structural integrity and energy efficiency while potentially allowing a lower barrier to entry for re-use and repair of existing buildings.

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Balancing resources and cultural values in building adaptations

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ABSTRACT: This article examines the relationship between cultural heritage and environmental impact in building adaptations through a proposed matrix combining SAVE (Survey of Architectural Values in the Environment) and LCA (Life Cycle Assessment) methodologies. It indicates that a direct methodological merge of the systems increases the awareness of both ecological and cultural values and sharpens priorities and approaches when adapting existing structures for new use. Initial case studies suggest that buildings with high preservation values tend to achieve lower environmental impacts when adapted, while buildings with low preservation values, despite offering greater adaptation potential, often lead to more extensive interventions with higher environmental impacts. The study reveals a significant correlation between the systems, suggesting that traditional building approaches and restrained intervention strategies may offer valuable insights for more thoughtful and ethical solutions. The proposed matrix serves as an analytical benchmarking tool for integrating cultural and ecological values in early-stage architectural design decisions.

1 INTRODUCTION

Preserving, reusing, and transforming existing buildings are key in the green transition of construction, as they represent significant resources and embedded CO2 (IPCC, 2023) Yet, existing buildings refer to many value systems besides the ecological ones. Buildings also represent cultural values and architectural heritage, which involve historical aspects that infuse them with meaning, character, and a sense of belonging in a place. Architectural styles and an archaeological approach have traditionally guided our view of buildings worthy of preservation (Venice Charter, 1967) However, the growing emphasis on preserving structures has led to increasingly diverse approaches to building adaptations. Modern interventions must balance the purpose of preserving building heritage while also reusing resources and adapting buildings to meet society's changing needs (Plevoets & Van Cleempoel, 2019). A new Danish study further shows significantly and unambiguously that renovation is better for the climate than demolition and new construction (Realdania, 2024).

In Denmark, Life Cycle Assessment (LCA) by legislation has been introduced as a standard method for estimating CO2 emissions ((Danish Building Regulations, 2024). LCA presents a fundamental but narrow view of the environmental impacts since it does not include all planetary boundaries and has a somewhat arbitrary scope of 50 years with no regard to the type, placement, or ambition level of the architecture (Munch-Petersen, 2020). Regarding architectural heritage, assessment systems like the Danish method; Survey of Architectural Values in the Environment (SAVE) focus on buildings' cultural and historical aspects (Didriksen, Tønnesen, Høi & Stenark, 2011), but they pay no attention to the climate agenda. Neither refers to the social characters of place or community level nor do they touch upon phenomenological aspects relating to buildings.

It can be argued that the value systems inevitably shape how we understand and prioritize intervention processes. This raises important questions: How can these different value paradigms

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coexist in building adaptations? Do they inherently conflict or can they be strategically aligned to reinforce each other? To investigate these questions and test the balance between the value systems a matrix is set up merging SAVE and LCA. The purpose of the tool is to bring attention to both methodologies informing preliminary phases and being able to make informed decisions before and in the design process.

In this paper the term ***adaptation*** is used to describe an extensive change to a building and *"any work to a building that goes over and beyond maintenance to change its capacity, function, or performance"* (Douglas, 2006). The word ***intervention*** is used as a more neutral but concrete act or process of intervening in and working with any type of existing structure in general.

2 METHOD

2.1 *Assessment methods and building adaptation strategies*

Assessments of existing buildings and their context are crucial when intervening in them. Evaluating inherent values based on different systems, along with more objective technical registrations and preparatory investigations, establishes the foundational core values. With new needs and functions, this forms the basis for selecting the appropriate approach and design strategies when adapting old buildings to new use (Cramer & Breitling, 2007). Interventions in existing buildings is a field of many professions and research areas and it presents a complex challenge that intersects multiple disciplines, demanding a nuanced understanding of historical, environmental, and technical considerations (Plevoets & Van Cleempoel, 2019). The common purpose is the process of working with an existing situation and the ambition of retaining (some of) the original structure, resources, and collective memories related to the place (Stone, 2019). The process demands a different way of thinking and seeking what inherent possibilities the existing building has to offer rather than dictating what it has to be (Cramer & Breitling, 2007).

But the desire to preserve can be ambivalent. On one hand, we strive to conserve specific historic structures, and on the other, the aging process is unstoppable. *"Because their structure tends to outlive their function, buildings have continuously been adapted to new uses – a fact which has enabled generation after generation to derive a sense of continuity and stability from their physical surroundings."* (Cantacuzino, 1975). This observation underscores the historical practice of building reuse, driven by both pragmatic and symbolic considerations. And that preservation is no contradiction to change in the built environment. Adaptations of existing buildings are not a static or retrospective approaches, as attitudes develop as well. Even with the same facts and details, our interpretation and perspectives on the subject may well adjust (Strike, 1994).

In this ephemeral reality where attitudes change over time, common frameworks guide us to point out values for the further process. The tools and methodologies we employ in assessing and adapting existing buildings significantly influence our approach to preservation, serving as crucial guides in decision-making processes (Stylsvig Madsen, Beim & Reitz, 2015).

2.2 *Life Cycle Assessment – A new value system*

On the 5th of March 2021, the Danish parliament voted for an agreement to implement the National Strategy for Sustainable Construction (Ministry for Interior & Housing, 2021). It was initially implemented in January 2023 as an expansion to the Danish Building Code (Danish Building Regulations, 2018). This means that from 2023 onward all new construction must have a life cycle assessment {LCA} as part of the building permit application. It was implemented with benchmarks for different sizes of buildings. As part of the agreement, these benchmarks should be adjusted continuously, ensuring an increasingly ambitious environmental aim for new construction over time.

On the 20th of May 2024 a new agreement defined new benchmarks for construction with values per typology this time around. Dwelling, offices, institutions, and more have different specific benchmarks that are heightened in 2025, 2027, and 2029 (Ministry of Social Affairs & Housing, 2024).

Building regulations have long incorporated various performance requirements that have become ingrained in standard construction practice to such a degree that we hardly think of them as value systems (Munch-Petersen & Ejstrup, 2017). Chief among these is the steadily increasing energy efficiency mandate, originally driven by the 1970s oil crisis and political aims to reduce OPEC dependency. Today, these standards align with the Paris Agreement and broader environmental sustainability goals. A building's value is now intrinsically tied to its calculated energy performance - if it fails to meet the standards, construction approval will be denied (Danish Building Regulations, 2018, chapter. 11) Energy efficiency has effectively become a core value system for contemporary construction.

The climate crisis has now introduced another value system in the form of LCA. It focuses primarily on Global Warming Potential (GWP), measured in CO2-equivalents, as the primary environmental indicator based on the Paris Agreement's priorities (United Nations, 2015). Other common LCA metrics like Ozone Depletion, Photochemical Smog, Acidification, and Eutrophication are not specifically targeted. Sustainable construction is thus defined through benchmarked, relativistic LCA measures addressing only GWP.

The mandatory inclusion of LCA in the building code signals a new mindset - sustainability is now a compulsory value system for all new construction. As the LCA benchmarks become more stringent over time, a sense of urgency is implied. However, this sustainability framework does not currently extend to existing buildings, where conservation, renovation, and adaptation projects remain exempt from LCA requirements. This represents a significant gap in harmonizing cultural and environmental values across the built environment (Schjødt Worm, 2016).

2.2.1 *A (new) focus on the materials of architecture*

LCA is done on material/component level. As such, the value system LCA represents is a material value system. Some material represents high GWP and some less (Munch-Petersen & Ejstrup, 2017). The 'right' material of architecture then becomes a question of environmental loads of materiality and not functionality, cost, aesthetics, and to a lesser degree performance – and this represents a change in view on architectural material performance.

As a value system, LCA dictates a new focus on low-impact materials, and this has a significant influence on how architecture is understood and performed. In public architectural discourse the idea of 'new-construction-stop' and 'demolition-stop' is born from this new perspective. Adaptive reuse and material reuse are ways to make sure that the materials in use in construction stay in use. From an LCA perspective, this means that reused materials and architectural compositions represent zero impact according to the specifications of LCA calculation. Finding aesthetic value in construction that is already there has become key and is becoming a mainstream idea in sustainable thinking in construction.

2.3 *SAVE – Architectural historic value*

Survey of Architectural Values in the Environment (SAVE) is a method to assess architectural, cultural-historical, and environmental (not ecological) values in buildings, lands- and townscapes to identify buildings and cultural environments worthy of preservation (Didriksen, Tønnesen, Høi & Stenark, 2011). The system is focused on 'the bigger picture' rather than on the individual building, as it can analyze a large number of buildings and settlements within a short time (Stylsvig Madsen, Beim & Reitz, 2015).

SAVE emerged from the evolution of preservation strategies both in Denmark and internationally. Denmark's Building Preservation Act (Bygningsfredningsloven) of 1918 initially established two listing categories: A-listings (interior and exterior) and B-listings (exterior only), which were merged in 1980. The post-World War II period saw increased interest in heritage preservation, marked by the establishment of numerous preservation associations (Bendsen, Morgen & Lindhe, 2018). Denmark's joining of the Granada convention in 1985 was significant, as it promoted architectural heritage preservation across Europe (Council of Europe, 1985). While the Building Preservation Act could address buildings and their immediate surroundings, it couldn't protect independent landscape elements like parks and cityscapes.

In response, the Ministry of Environment and Energy and The National Forest and Nature Agency instigated the development of SAVE in 1987. Launched in 1990-92 as an open-source method, it led to the creation of 90 municipal atlases documenting local heritage and cultural identity (Didriksen, Tønnesen, Høi & Stenark, 2011). The methodology went international with the 1997 publication of InterSAVE (Didriksen & Tønnesen, 1997). Today, buildings deemed worthy of preservation through SAVE are regulated by municipalities under The Act of Planning (Planloven, 2018).

2.3.1 *Methodology and legal framework*

SAVE is built upon 5 criteria for assessment: Architectural value, environmental value, cultural-historical value, originality, and technical condition. The final SAVE value is a weighted summarization of the 5 criteria (Didriksen, Tønnesen, Høi & Stenark, 2011). SAVE has a twofold focus: 1) Environmental structures (built or landscape) and 2) Single Buildings. When SAVE is used for assessing environmental structures, a more rigorous process for registration is being commenced, than when assessing single buildings, but the 5 criteria are the same (Didriksen, Tønnesen, Høi & Stenark, 2011). Furthermore, the methodology of the 5 criteria is also reflected in the Assessment of Conservation Values used when assessing and describing the listed buildings hereby creating a coherent assessment methodology across both listed buildings and buildings worthy of preservation (Agency of Castle and Cultures, 2010).

When SAVE is used for assessing buildings, the screening is very quick, 10-20 minutes including preparations/transport, description, photography of the facades, and reporting. SAVE only focuses on the present state of the building on a local/regional scale and therefore not comparable across the different regions (Didriksen, Tønnesen, Høi & Stenark, 2011). The assessment is not legally binding in itself unless the building is recorded in a local plan or municipal plan as a building worthy of preservation (Bygningsfredningsloven, 1986). In this case, the owners are legally obliged to obtain a permit from the municipality, before changes or building works can be commenced on the facade of the building. Furthermore, the municipality can ask for further specifications, and documentation or impose constructional or material conditions before a permit can be obtained. Also, a building worthy of preservation cannot be demolished without the case being accepted by the city council based on a public hearing and illegal demolitions can result in legal action and compensation claims.

3 AN ECOLOGICAL-HERITAGE VALUE MATRIX

3.1 *Combining the two value systems*

It is clear that SAVE and LCA are different value systems but both are important systems to gauge the cultural significance and the ecological impacts of building now and over time. The question then is whether the climate agenda or the architectural heritage agenda can coexist in one assessment tool. If they have a common language and they can be understood as two sides of the same value assessment? To explore this discrepancy or coherence of the two systems within building adaptation, a simple matrix system has been developed (see Figure 1). As both systems deal with a quantitative methodology a mathematical matrix can be an obvious choice as a point of departure for this inquiry. It combines *culture-scores* with *ecology-scores* in a system where it's not an either/or scale, but an emphasis and balance between the two. The matrix operates with quantifiable values representing the number span for the two systems. By simply showing both results simultaneously the idea is that both value systems can be addressed at the same time.

Both LCA and SAVE are valuation tools that use simplified approaches to complex relations and interdependencies of construction. SAVE is based on both qualitative descriptions and a final grading, which indicates the overall preservation value. Similar to an LCA assessment, the final score in both systems does not cover the comprehensive assessment but is an attempt to provide a single simplified overall statement. In other words, something we might best describe qualitatively becomes something that can be given a score, which, in turn, can be useful for comparisons. Therefore, knowing that none of the value systems manage to embrace the complexity of architecture fully, they are today embedded in the Danish systems and legal framework and the only valid practice-based assessment tools we can employ.

The respective scales in the matrix are the score 1-9 aligned with SAVE and the LCA score span between 0 to 12 kg CO2-eq/m2/year on the vertical line, which refers to the threshold limit value per 2024 (Ministry for Interior & Housing, 2021). The results from LCA and SAVE assessments are placed in relation to each axis in the matrix. Structuring the diagram this way allows for the two systems to complement each other rather than being opposites or done independently. By combining the two systems the discussion about the architectural heritage also becomes an ecological discussion on how much we can afford to preserve or demolish when the ecological budget must not be exceeded. This could foster a relationship where the two systems strengthen one another in practice.

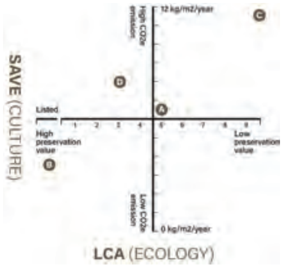

Figure 1. Value matrix including placement of cases.

3.2 *Testing the matrix*

It is clear that the two value systems have contrasting temporal perspectives and come from two different time periods - one focusing back on the value of existing architectural conditions and the other on environmental impacts now and in the future. This is especially evident when it comes to data availability. Only a few buildings have undergone both assessments, largely because LCA is not yet a legal requirement for adaptive reuse and renovation projects (Schjødt Worm, 2017). But also, because systematic assessment of post-1940s buildings only began recently, leading to limited database entries for more recent architecture (Realdania, 2024). To connect those contrasting foci, using the matrix at multiple stages throughout the design process could prove valuable: initially to understand the inherent value before intervention and set ambition levels; then to evaluate how different strategies might affect both indicators; and finally, to assess whether the project succeeded in preserving architectural value while minimizing environmental impact. As an initial test, four cases were found and placed in the matrix (see Figure 1). Three of them have a SAVE and a LCA made in accordance with common practice for SAVE and LCA in Denmark. The last one (case C) does not have a SAVE but is treated in its transformation as being of low preservation value. As such all four cases are methodologically compatible. In the following, the cases are described and placed in the matrix.

A) ***A functionalistic office building*** from 1957, built in classic modernistic prefab concrete elements and situated in the heart of Copenhagen. It holds a formal SAVE value of **5**, characterized as

Figure 2. Case A-B-C-D, Credits: A+C *Henning Larsen*, B *Agency for Culture and Palaces,* D *Peter Elfelt.*

a middle preservation value. The actual assessment is from 1995 and with very limited information. In 2021 the roughly 12.000 m2 building was reused through a deep renovation to create a modern, energy-optimized mixed-use building adapted to contemporary standards. The original concrete facade was replaced with a new sandstone facade and the interior of the building was in the rebuilding process stripped down to the raw structure. The result for the final in the LCA assessment was **6,5** kg CO2e/m2/year.

B) ***A historic farmhouse*** dating back to different periods between 1778-1853 and a part of a preservation-worthy and cohesive village environment. A traditional four-lane farm with a thatched roof and timber frame construction, and it contains constructional detailing and materials used for the specific region. The building itself is **listed** and therefore subject to special restrictions. For many years the farm had been neglected and the condition was such that the deterioration was accelerating and without intervention, there was a risk of collapse. By using solely reused materials, new biobased ones, and change to a geothermal heating source, the intervention managed to gain a final LCA result of **3,3** kg CO2e/m2/year.

C) ***A former court and police station*** is transformed into a new health and care centre. The 4.300 m2 building from 1973 is a characteristic rational prefabricated concrete element construction with a great deal of repetition. It does not hold a SAVE value itself but is placed in an area designated as worthy of preservation. The building has been stripped down to its structure. The ambition for the client is to do an extension to the existing building and establish a coherent whole in a completely new contemporary expression hiding the original building. The project is assessed to have an LCA value of **11,2** kg CO2e/m2/year.

D) ***A classical Copenhagen block*** from 1893, placed in one of the city's most central and prominent locations. Its approximately 7.000 square meters have contained changing residential and commercial functions throughout its lifetime. The building is constructed with a base of sand-lime blocks and top of red bricks and with extensive use of ornamentation that was characteristic for the historicistic period. The SAVE value assessment was done in 1995 with a score of 3, but holds no further description. Besides both conservation and renovation of the existing parts, new construction is added up- and inwards adapting the building to fit new purposes. The project is estimated to reach a LCA value of **8,1** kg CO2e/m2/year.

4 DISCUSSION

The matrix is primarily designed to inform early-phase decisions, focusing on initial intervention ideas while incorporating LCA considerations, which require detailed material knowledge. This creates a process where cultural preservation values must align with LCA score targets and vice versa. Additionally, the matrix serves as a benchmarking tool to evaluate different design approaches, revealing their ecological 'costs' and helping identify preferable strategies regarding environmental impact. As such the studied cases are not optimal since SAVE assessments were completed before design proposals, while LCA was conducted post-intervention. As a design tool, the matrix should be tested multiple times during early design stages, ensuring teams maintain awareness of both cultural heritage and ecological concerns throughout the process.

Higher SAVE values impose greater legal constraints and limit building adaptation freedom. This protects heritage authenticity from radical changes, following the principle that less intervention means less damage. It can also reduce environmental impact by minimizing resource use, as demonstrated in ***Case B***, where a high SAVE score correlates with a relatively low LCA score. The preservation requirements limit unnecessary interventions, and the use of biobased materials compatible with the original construction helps maintain ecological boundaries. Here the initial ambition of ending up with a low LCA score made the design team choose low-impact solutions for the adaptations - showcasing both value systems at play in the design process.

Conversely, buildings with lower heritage value offer more freedom to intervene. The adaptation potential increases as architectural heritage value decreases. With fewer constraints and emphasis on use and resource value, there are fewer limits on structural modifications and material changes, as seen in ***Case C*** where the low value opens up all possible approaches and design strategies. However, if the matrix had been used early in design, the LCA score might have been lower as ecology would have been a visible design parameter.

Case A demonstrates how focusing on operational energy carbon savings helped meet the standards of new builds while the preservation value was important for keeping the original facade expression. ***Case D*** significantly shows how preservation and adaptation can coexist, with street-facing facades carefully conserved due to a high SAVE score, while allowing roof extensions and courtyard modifications to create new relevance for the building.

The examples demonstrate that greater interventions typically create larger carbon footprints, aligning with literature on renovation and building adaptations (Realdania, 2024). It indicates potential CO2 savings of up to 40% through reuse rather than recycling (Andersen, 2023), suggesting that maintaining materials in existing buildings is the most effective resource preservation strategy. The initial tests also indicate that a high SAVE score instills a will to do as little as possible in the design team. Suggesting that high cultural value, in itself, leads to more ecological thinking. This needs to be tested further in the coming research.

5 CONCLUSION

This article has aimed to examine the relationship between cultural and ecological value systems and how their integration could inform and improve our approach to building adaptations. While the proposed matrix uses methods that offer limited views of their respective fields, understanding the balance between ecology and culture in building assessment could foster more dependent cohesion between these value systems.

Although the matrix has not yet been implemented as an early-stage design tool, the initial tests in this article suggest that cultural and ecological values can successfully coexist in a quantitative relation. The matrix serves as an effective benchmarking tool, allowing comparisons between projects with different ambitions.

The cases in the study show that adaptation of buildings with a high preservation value (SAVE score) does achieve lower environmental impacts (LCA scores). It also shows that buildings with low preservation value may offer rebuild potentials to a degree where missing legal limitations could lead to higher environmental impacts. As more data come to light it will be interesting to see if a larger empirical dataset could verify this result and how further ecological priorities might influence future adaptation projects.

Interestingly, our search for solutions to current ecological challenges often leads us back to architectural heritage which points to a significant correlation between the two systems. Pre-industrial, biobased building approaches may offer insights into contemporary sustainable design as showcased in case B. At the same time, more humble and thoughtful approaches to all buildings - where as much material as possible remains and where the existing fabrics shows the future possibilities - may prove to be a good strategy for both minimizing environmental impacts and respecting the architectural heritage. Understanding that buildings emerge from specific contexts and changing socio-cultural conditions allows us to take a more comprehensive approach to their entire lifecycle. This includes appreciating their values and understanding their impacts while adapting them to evolving societal needs. The matrix attempts to visualize the value systems simultaneously, helping integrate the understanding into early architectural design phases.

6 PERSPECTIVES

The preliminary testing of juxtaposing SAVE and LCA assessment systems highlights the need for more extensive evaluation across a broader range of adaptation projects to determine the generalizability of the findings.

The use of the SAVE methodology in the matrix presents several limitations. Beyond its single-score approach that excludes qualitative descriptions, the system was not originally designed to holistically capture cultural aspects. It's simply not what SAVE is developed to do. Furthermore, outdated SAVE assessments may fail to reflect contemporary attitudes and neglect important aspects of the self-grown that have been formed over time representing identity and narratives. While SAVE is effective for screening historic buildings, it is less suitable for evaluating final adaptation projects and assessing whether preservation value has been increased or not. Proper historical-stylistic evaluation requires temporal distance to observe societal and architectural trends, posing challenges for contemporary interventions.

A key challenge is the limited translation of ecological factors within the current LCA framework. Incorporating additional environmental indicators, such as biodiversity and planetary boundaries, could enhance the comprehensiveness of the assessment, either within the existing matrix or through a series of interconnected matrices. When adapting buildings for new uses, accepting higher environmental impacts may be necessary and justified if it secures the building's continued relevance and prevents demolition. The key is finding the right balance - making enough changes to ensure the building remains functional and relevant for contemporary needs while being mindful not to over-intervene.

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Structures and Architecture. REstructure REmaterialize REthink REuse - Rinke & Frier Hvejsel (Eds)

Hidden in plain sight: Exploring roofs in the reuse of Flemish post-war Parish churches

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ABSTRACT: This paper explores the role of the roof construction in the adaptive reuse of post-war parish churches in Flanders, focusing on the work of architect Marc Dessauvage (1931-1984). Concentrating on the entanglement between roof structure and ceiling, this paper investigates how both layers were handled in the original design of the parish church and how this influenced decisions during their refurbishment process. Specifically, this is accomplished by a historical and pathological analysis of four of Dessauvage's parish churches, revealing how these structures, besides their 'hidden' nature, would strongly affect each phase of the refurbishment process. Hence, this paper hopes to unravel the various roles the material dimension of post-war parish churches play or could play within their adaptive reuse, thereby contributing to our understanding and interaction with this religious heritage.

1 INTRODUCTION

The roof construction plays a characteristic role in church architecture, as it helps define the morphology and appearance of the church building, both from within and from without. Existing research already looked into roof trusses of 19th and early 20th century parish church buildings (Wibaut, 2021). The masonry vaults that hide these trusses from the interior have also been extensively analysed (Fuentes Gonzalez & Wouters, 2021, Wendland & Ventas Sierre, 2018). While the importance of both the structure and the ceiling for this building typology is thus certainly evident, they are often considered as separate entities, while their entanglement and the plenum or 'void' they create between them is often left disregarded.

This distant and traditional relationship between roof structure and ceiling in churches will change significantly in the post-WWII period. At this time, Western Europe experienced a large church building campaign to accommodate the ever-growing population in suburban areas (Sterken, 2013). This led, for example, to the building of more than 400 churches in Flanders alone during 1945-1975 (Boone et al., 2008). Marking a radical deviation from traditional parish churches, new architectural approaches were gradually introduced (Morel & Van de Voorde, 2012). These new approaches can be primarily linked to two developments: changing liturgical practices, which also affected the appearance of the roof, and a steep development of the construction sector, where new construction materials and techniques would provide new ways to construct the roof faster and cheaper. This shift in execution and liturgical tradition altered the relationship between the roof structure and ceiling in parish church architecture. Initially, church roofs were designed to match the vaulted ceilings below. Over time, the vaulted ceilings were replaced by lightweight structures to accommodate the increasing spans in church buildings (Wibaut, 2021). By the post-war period, the ceiling became integrated with the roof structure, making it sometimes difficult to clearly distinguish both

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elements from each other. This evolution would further influence how we experience, perceive and interact with these modernist religious buildings, both then and now.

From the 1960s onwards, the secularisation of Western society has led to the obsolescence of parish churches in Western Europe, making them on of the most discussed building typologies in current debates on adaptive reuse (ten Hove, 2022, Gerhards, 2022, Weber, 2023, Ardui et al., 2024). The parish church not only offers several spatial advantages for reuse, such as a large, open space situated on a distinct location, but also expresses a cultural experience as a former public building, which is instrumental in revitalizing local communities (De Ridder, 2021). This is especially true for post-war churches, that were built to bring liturgical practice closer to everyday life and therefore played a central role for the neighbourhood around it (Ardui, 2023). Today, however, post-war parish churches in Flanders are very susceptible to bad renovations or even demolition, further facilitated by their lack of maintenance and 'precarious' heritage status (Ardui & Sterken, 2021). While the urban, social and spatial role of these churches in adaptive reuse projects is already broadly explored (Ardui, 2023), their structural dimension, in particular their roof construction, is only addressed at case study level (Sterken & D'hoe, 2022).

In this paper, we specifically investigate the role of the roof, and more specifically, the entanglement between roof structure and ceiling, from both a historical and contemporary perspective. The focus is both on design and construction. Firstly, looking into the history of the church, we aim to understand the architects' original intention in the design of the roof structure and the ceiling, and which construction techniques were used to materialise this. Secondly, moving to the reuse of this post-war heritage, we analyse whether the original design concept was translated into the new adaptive reuse project for the building and what alterations or adaptations were necessary to achieve this. In this way, the paper aims to unravel the various roles that the roof of post-war parish churches plays or can play in the repurposing process, exploring how past design and construction decisions have contributed/can contribute to broaden their adaptability.

To investigate the architectural and structural role of roof structure and ceiling, this research delves deeper into the historical and pathological analysis of the roof construction of four post-war parish churches designed by the renowned Flemish church architect Marc Dessauvage (1931-1984). All buildings are situated within the former Archdiocese of Mechlin-Brussels, that played a pioneering role during the post-war church campaign (Sterken, 2013, Sterken & Weyns, 2022) and had the highest number of post-war churches built (Boone et al., 2008). All four were designed and built around the Second Vatican Council (1962-1965) (Sterken et al., 2016). They have been selected for their complementary characteristics in terms of current usage and their physical conditions. Each case involved an extensive literature review, archival research at the *Documentatieen Onderzoekscentrum voor Religie, Cultuur en Samenleving (*KADOC) in Leuven, site inspection, interviews with local actors, and a consultation of existing reports and studies.

2 ROOF AND CEILING: A SHELL FOR NEW FUNCTIONS

As Bart Verschaffel succinctly summarizes in his book *Van Hermes naar Hestia*: "The roof separates the inside/below from the outside/above." (Verschaffel, 2010). This duality translates into the terms 'roof' and 'ceiling,' where the roof 'connects' to the outdoors and the ceiling 'covers' us from it. The roof is almost always associated with structure and water (drainage) (Koolhaas et al., 2018). Therefore, the functions 'span' and 'protect' are considered the most important from this perspective. On the other hand, this also indicates that the roof is often the building element most susceptibility to decay (Harris, 2001; Van den Bossche et al., 2023). As once pointed out by Frank Lloyd Wright, a good roof design is one that inevitably leaks (cited in Brand, 1995). This is not the same for the ceiling, whose role and appearance within the building vary greatly depending on the time period and building type.

As seen before in 19^{th} and early 20^{th} century parish churches, historical vaults–normally used as roof structure– were also implemented as ceiling elements, creating a significant impact on the morphology and experience of the space due to the way they were constructed. On the other hand, several building types contain 'false' ceilings, executed in a totally different manner and thereby influencing the space in a complete other way. A false ceiling 'pretends': it imitates (presenting itself as a structural element or idyllic heaven like e.g. in domes), it sometimes symbolizes (representing a particular culture or tradition, as seen in mosque architecture) and it manipulates our perception of how we experience the internal space (Hvattum, 2023). False ceilings are used to create indirect light effects like e.g. in exhibition rooms or to meet specific technical and acoustic requirements (Somer & Stenvert, 2024). The latter especially counts for office buildings, where the separation between roof and ceiling gradually increased after WWII (Koolhaas et al., 2018). This separation poses some opportunities during refurbishment or renovation like gaining extra floor height as seen in e.g. the refurbishment of the Antwerp tower (Wiel Arets Architects, s.d.). Often constructed as a modular system, these false ceiling elements can easily be dismantled and reused, sometimes even for other purposes (Rotor Deconstruction sc., s.d.).

Religious architecture, however, underwent the opposite evolution. Roof structure and ceiling grew closer together, literally and figuratively, whereby both elements would actively represent the experience of a changing liturgy. For example, the innovative materials strongly symbolized the search for modesty and honesty in religious architecture but also the progressive spirit of the post-war period. Not only did these structures enable large spans, allowing the local congregation to gather around the altar, the slope of the roof brought an extra dynamic to the church space (Morel & Van de Voorde, 2012), while its structural lay-out emphasized the division between sacred and secular spaces (Sterken, 2013). At first glance, these characteristics seem to help the adaptation of post-war parish churches to new purposes and contradict their status as unchangeable, institutional buildings (Brand, 1995). The roof can thus become the existing 'shell' that accommodates and sometimes even organizes new functions (Böröcz & Sterken, 2014). However, new uses will also introduce new comfort requirements, which will significantly impact the structural and spatial properties of both sheared layers in the roof.

3 FOUR PARISH CHURCHES OF MARC DESSAUVAGE: FROM SACRED TO SECULAR

During the post-war period, Dessauvage was appointed by the archbishop to commission several churches for the archdiocese Mechlin-Brussels (Sterken, 2013). Throughout his career, he built a total of fourteen churches and chapels in Flanders between 1959-1974 (Morel & Van de Voorde, 2012). The four examples chosen from his portfolio are built during and after the Second Vatican Council, that announced a clear liturgical reform and new organisation of the church building in the Sacrosanctum Concilium at the end of 1963 (Geheugen Collectief, 2012). Each of the four buildings currently finds itself at a different stage of life, both in terms of current use (from a church building, possibly with a secondary programme, to a fully repurposed building with a new function) and condition (from completely neglected to recently renovated), providing different perspectives integral to the research question. An overview of the illustrations from each project discussed below can be found on the research portal of the VUB using this link.

The Sint-Jozef church in Vosselaar (1966-1967) (poster 1) was Marc Dessauvage's first church design, now repurposed for public use. Later, he designed the Sint-Rochus chapel in Aarschot (1964-1965) (poster 2), for which the church council currently considering a permanent secondary use, while the Sint-Jozef Ambachtsman chapel in Willebroek (1964-1966) (poster 3), was repurposed decades ago. The fourth case is the Sint-Paulus church in Westmalle (1966-1967) (poster 4) that, besides being the most recent example, remains active for both primary and secondary functions. Characterized as large, inward-facing spaces, serving as an enclosed yet sturdy 'shelter' no bigger than a family home (Böröcz & Sterken, 2014), these parish churches from Dessauvage are also renowned for their use of 'honest' materials (Dessauvage, 1950-1980, Sterken & D'hoe, 2022). However, when looking deeper into the construction of his first projects, Dessauvage appealed on hidden beams and columns–concealed behind masonry walls and false ceilings– to create the effect of a sober and open building with as few supporting columns as possible (Ardui & Sterken, 2021, Van Hecke, 2024).

3.1 *Balancing form and function: The role of the roof in Dessauvage's churches*

While designed around the same time and similar in spatial expression and materialisation, each parish church was uniquely designed for its context (Sterken, 2013), shaped by Dessauvage's evolving design attitude and other external factors that controlled (and changed) his design process. This is especially the case for the Sint-Jozef church in Vosselaar (Figs 1,2,5). Initially based on Dessauvage's winning design for the Pro Arte Christiana competition in 1958, he eventually changed the project completely due to economic but also technical reasons (Dessauvage, 1960-1967). The church became a liturgical centre. The roof structure was conceived as a grid structure on which the several functions, like the sacristy, the organ and two patio's, were aligned. The horizontal windows all around the roof created the effect of a floating roof element. A similar approach to the roof is visible in his designs for the Sint-Rochus memorial chapel in Aarschot (Figs 9,10,13) and the Sint-Jozef Ambachtsman chapel in Willebroek (Figs 16,17,20). Both chapels are characterized by a strict geometrical and open plan, covered by a roof that is supported on a limited number of supporting points. Furthermore, as for the exterior of both churches, the roof is conceived as a large, concrete 'crown', evoking a sense of gravity and mass (Sterken, s.d.). Especially for the chapel in Aarschot, this crown made the building 'stand out' more from the uneven landscape it is embedded in, while in the interior the slanted ceiling edges ensure "that it is no longer merely a structural element that anonymously defines the space" (Dessauvage, 1960-1965). Also the fourth example, the Sint-Paulus church in Westmalle (Figs 24,25,28), started from a geometrical layout similar to the three other examples. However, the parish church gradually evolved into an organic and 'more engaging' project, drawing inspiration from the surrounding nature and the 'communal' feeling (Dessauvage, 1967). The roof played a defining role in this, aligning with the three-aisled floor plan and drawing light and nature inside, thereby creating the building's autonomous character (Dessauvage, 1967, Böröcz & Sterken, 2014).

During Dessauvage's design process, the materialization of the roof structure would often change along with his new concepts. For Vosselaar, the concrete grid structure had to be accompanied by a secondary structure of metal "Litzka" beams, hidden behind a false ceiling, to make the span of the building feasible (Fig. 3) (Dessauvage, 1960-1967). For the chapel in Aarschot, where Dessauvage treats the entire roof element as a 'structure', the roof in fact consists of multiple metal trusses hidden behind a false ceiling of stone mesh, to create a smoot and uniform surface (Figs 11,12) (Dessauvage, 1960-1965). This is quite similar to the construction of the roof for the chapel in Willebroek. First, a glue laminated construction was considered to span the hexagonal form. Eventually, the choice was made for a steel roof truss for the chapel, both designed and executed by a local construction firm (Fig. 18) (Dessauvage, 1962-1963). As for Westmalle, the roof consists of a ribbed concrete structure, also largely concealed behind a plastered ceiling (Fig. 26) (Dessauvage, 1967).

At first glance, Dessauvage's attitude towards the roof structure and ceiling suggests that their spatial consequences for the architecture of the parish church were of more importance than their materialization. Dessauvage always started his designs from a study of the floorplan, focusing on the internal organization of the liturgical activities housed within his buildings. As he himself noted with Aarschot, for him, the roof 'structure' was a spatial element that shaped the exterior of the building while creating a large, open interior space. In the first examples, the roof was indeed treated as this abstract element and the emphasis was laid on the roof windows that strengthened the experience of light and liturgy. However, in the design of Westmalle, the roof would also further enhance this, providing the necessary hights and connections to the surrounding nature.

Although each example was constructed in a different way, this was not done intentionally. Nevertheless, since different materials and construction techniques were used, the roof structure would impact the spatial experience of the building in different ways: sometimes directly, sometimes not at all, as long as the roof adopted the 'appearance' and 'form' that Dessauvage envisioned for his project, both on the inside and the outside. This attitude and lessened attention towards how the roof was executed, seems however not to be without consequences. Today, these post-war churches show severe signs of degradation. For instance, moisture damage at the roof is often visible due to the low quality of the material or a bad connection between construction materials. The rain pipes, often clogged because of poor maintenance, enhance this. Almost all of his projects also suffer from rising damp, due to the construction methods that were used then and the high groundwater level (Van Hecke, 2024).

3.2 *Out of sight, out of mind: Challenges and possibilities in adaptive reuse*

Today, each of the four churches finds itself in a distinct phase of their service life, offering insight into the various stages of adaptive reuse for post-war parish churches. In Westmalle, the church hasn't been altered yet for other functions as it is still an active church that is rented out for secondary uses as an extra income source. The chapel in Aarschot is rarely used, and a refurbishment study was conducted to add a museum function to the building. In Vosselaar, the parish church recently underwent an intense repurposing process to make a library and cultural centre (Sterken & D'hoe, 2022). Finally, the chapel in Willebroek was already repurposed in the 1990s by the Red Cross as a blood donation and training centre. This part of the paper focuses on the life of these parish building after completion, zooming in on how structural and pathological problems (together with the original design intention) would become a decisive factor during their reuse process.

After the church in Westmalle was constructed, several problems in the roof element limited the (new) use throughout the years: severe moisture damage and heating problems, exacerbated by the poor execution of the window profiles by the subcontractor (Dessauvage, 1967), needed to be tackled in the last couple of years, which led to the complete replacement of these window elements (Fig. 27). The morphology of the roof also creates discussions within the local community on the possible future use of the building. Because the roof generates a distinct echo, some want to acoustically adapt the ceiling to open it up for a wider range of functions while others do not, as the echo is seen by them as an intrinsic quality of the church, one that enhances the already present activities (e.g. choir singing) (Rothier, 2024).

Before the refurbishment study of 2023 for the chapel of Aarschot, there was little information about its roof structure. The false stone mesh ceiling made inspection difficult, leading to its omission in previous reports by the provincial organisation responsible for the maintenance of such listed buildings (Monumentenwacht, 2020). In 2022, a simulation of the loadbearing capacities of the roof was made, based on existing plans, current standard loads, and non-destructive techniques (Fig. 14). The simulation indicated that the roof could support some additional load (for e.g. UV-panels) but that this was limited (BAS bvba, 2022). However, the conclusions from this simulation are few, as some elements weren't taken into consideration, like the connection between the roof and columns; as such, possible corrosion and thermal expansion at this location could still affect the calculated loading capacity of the structure (Jaspaert, 2024). The simulation did however include the introduction of a new ceiling: since the current stone mesh ceiling doesn't have any loadbearing properties, a new ceiling was deemed necessary to improve the acoustical performance, to implement new techniques and to delineate the new museum function (Fig. 15) (Heynickx et al., 2023). The new organisation is thus translated into the new false ceiling, but doesn't connect to the roof structure itself, that is only encountered as an empty shell that needs to be repaired.

Also in Vosselaar, the hidden nature of the roof was a significant factor in causing delays and increased costs during the repurposing process of the church. Despite renovations of the entire roof in the 1990s, thermal and mechanical fractures re-emerged in the concrete beams afterwards. Notably, corrosion of the (non-twisted) reinforcement steel at one corner raised concerns about potential failure (Figs 7,8). The precast concrete slabs also needed to be replaced: during the renovation, it was discovered that they were placed upside down, with the main reinforcement bars thus at the top instead of the bottom of the slabs (Fig. 4) (Sterken & D'hoe, 2022). These construction errors stemmed from the contractor's inexperience, the choice for low-quality concrete (Ardui & Sterken, 2021), and the strained collaboration between Dessauvage and engineer De Cuyper, possibly leading to insufficient site inspections (Dessauvage, 1960-1967). Although eventually solved, these issues posed extra challenges to the already long list of requirements for the new function (Sterken & D'hoe, 2022). The different components of the new program, such as the library, office rooms, study space and multipurpose room, are arranged in alignment with the roof structure's grid (Fig. 6). However, despite the open plan, the density of the program has reduced the space's sense of openness and fails to fully utilize the roof's potential as a 'structuring' element (Fig. 2). Furthermore, unresolved water infiltration issues necessitated multiple repairs post-completion to the roof, with one ongoing leak still present today (Proost, 2024).

In Willebroek, the roof was not addressed when the Red Cross moved in: only new windows and an additional roof on the patio were added (Fig. 19). Internally, the space was compartmentalized, annihilating the effect of the floating roof and the large open area completely (Fig. 17). In the subsequent years, a lack of maintenance led to severe moisture issues in the roof structure (Figs 22,23) (Menting, 2024), ultimately forcing the Red Cross to seek an alternative location because the building was deemed unsanitary for medical procedures (Fromont, 2024). This lack of maintenance was caused by the strange management constellation that had made no clear agreements about the upkeep of the building: the Red Cross had a lease with the municipality, who had an arrangement with the church fabric, the Flemish Catholic organisation that owns and maintains the parish church building (Menting, 2024). Today, the church fabric faces significant renovation costs. In addition to moisture damage, the roof of the chapel has the lowest thermal comfort among the examples in this paper, with a U-value of 5.88 W/m²K (Fig. 21) (Thérèse, 2024). Without assistance from the municipality, who previously already opposed other repurposing options, the church fabric now seriously considers the demolition of the chapel (Menting, 2024).

In the adaptive reuse of Dessauvage's parish churches, it remains crucial to preserve the open space facilitated by the large spans of the roof structure. When this principle is neglected, as in Willebroek, the fundamental design intention—and the primary function of the roof structure—are compromised. In Vosselaar, even though the open plan is preserved, the overcrowding from new functions, aligned along the concrete beams, detracts from the intended spatial effect of the grid structure. Compared to larger reuse projects that are often compartmentalized in smaller units (like office buildings, industrial sites and large cathedrals), it thus seems difficult to adapt these parish churches to new requirements when a new program is projected onto the building without annihilating Dessauvage's original design intention.

Combined with the presence of several degradation issues, Dessauvage's churches now demand increased attention to address and adapt their material and structural integrity. These adaptations are often confined to the "void" between the roof structure and ceiling, a space Dessauvage originally minimized to preserve the unity between structure and spatial experience. However, in the example of Vosselaar and Aarschot, all interventions were required to remain hidden in this void (Sterken & D'hoe, 2022), enlarging the gap between roof and ceiling, thus risking the loss of the roof's conceptual role. Despite their entanglement, both layers are thus treated entirely different: the hidden roof structures are only considered from a pragmatic perspective, to reinforce and repair them as necessary. In contrast, the false ceiling is sometimes actively utilized in the design, but often retrofitted or completely replaced. A more integrated approach to both sheared layers is currently missing.

4 CONCLUSION: FROM EMPTY SHELL TO MEANINGFUL SHELTER

The changes in liturgy and construction during the post-war period will lead to a radical transformation in religious architecture. Post-war parish churches almost completely break away from the traditional typology of parish churches, resulting in a different attitude towards the design and construction of the roof. The roof structure and ceiling become more entangled, actively shaping the experience of the church building both internally and externally. However, it becomes clear that despite its structural and spatial importance in parish church architecture, the roof is mainly treated pragmatically in the repurposing of post-war parish churches.

For Dessauvage, the roof structure was a way to realise the large spans of his designs, but remained largely hidden. However, by maintaining a minimal distance between roof and ceiling, Dessauvage ensured that the roof could shape both the interior and exterior experiences, even when its structural logic was not fully visible. The roof served an organizing role for the building, both on the outside (where the roof structure was explicitly articulated) and on the inside (though not always structurally honest in exposing the supporting elements).

Unfortunately, this strong entanglement eventually creates degradation in the church, influenced by the experimental construction sector of the post-war period, a lack of maintenance and previous alterations to the building throughout time. This turns the roof into a problem rather than an opportunity for adaptive reuse. Preserving the open space in Dessauvage's parish churches is crucial for maintaining their design integrity, as neglecting this principle compromises the roof structure's function. The role of the void might be overlooked, as pragmatic approaches to roof repairs are often limited to basic reinforcement rather than a holistic reconsideration of the structure's design role.

There is thus a need to look more into the material dimension of parish churches during their adaptive reuse, especially the roof structure and ceiling. These elements not only provide the large span of the church space and shape interior and exterior, but also embody different social and economic relationships of the post-war building culture that literally and figuratively shaped them. By starting from the uniqueness of their materialisation in the adaptive reuse of post-war churches, not only defects in the building can be addressed, but also maintenance and management issues that often come with the upkeep of parish churches. This approach may even create new spatial possibilities that accommodate functions tailored to the building instead of the other way around. In conclusion, this paper advocates the transition from an empty shell to a meaningful shelter, where both construction and function are brought closer together.

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Towards sustainable structures with reused timber: Validation of enhanced technical standards and practical guidelines

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ABSTRACT: This paper explores the current possibilities for reusing structural timber, emphasizing the importance of combining reuse assessments with a dismantling protocol. By testing both visual and mechanical evaluation methods, the study investigates how effectively structural properties can be retained in reclaimed timber elements while accounting for reuse-typical anomalies. These anomalies present unique challenges to structural integrity assessments and require careful documentation. Additionally, the research introduces a traceability framework to record dismantling, storage, and transport stages, preserving information on prior use, dismantling method, and any damage. This structured approach enhances risk management and builds confidence in reusing timber for new applications. Findings suggest that visual grading, when combined with traceability and selective testing, can provide an efficient, case-specific solution to reusing timber in construction while minimizing the need for extensive testing. This protocol offers a promising foundation for expanding sustainable timber reuse practices.

1 INTRODUCTION

Today, when structural timber is found at a demolition site, it usually ends up in a recycling plant. (emis, 2024) Reuse of structural timber elements is not yet common practice, resulting in a loss of material value and premature release of the stored CO_2. (European Panel Federation, 2019) The main reasons for this are the demolition practices often resulting in damaged timber elements on the one hand, and the lack of a technical framework to assess the technical properties of reclaimed timber on the other hand. (Poncelet, Vrijders, & Deweerdt, 2020) Indeed, since existing frameworks and standards are designed for the controlled production process of elements made out of virgin materials, they are not aligned with the challenges of reuse.

This paper presents some results obtained within a collaborative research project between a research institute and a private contractor. By providing case studies focused on the reuse of timber for structural applications, the contractor challenges the existing technical framework. The general objective of the research is therefore to transition from a case-by-case approach to the development of a comprehensive technical framework suited for reclaimed timber.

In this paper, both the potential and the limitations of different existing methods for evaluating the performances of reclaimed timber for its reuse in structural applications are examined.

First, the extension to reclaimed timber of the existing Belgian standard for the visual inspection of (virgin) timber is considered. The idea is to combine visual examination of the reclaimed timber with chosen mechanical tests, in order to evaluate the reliability of visual grading on the one hand, and to measure the impact of different reuse-typical anomalies on the other hand.

Secondly, a dismantling protocol is proposed to ensure the traceability of timber elements and preserve their structural characteristics. The presented proof of concept includes a code of good practice for dismantling, storing, and transporting timber, along with forms tailored to each type of element to collect information and maintain traceability throughout the process.

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Then, some cases studies illustrate how adapted methodologies have be developed to ensure that the properties of reclaimed timber match the requirements of the new application.

Finally, the results of the adopted methodologies are discussed, as well as the current best practices and future research directions for effectively integrating reclaimed timber into new construction projects.

2 CHARACTERISATION OF RECLAIMED TIMBER: SOME CHALLENGES

In order to be used for structural purposes, timber must be graded. In the Belgian context, this can be done for virgin timber thanks to a visual inspection, following the standardized methodology of NBN B 16-520, or by mechanically grading according to NBN EN 408+A1. The elements can then be classified in visual strength classes (S) or mechanical strength classes (C), which are linked to each other as shown in Table 1. According to standard NBN EN 408+A1, minimum values for the mechanical parameters (density, bending strength and local modulus of elasticity in bending) can be assumed for each strength class (Table 1).

Table 1. Visual strength class and mechanical strength class according to NBN B 16-520 and NBN EN 338.

Visual strength class		S4	S6			S8		S10
Mechanical strength class	C14	C16	C18	C20	C22	C24	C27	C30
$f_{m,k}$ [N/mm²]	14	16	18	20	22	24	27	30
$E_{m,0,mean}$ [kN/mm²]	7,0	8,0	9,0	9,5	10,0	11,0	11,5	12,0
ρ_k [kg/m³]	290	310	320	330	340	350	360	380

When it comes to the characterisation of reclaimed timber, one can think that extra parameters should be involved in the visual classification method, in order to take into account some anomalies due to the history of use or dismantling of the reclaimed elements.

This section is devoted to the analysis of the impact of several of these parameters with final objective to propose an adaptation of the current standards. The analysis is carried out on the basis of visual inspection and mechanical testing of a series of 30 beams provided by the contractor.

2.1 *Visual grading vs mechanical testing*

The 30 reclaimed beams have been visually graded into 4 visual strength classes according to NBN B 16-520. For the following analysis, timber beams classified in the same visual strength class has been assigned to the same lot: 16 of the beams were assigned to class S10, 5 were assigned to class S8, 2 were assigned to class S6, 0 were assigned to class S4 and 7 beams were rejected.

Afterwards, the density, bending strength and local modulus of elasticity in bending have been determined for each individual beam according to NBN EN 408+A1, in order to be compared to the visual grading. The results are presented in Table 2.

For each lot, the mean and characteristic values for bending strength and density, as well as the mean modulus of elasticity of the previously determined lots will be. These values can be found in Table 3. For lot S6 the statistical values are non-representative (2 beams).

Density - The mean values of the density of the different lots is greater than the mean values of their corresponding strength class. Furthermore, none of the samples has a density lower than the characteristic density of its class.

Bending Strength – The characteristic values of the different lots are smaller than the characteristic values of the corresponding class. Also, half of the individual beams show a bending strength smaller than the characteristic values of their corresponding class.

Table 2. Results for visual grading, density, bending strength and modulus of elasticity.

N° Beam	Visual grade	ρ [kg/m³]	f_m* [N/mm²]	$E_{m,0}$ [kN/mm²]
1	S6	501		6,8
2	S8	424	20,5	6,0
5	S8	597	33,9	9,0
6	S8	577		9,6
8	S10	584	31,6	9,9
9	S10	502	27,5	8,4
10	S10	635		11,2
12	S10	577		12,9
13	S10	409	29,4	10,9
14	S10	559	35,8	12,4
15	S10	471	39,5	12,4
16	S10	454		12,0
17	S10	405		8,2
18	S10	475		10,7
19	S10	496		9,2
20	S10	566	28,4	13,1
21	S10	456		8,0
22	S8	490		9,5
24	S10	552		11,2
25	S10	428		7,6
26	S10	461		8,3
28	S6	562		10,5
30	S8	445		6,6

* Bending strength was only tested for beams that didn't have to be reused in the case studies

Table 3. Results for density, bending strength and modulus of elasticity for every lot.

Lot	ρ_{mean}	ρ_{sdev}	ρ_k	$f_{m,mean}$	$f_{m,sdev}$	$f_{m,k}$	$E_{m,0,mean}$
	[kg/m³]	*[kg/m³]*	*[kg/m³]*	*[N/mm²]*	*[N/mm²]*	*[N/mm²]*	*[kN/mm²]*
S10	502	69	389	32,0	4,7	24,3	10,4
S8	507	78	379	27,2	9,5	11,6	8,1
S6	532			*			8,7

Modulus of elasticity - The mean values for the modulus of elasticity of the different lots are lower than the expected mean values linked to the visual grading classes.

2.2 *Visual grading adaptations for reuse*

The sample in this research was small, too small to be able to propose adjusted visual grading identifiers. The results show that the visual grading overestimated the mechanical characteristics of the beams. Timber is a natural material, with large variabilities in material properties. Therefore a bigger sample is necessary to draw any conclusions. It is impossible to judge whether the visual standard is applicable to reclaimed timber or not based on these tests.

Starting to use the existing standard for visually grading timber is not possible due to several factors. The visual grading standards differ from country to country, and are only applicable to certain local wood species and growing areas. Since it is not possible to know the growth area of a reclaimed beam, it is not possible to know which visual standard should be used. Also, the visual standard only applies to solid timber, so it cannot be used to grade laminated timber. Apart from that, the visual defects (like knots) are harder to recognise than on virgin timber beams. Let alone the reuse-typical anomalies which are not included in these standards.

2.2.1 *Reuse-typical anomalies*

When visual grading reclaimed timber, different types of reuse-typical anomalies can be taken into account such as nail holes, fall fractures, compression damage and sawn-out damage. For every type of anomaly a proposition will be done on how they should be evaluated whilst visually grading timber.

In this paper, only one type of damage has been considered and tested: compression damage caused by sorting grabs. This type of damage will be mimicked by compressing the middle of the beams with different loads which correspond to different types of sorting grabs. Comparing the modulus of elasticity in bending before and after the damage will show the expected impact this dismantling method has on the capacities of the timber beams.

When nail holes were detected in the beams, they were judged as if they were knots. Just like with knots, nails push away the wood fibres. In the nail holes (and knots), there is no tension strength. Since the nail holes detected during the test for this paper were small, they didn't have impact on the knot projection. This means the visual strength class of the beams didn't change. Future research steps will focus on quantifying the impact of nail holes on the structural integrity of the beams.

A fall fracture is a crack in the timber perpendicular to the wood fibre that occurs after a fall from sufficient height. Since a fall fractures interrupts the wood fibre, no tension forces can be absorbed. Therefore, in the case of a fall fracture, the beam gets rejected. During the tests for this paper, none of the beams showed this defect. In the future, the damage caused by a fall fracture will be mimicked by dropping the beams from sufficient heights to quantify the impact.

With mechanical damage, a distinction is made between sawn-out damage and damage due to compression caused by a big force. Sawn-out damage can be recognised by wood fibres that have been cleanly cut off. For sawn-out damage, the visual grading doesn't differ from the usual visual grading. Nonetheless, when designing a structure, the cross section used to calculate the strength of the beam should be measured there where it is the smallest.

Ten beams were damaged by compressing the wood fibres in the middle of the beam. Different compression forces were used, relating to different types of sorting grabs. The modulus of elasticity of each beam was tested before and after the damage was applied. As shown on Figure 1. every beam has a reduction of modulus of elasticity. The average reduction amounted to 20%, with reductions over 60% for higher compression forces. These results are without a correction for the reduced cross section. Since it is not possible to determine the compression force of the sorting grab used for disassembly, a rejection of the beams that visually show compression is suggested.

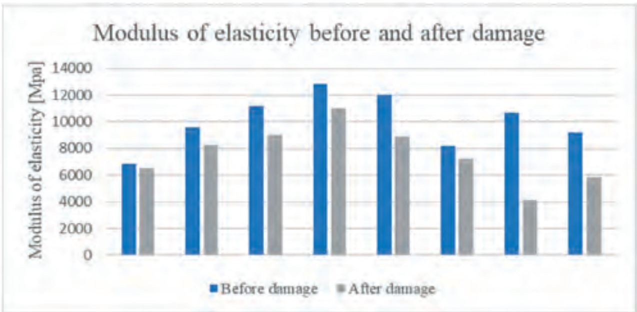

Figure 1. Modulus of elasticity before and after damage.

To minimize variability between samples in the continuation of this research, the different kinds of damages could be artificially introduced to already-graded virgin timber. The findings could then be used to expand visual grading standards by incorporating additional visual indicators specific to reuse-related anomalies.

The impact of insect and fungal infections as well as rot will not be further tested in this research, since it also applies to virgin timber and is already incorporated in the existing visual grading standards. This however does not mean the impact is not important for reclaimed timber.

In summary, adapting visual grading for reclaimed timber requires addressing the limitations of current standards and incorporating assessments of reuse-specific anomalies. By conducting further research with larger sample sizes and controlled damage scenarios, it is possible to refine visual grading methods to better tackle the challenges of evaluating reclaimed timber for structural reuse.

3 DISMANTLING PROTOCOL

Currently, visual grading alone cannot reliably determine the structural characteristics of reclaimed timber beams. However, insights from evaluating various reuse-specific anomalies have already provided initial criteria for identifying timber with reuse potential and understanding which dismantling methods may compromise its future applicability.

Key factors such as the timber's application in the donor building, the dismantling method used, and storage practices significantly influence its condition and expected performance. Maintaining traceability throughout the process is crucial, as it allows new users to accurately assess the current state of the beams and their suitability for reuse (Davari, Jaberi, Yousfi, & Poirier, 2023).

This part of the research employs a qualitative approach to identify best practices through interviews with industry professionals, including contractors, architects, and testing experts. These interviews explore the challenges and solutions encountered at each stage of the reclaiming process, producing a comprehensive set of "do's and don'ts." The resulting insights will guide the creation of a practical framework, incorporating a code of best practices and customized forms to support traceability and build confidence in the reuse of structural timber.

A complete guideline, called "Dismantling Protocol" was designed including descriptions of the correct way to dismantle, store and transport timber beams for reuse. For each step of the process, the guideline offers a form with all the necessary fields to preserve the traceability and contribute to risk management.

Since different parties will be involved in different steps in the process, the information is stored in a decentralized database. Using a reference code for each project and for each lot of timber beams, the information of the different parties involved will be gathered. As a result, different documents can be generated, like material passports for the different batches, traceability tags, proof of reuse, and so on.

The proof of concept can be found through this link.

Systematic guidelines for dismantling, storing, transporting and tracking timber (and other materials) can contribute to the quality and safety of reuse. There lays a great potential in the use of a decentralized database for traceability. This will streamline the communication between stakeholders across the reuse supply chain whilst safeguarding traceability. More so, it could serve as a way to align offer and demand and as a way to proof reuse.

The Dismantling Protocol is a living document. Thanks to feedback from the industry, this document will keep improving over time. In the continuation of this research this document will be expanded to include multiple reuse materials with their specific methods for dismantling, storing and transporting, as well as the collection of the necessary data.

4 CASE STUDIES: AN APPLICATION-BASED APPROACH

Even though the existing visual grading standards currently cannot be used for grading reclaimed timber, this does not have to mean that reuse of timber in structural applications is impossible. When timber is harvested with a new application in mind, there is not always the need to evaluate all the different characteristics, let alone assign a strength class to every beam. In this part, the requirements of three different applications will be defined. This means that for each application, a specific assessment method can be determined for the different requirements. Three examples of specific requirements linked to three different cases studies are presented in this section. The harvesting process of the timber used in the different cases was supported by the Dismantling Protocol to ensure traceability, careful dismantling and storage to contribute to the risk management.

4.1 *Reuse in a raised floor*

In a construction project in Brussels, the contractor wanted to use reclaimed timber to build a raised floor. When timber beams are reused on a concrete slab to support a raised floor (see Figure 2), they are not subjected to bending forces. Consequently, it is unnecessary to evaluate their bending strength or modulus of elasticity. Additionally, since the compression strength of timber exceeds the design value of floor loads (with floorboards directly laid onto the beams), compression tests are also deemed unnecessary.

Figure 2. Reuse in raised flooring.

However, the quality of the timber remains a critical factor. Beams must be free of rot and insect damage to ensure their suitability for reuse. A visual inspection was conducted to identify appropriate beams, with a screwdriver test (Figure 3) employed as part of the assessment. In this test, fractures in healthy timber were observed to follow the direction of the fibers, while decayed timber exhibited breaks into small fragments or splits across the fibers. (Rotor vzw, 2021)

Figure 3. Screwdriver test.

Humidity levels in the beams were also monitored. Only when the relative humidity of the timber fell within the acceptable range were the beams covered with other construction materials to complete the raised floor system. This approach ensured the durability and performance of the reused beams in this specific application.

4.2 *Reuse in a roof structure*

In the same project in Brussels, the contractor wanted to reuse laminated timber beams in the roof structure of a communal space on the first floor of an apartment building. The structure had already been designed. Therefore, the expected loads the structure will have to endure, as well as the maximal deflection that is accepted are known.

The batch of beams available was not homogeneous, either in terms of dimensions (cross-section, lengths) or the apparent quality of the wood. Therefore it was decided to opt for direct bending tests according to EN 408 to characterise the mechanical behaviour of the laminated timber beams. The loading is limited to a value that generates a bending moment with an intensity identical to the design bending moment (ULS) likely to act in the real structure. Supposing the beams are able to resist to this loading without any damage, we can consider it as a non-destructive testing procedure. So, it allows the specific reuse of all the tested beams for which the test was successfully passed. Moreover, the tests allow to obtain a safe estimate of the effective bending strength without any statistical uncertainty, as well as an effective measure of the E-Modulus (using a DIC measurement system). The tests showed that all the beams meet the stability requirements and can therefore be used for the application in question.

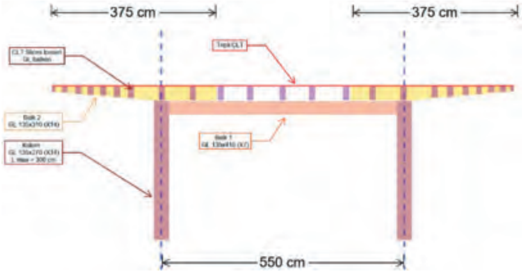

Figure 4. Cross section timber structure.

Figure 5. Timber construction with only reused beams.

4.3 *Reuse in a floor structure*

For a construction project in Genk, the contractor wanted to reuse timber beams in a load baring floor structure of a residential building. The contractor worked together with a timber trade for the supply of timber. Since testing every beam individually would be too expensive, they opted to only test a fraction of the beams. Therefore, the trained timber trade visually graded the beams into different lots. The contractor and timber trade agreed on using beams that are visually graded into S10, the beams that visually look the strongest. To assure that the beams of this lot are strong enough for the application, a sample was taken out of the lot. In total 10 beams were tested on bending strength, modulus of elasticity and density.

The results showed a characteristic bending strength of 24,3 N/mm², just higher than C24. The mean modulus of elasticity was equal to 11,1 kN/mm², which is also just higher than C24. The characteristic density amounted to 404 kg/m³, which is just higher than C40.

Since for this application, the most important characteristic are the bending strength and modulus of elasticity, the contractor and its design team assumed the strength class of C24 to design the structure.

Figure 6. Bending test solid timber beam.

5 CONCLUSION

This paper highlights both the potential and the current limitations of visually grading reclaimed timber for reuse in construction. While visual assessment is not sufficient as a standalone method, it offers significant value in initially estimating which timber elements are suitable for reuse. Visual grading can efficiently identify usable wood and distinguish it from damaged or degraded material, streamlining the reuse process.

One of the key outcomes of this paper is the development of a dismantling protocol, which enhances confidence for the end user. By documenting the previous applications of the reclaimed wood, including whether it met prior usage requirements, as well as ensuring careful handling during dismantling, the protocol helps to reveal any potential hidden defects. This structured approach mitigates risks associated with unknown wood conditions, ensuring a clearer understanding of the timber's quality and history.

Currently, a case-by-case approach dominates timber reuse practices, which often involves testing individual beams. However, this paper suggests that combining traceability with visually sorting beams into batches can help limit the number of tests required, providing a more efficient pathway for reuse. When the requirements of the new application are well-defined, not every beam must undergo exhaustive testing or be assigned a specific strength class. Instead, a selective testing approach, informed by the known performance demands of the new structure, is often sufficient. This flexibility is a distinct advantage of reuse, allowing projects to focus only on relevant tests and avoid unnecessary procedures.

Future steps in this research should focus on quantifying the various types of damage typical to reclaimed timber through controlled testing. To minimize variability between samples, this damage could be artificially introduced to already-graded virgin timber. The findings could then be used to expand visual grading standards by incorporating additional visual indicators specific to reuse-related anomalies.

Furthermore, further investigation is needed to determine which non-destructive testing methods could effectively assess the structural characteristics of reclaimed timber. These methods could complement visual grading, providing a more accurate and comprehensive evaluation framework to support the sustainable reuse of timber in construction.

Overall, this study underscores the promise of timber reuse in structural applications. With further refinement, visual grading, combined with traceability protocols and non-destructive testing, can serve as a foundation for a more sustainable and effective practice of timber reuse in the construction industry.

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Embodied carbon calculations as a design tool in the adaptive reuse of a campus building

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ABSTRACT: This paper presents a case study of a small campus building adaptive reuse and preservation project. BEAM was effectively used to calculate material carbon emissions at both the building scale and assembly scale for wall and roof options. Sankey diagrams were used to visualize these results and a carbon key developed to compare the emissions to more relatable metrics. This is a replicable process to effectively communicate CO_2e information for projects and aid project teams to make decisions for a low carbon building future.

1 INTRODUCTION

Historically, sustainability standards for the energy use of a building focused almost exclusively on operational energy and, therefore, operational carbon emissions. As the architecture and construction industries have become better at building net zero operational energy buildings, the net impact of embodied carbon relative to operational carbon and lifecycle emissions has increased (Rock, 2019; UN, 2023). To keep global warming to a 1.5-degree Celsius limit, total emissions from buildings needs to be eliminated by 2040 (Architecture, 2030). Understanding the speed and scale of development currently underway, and understanding that material carbon emissions are released today as materials are sourced and processed, reducing these up-front emissions becomes imperative. One way to do this is to recognize the embodied carbon value of our existing building stock and extend the usable life of these structures through adaptive reuse and historic preservation (Rosenbloom 2023). This paper will discuss a case study of a small wood framed building on the Mount Holyoke College campus and the role of embodied carbon calculations and visualizations as part of a holistic design process to quantify the carbon impacts of an adaptive reuse project while also providing data to aid the design team select wall and roof assemblies.

2 THE PHOENIX PROJECT

2.1 *The Phoenix*

Faced with the question of whether to demolish or renovate, Mount Holyoke College made the decision to renovate a small campus building as it has historic significance to the town and campus and the project aligns well with the campus net zero 2037 goal. The "Phoenix" is a small wood framed building (Figures 1 and 2) that was home to the first all-women's fire brigade in the United States. The campus archives held records of newspaper articles from the late 19th

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century detailing the exploits of student firefighters and the South Hadley fire chief had historic photographs showing a photo from the mid-20th century with a fire engine in front of the building. With this history, there was reluctance to demolish the building despite the fact that it had fallen into disrepair in the last decade as it stood empty. Seeing that the foundation and structural systems were intact, the design team made the case to the college that a historic preservation of the exterior and an adaptive reuse of the interior to make it net-zero operational energy would result in a lower embodied carbon project and an exciting case study for how Mount Holyoke College can innovate in the renovation of the smaller wood framed buildings on the campus perimeter as part of the larger campus goal to achieve low lifecycle carbon buildings.

Figure 1. Historic Photo of the Phoenix as an active Fire Station.

Figure 2. Plans of the Phoenix as existing and proposed showing added in yellow - 2x4 stud wall, insulation, new windows, kitchenette and accessible restroom.

2.2 *The project team*

The design team is a collaboration between the authors - an architecture professor with an active design practice who teaches on the campus, working with an architecture firm who practices in the region. Mount Holyoke College was supportive of engaging students in the design process and over the course of the year, six undergraduate liberal arts architectural studies students worked with the architecture team on the design, visualizations, and embodied carbon calculations. All of the students selected were students who would be on campus during construction in the 2024-25 academic year giving them the opportunity to see the project completed and participate in weekly site meetings during construction.

2.3 *The process and method*

Over the course of an academic year, the project team worked to research the archive, select an appropriate carbon calculator tool, develop schematic designs, understand where there were options that would impact aesthetics, embodied carbon and final cost, and investigate those options to abet the college in the final design and material decisions. This paper will focus on the embodied carbon calculations and diagrams for the selection of the wall assembly.

3 MATERIAL CARBON EMISSIONS

3.1 *Choice of carbon calculation tool*

In the past decade, a number of tools have become available for material carbon estimation calculations. Our process required a tool that was simple enough for undergraduate liberal arts architectural studies students to be able to use without extended training. Tally, Beacon, Kaleidoscope, Epic, Care and BEAM were all considered as potential tools. Tally (https://kierantimberlake.com/page/tally), developed by Kiernan Timberlake Innovations and Beacon (https://www.thorntontomasetti.com/capability/beacon), developed by Thorton Tomasetti, are both Revit plug-ins and therefore not suitable for our students. Kaleidoscope (https://payette.com/kaleidoscope/), developed by Payette, only works for given assemblies with a focus on larger building types. EPIC (https://www.epic-docs.dev/), the Early Phase Integrated Carbon tool built by C. Scale also did not seem useful as its strength is in testing a wide range of broad strokes at the start of a project. In our case, with many of the parameters already determined by the fact that we were doing an adaptive reuse project, EPIC was not as fine grained as we needed to be useful. CARE (https://caretool.org/), the Carbon Avoided Retrofit Estimator provided overall estimated emissions but did not allow for a fine-grained analysis to help in our decision-making process.

Ultimately, we chose to work with BEAM, the Building Emissions Accounting for Materials Estimator, developed by the Builders for Climate Action. BEAM allows for fine grained comparisons between different material selections and assemblies calculating the A1-A3 “Product Phase” emissions of embodied carbon within the building materials without the complexity of a BIM model and requiring only square footages of different materials. BEAM Estimator data outputs enabled us to quantify the carbon impact of renovating instead of demolishing and rebuilding, as well as more detailed data about the carbon impacts of alternative wall and roof assemblies that contributed to design decisions for assemblies and material selections during the design phase of the project. BEAM’s usability also enabled involving undergraduate research assistants in the process, an important factor for Mount Holyoke College.

3.2 *Calculating and visualizing materials carbon emissions for Phoenix*

A summary diagram visualizing the carbon impact of adaptive reuse versus new construction (of the same building) with various options for roof and wall assemblies in the renovation can be seen in Figure 3. To the left is the base scope – that part of the building that would be constant – while to the right are two options considered for roof assemblies that also had big design implications and three options considered for wall assemblies that didn't have as significant design implications but did have financial and carbon cost implications.

To develop this summary diagram, fine grained analysis was undertaken in BEAM to understand the carbon impacts of each component of the existing building. Figure 4 shows a detailed breakdown of the existing materials within the base scope CO_2e as outputted by the BEAM software. The base scope includes those aspects of the building that had a single obvious pathway forward including keeping the concrete foundation, insulating the flat roof over the former truck bay as a hot roof with polyiso roof insulation and a roofing membrane, and drywall on the interior walls. To make this data more visually legible, Sankey Diagrams were developed in illustrator (Figure 5). The bottom half of the Sankey Diagram shows the carbon emissions associated with all of the materials in the existing building if they were to be installed today. The top half of the diagram shows those base materials that will be added as part of the renovation. Color was used to group materials and to easily associate existing and added components of the same materials. For example, a light turquoise was used for all windows in the project including those in the existing building that are to be removed and new windows that will be added in the renovation. Components that cannot be reused and will be discarded transition from a color to gray to indicate waste.

The Sankey visualization makes clear our accounting methods in calculating our total CO_2e. Although we calculated the embodied carbon in the existing building using BEAM, we did not count these emissions for the current adaptive reuse project as these emissions were released into the atmosphere when the project was first built over 100 years ago. The CO_2e that were already released that we can continue to use productively is the advantage that we gain through the adaptive reuse and renovation project. We did, however, count as part of our project emissions the end of life (C1-C4) emissions for those materials that we are removing from the project.

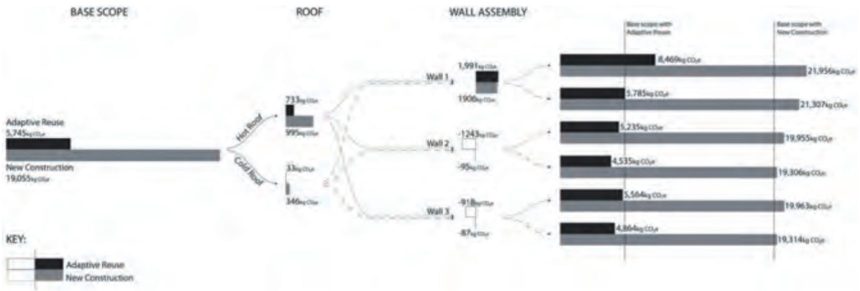

Figure 3. Summary Diagram of Material Carbon Emissions with Options.

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SECTION	CATEGORY	MATERIAL	NET EMISSIONS	CARBON EMISSIONS	CARBON STORAGE
[illegible]	CONTINUOUS CONCRETE FOOTINGS	Concrete - 0-2500 psi. Standard mix / NRMCA [Industry Avg] US & CA]	2,210	2,210	0
[illegible]	CONCRETE SLABS	Concrete - 0-2500 psi. Standard mix / NRMCA [Industry Avg] US & CA]	6,747	6,747	0
[illegible]	CONCRETE MASONRY UNIT [illegible] WALLS	CMU - Normal weight / 8" Normal weight blocks / 390 x 190 x 190 mm / CCMPA [Industry Avg] CA]	531	531	0
Windows	WINDOWS – DOUBLE-GLAZED	Window - double glazed / Wood frame / BfCA Study [US & CA]	386	386	0
[illegible]	LIGHT WOOD FRAME INTERIOR WALLS	Wood / SPF / 2x4 Lumber / AWC & CWC [Industry Avg] US & CA]	82	82	0
[illegible]	CLADDING FOR INTERIOR WALLS	Drywall 1/2" [BEAM Avg] US & CA]	285	285	0
[illegible]	LIGHT WOOD FLOOR FRAMING	Wood / SPF / 2x8 Lumber / AWC & CWC [Industry Avg] US & CA]	42	42	0
[illegible]	SUB FLOORING	Plywood / 3/4" / AWC & CWC [Industry Avg] US & CA]	158	158	0
[illegible]	FLOORING	Hardwood flooring / mah / Natural Hardwood Planks / 3/4", 3 ply laminated solid, oil pre-finished	528	528	0
Roof	WOOD ROOF FRAMING	Wood / SPF / 2x8 Lumber / AWC & CWC [Industry Avg] US & CA]	153	153	0
Roof	ROOF DECKING	Plywood / 3/4" / AWC & CWC [Industry Avg] US & CA]	437	437	0
Roof	WATERPROOFING MEMBRANE	EPDM Roofing Membrane / Non-reinforced single ply / SPRI [Industry Avg] US]	700	700	0
Roof	ROOF CAVITY INSULATION	Fiberglass batt / R3.6/inch [BEAM Avg]	206	206	0
[illegible]	WINDOWS – DOUBLE-GLAZED	Window - double glazed / Fiberglass frame / BfCA Study [US & CA]	649	649	0

Figure 4. Summary Output from BEAM for Base Scope of Existing Materials.

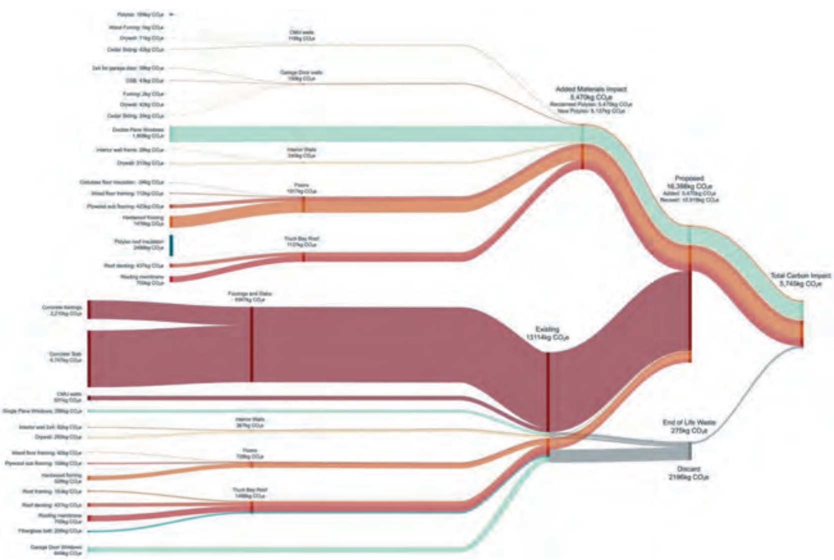

Figure 5. Summary Output from BEAM for Base Scope of Existing Materials.

3.3 *Assumptions*

The end-of-life emissions were estimated using a ratio of 1/8 of the A1-A3 carbon emissions. This is a rough estimate calculated to be about midway between the ranges given that C1-C4 emissions are 3%-15% of total CO_2e while A1-A3 emissions are 65%-85% of total CO_2e (Rosenbloom, 2023). Another area where we had to make an assumption was in the calculation of the existing single pane windows in the building. BEAM does not have a value for single pane windows as part of its database and so we needed to use embodied carbon values for double pane windows. In our models, we calculated the surface area of the existing windows and divided by two as our best approximation using the CO_2e values for double pane windows in BEAM. Finally, now that construction is underway, we realize that we also underestimated the slab thickness of the existing concrete slab in the truck bay. While we modeled a 4-inch-thick slab, the slab is 8-inch thick meaning the CO_2e associated with the slab is twice what we projected.

3.4 *Carbon communication*

In addition to visualizing the relative carbon impact of various materials and assemblies, we recognize that most people still don't have a relatable understanding of what 1 kg, 10 kg or 100 kg of carbon emissions means in the same way that we understand the value of $1, $10, or $100. To begin to address this issue, we felt that it was important to associate emissions to metrics that we can all relate to. We developed the Carbon Comparison Key in Figure 6 to address this gap in understanding. For ease of comparison, we selected relatable sources of emissions that increase by a factor of 10 – i.e. the emissions released for one hamburger is approximately 1/10 the emissions released when one drives 100 miles or 1/100 the emissions of flying from New York City to Orlando. Of course, all of these numbers are approximations – driving 100 miles in an electric car versus a car that runs solely on gasoline would be different. This assumes an average US car that gets 25 miles/gallon (Berners-Lee, 66). Nonetheless, this key gives an order or magnitude "gut check" on the relative emissions of the different component of the building. In addition to positive emissions, we also added trees and an acre of forest that absorb carbon. Some of the biobased materials serve as carbon sinks with negative emissions and so the trees give us a framework to understand the scale of these carbon sinks.

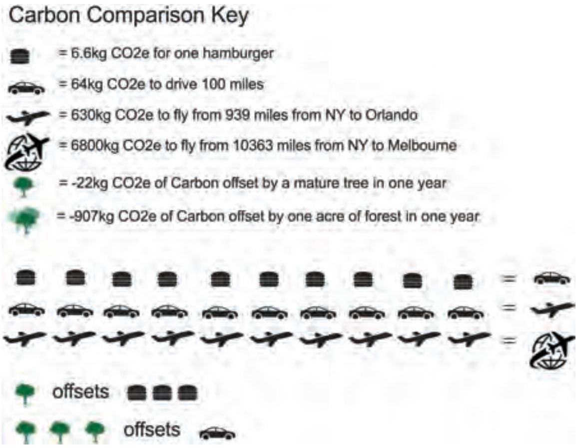

Figure 6. Carbon Comparison Key.

3.5 *Assembly selections*

Looking at the summary diagram in Figure 3, it becomes immediately apparent that the biggest decision impacting overall carbon emissions for the project was in the decision to do an adaptive reuse project instead of a tear down and rebuild. No matter the choice of roof or wall assembly, the reuse option carbon emissions are between about a quarter to a third of the total carbon emissions of a tear down and rebuild, if we were to rebuild exactly what is existing. Furthermore, the existing concrete in the project including the concrete footings, slab and CMU walls are responsible for the largest embodied CO_2 emissions in the project – 9488kg CO_2e/13114 kg CO_2e for the existing building or 78% of total emissions of the existing structure. Therefore, even reusing

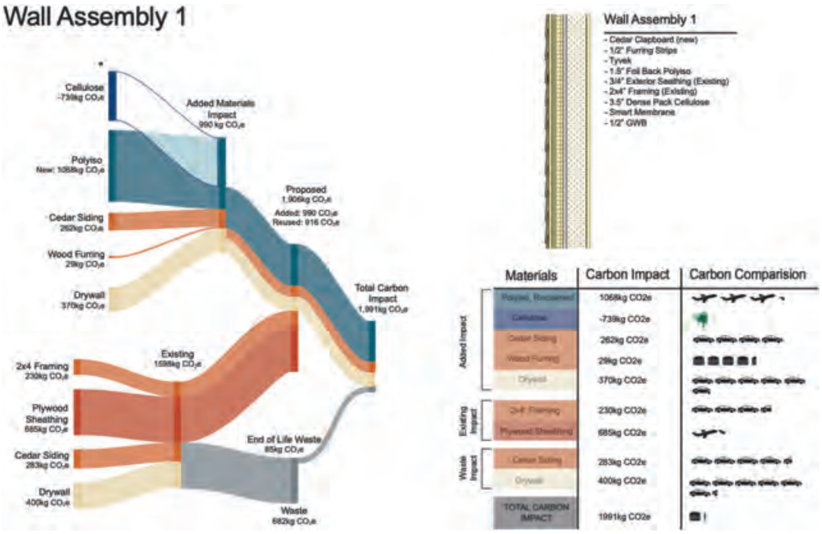

Figure 7. Wall Assembly 1 – Sankey Diagram, Wall Section and Carbon Comparison.

just the concrete would have a significant impact. With the increased attention paid to adaptive reuse projects for both heritage and carbon reduction potential especially in the past decade (Lanz, 2022; Hu, 2024) this was expected, but still helpful to quantify specifically the project impact.

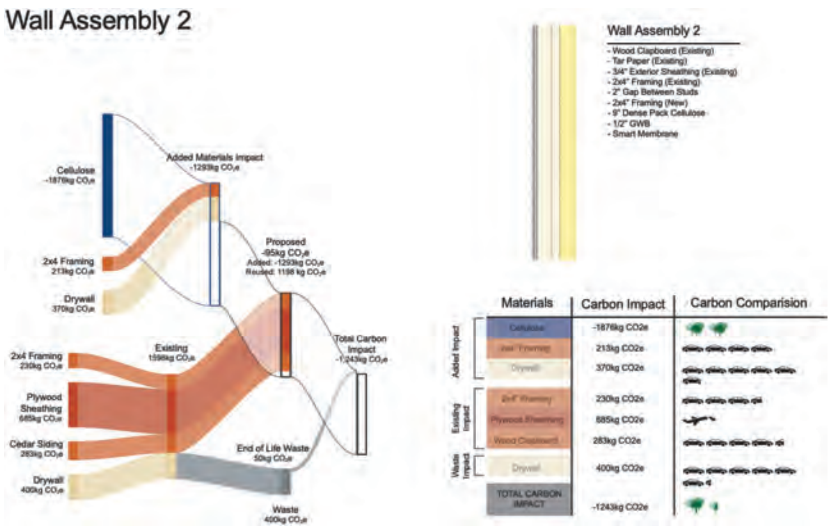

Figure 8. Wall Assembly 2 – Sankey Diagram, Wall Section and Carbon Comparison.

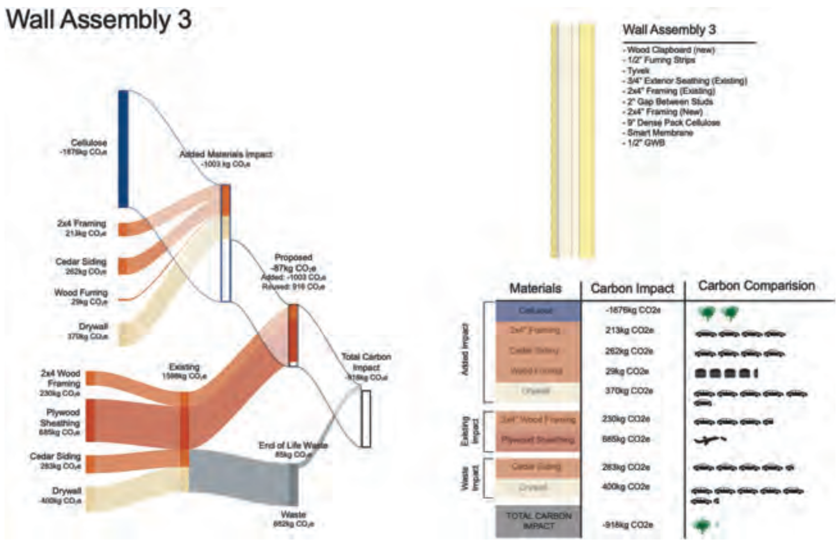

Figure 9. Wall Assembly 3 – Sankey Diagram, Wall Section and Carbon Comparison.

Having made the most significant decision to save the building, the subsequent design decision with the biggest carbon impact was in the selection of a wall assembly. Note that for all of the wall assemblies, added new material is indicated in darker yellow, while the existing exterior wall with added insulation is shown as a pale yellow. The existing sheathing or siding is shown without color. Wall Assembly 1 (Figure 7) shows a typical assembly with new 1.5" of foil faced polyiso on the exterior of existing framing and plywood with new cedar clapboards. Wall Assembly 2 (Figure 8) shows maintaining the existing cedar clapboards and building a second 2x4 wall internally with a 2" separation and 9" of dense pack cellulose. While this decreases the internal floor area, Wall Assembly 1 has a carbon impact of 1991 kg CO_2e while Wall Assembly 2 is a carbon sink absorbing 1243 kg CO_2e. Wall Assembly 3 (Figure 9) is a carbon sink absorbing 918 kg CO_2e and is similar to Wall Assembly 2 with the exception that the existing cedar clapboards were replaced adding a relative carbon cost of about 320 kg CO_2e, the equivalent of driving about 500 miles, and a significant financial cost. The carbon analysis, supported by significant cost savings, helped make the decision to proceed with Wall Assembly 2. The downside of deciding to maintain the existing siding is that the clapboards have been painted historically with lead paint that today shows distinct scaling. While there are significant upfront savings, maintaining the existing siding will require more frequent painting to ensure that lead paint chips are not falling on the surrounding property. A similar analysis was undertaken to aid in the selection of the roof assembly over the firehouse, to be discussed in a separate paper (Darling, 2025).

4 CONCLUSIONS

The method developed using BEAM to quantify the carbon impact of projects – from the large-scale comparisons of a tear down and rebuild versus undertaking an adaptive reuse/preservation project, to the smaller comparisons between material selections for building assemblies - can be useful for project teams and clients in the design and decision-making process. Further, clear visualizations of the components of a project using Sankey Diagrams helps to quickly grasp the relative impacts of different materials and components of a project. A comparison key that contextualizes the carbon emissions relative to other emissions metrics with which we are familiar can help in the transition as we become conversant in the meaning of kg CO_2e. We anticipate that these visualizations will contribute new ways of bringing these issues to a broader audience and aid in decision-making processes as more projects are undertaken with a mindfulness about embodied carbon. This is a replicable method that can readily be used for other projects. BEAM has an easy entry threshold while allowing big picture and fine-grained analysis at the level of an entire building as well as specific material selections making it a useful tool for design teams.

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Teaching reuse of existing structures at the University of Sheffield

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ABSTRACT: In response to the Climate Emergency, and to reflect the fact that many practising Structural Engineers work on existing buildings and other structures, staff from The University of Sheffield set up a new 'Reuse of existing structures' module in September 2022. The paper describes the rationale behind the module, the module content, the approach to learning, teaching and assessment., as well as reflecting on the overall success of the module, taking into account the quality of the working submitted and student feedback.

1 INTRODUCTION

Many practising structural engineers already work on existing buildings or structures, despite this topic not being covered in detail at university. Our response to the climate emergency means that reusing existing buildings and structures will almost certainly become an increasingly important part of what engineers do in the future.

In recognition of this, the University of Sheffield (UoS) set up a 15-credit 'Reuse of existing structures' module for final-year Meng students in September 2022. This article discusses our approach and experience of introducing this module.

Whilst the module isn't unique (indeed the authors are aware that a similar module was introduced by University College London at around the same time, details of which are unavailable at the time of writing), it is considered to be innovative.

The authors are keen to disseminate details of the module to fellow academics, with a view to them developing similar modules at other institutions. Similarly, practicing Structural Engineers are encouraged to lobby their local Universities (via Industrial Advisory Boards, for example) to introduce similar modules, and to provide guest lectures etc.

2 A DIFFERENT MINDSET

Although the underlying principles remain the same, working with existing structures requires a different mindset to designing new structures.

For a new structure, the structural engineer, in conjunction with the design team, has the luxury of being able to select the load paths and structural materials, but for an existing structure, the load paths and structural materials have already been determined.

Furthermore, it can reasonably be expected that a new structure will be built in accordance with the design intent, but an existing structure may have been altered over time (potentially changing load paths), while the condition of the fabric may have deteriorated.

Only when all these factors have been investigated and understood can new interventions be approached with confidence. Even then, the engineer must consider not only the behaviour of the structure in its final state, but also at every stage of construction.

3 MODULE OVERVIEW

The 15-credit, 12-week module is led by two senior university teachers, who have significant industry experience of working with existing structures, and who deliver the core content. This

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includes the philosophy of working with existing buildings, a brief history of building construction, the inspection and appraisal process, and testing procedures.

Appropriate calculations are also covered, building on previous modules for steel, concrete and timber, with masonry being introduced for the first time.

Guest lectures, by academic experts and practising engineers, address various aspects of working with existing structures. These include talks on vertical extensions, embodied carbon, reuse of masonry arch bridges and asset management, as well as the architectural and building services considerations associated with existing buildings.

Site visits to the two buildings used for the coursework (Figures 1 to 3), and other existing structures or buildings which have already been converted for reuse (Figure 4), help students learn how to translate lecture material and apply theory to real structures, including the development of skills in how to 'read', investigate and analyse existing buildings and structures.

Each student is expected to spend 10 hours per week on this module, which typically comprises a combination of lectures (originally lasting 3 hours per week as listed in Table 1, but now reduced to 2 hours per week as listed in Table 4), tutorials (2 hours per week) and independent working (at least 5 hours per week, during which students can focus solely on their coursework). Online discussion boards are an effective method for students to ask questions in-between tutorials.

Anecdotal feedback from students indicates that they really enjoy the module and can see its relevance to their future careers. Hence, they are prepared to put in the hours noted above.

It is also worth noting that the material covered in lectures, as well as the online resources provided to students, does not just cover the module coursework but a more diverse range of material which students should find useful after they have graduated/when working in industry.

Figure 1. Canada House (Angeli).

Figure 2. Broad Lane Building (Harpin).

4 LEARNING AND TEACHING THEORY AND PRACTICE

The learning and teaching approach is based on Fox's 'Travelling Theory' (Fox 1983) and the 'Constructive Alignment' approach developed by John Biggs (Biggs 1996).

'Travelling Theory' is ideal for open-ended academic exercises, with students as 'Explorers' who discover the subject with the help of teachers who act as 'Expert Guides' to lead the way.

The 'Constructive Alignment' approach starts with the intended learning outcomes, aligning teaching and assessment to those outcomes. Hence, learning is constructed by what activities the students carry out, and is therefore about what students do, not about what we teachers do. Likewise, assessment is about how well students achieve the intended outcomes, not about how well they report back what they have been told or what they have read.

Figure 3. Student site visit to Canada House (Carr).

Figure 4. Museum of Making, Derby (GCA Consulting Engineers).

Table 1. Lecture Topics 2022-23.

Week(s)	Lecture topic (3 hours per week)
1	Overview of module Making the case for reuse of an existing structure Presentation of brief
2	Appraisal of existing structures Sources of information Inspections
3	History of building design and construction
4	Reuse of existing masonry bridges Managing infrastructure assets
5	Material properties, defects and testing
6	Calculations on existing structures
7	Vertical extensions Architectural considerations
8	Building services considerations Case studies 'Existing building' career opportunities
9-12	Independent study time for group coursework

That said, the lecture material and resources provided are not just those required for the coursework. The intention is to provide a more diverse range of material and resources which students should find helpful after graduation/when working in industry.

4.1 *Intended learning outcomes*

The overall aim of this module is to help students develop an ability to assess existing buildings (in terms of their materials, condition and structural behaviour), in order to develop sustainable solutions, which extend the life of buildings, thereby addressing some of the climate challenges which society is currently facing. This translates to the following intended learning outcomes.

By the end of the module, students will be able to:

- assess/interrogate a real-world design brief for the reuse of an existing building, in order to identify the key (structural engineering) challenges and opportunities;
- develop a strategy to assess/analyse the existing building or structure, and obtain any necessary information to develop a (structural engineering) solution;

- produce and critically evaluate a range of potential solutions, with an emphasis on structural engineering and sustainability considerations;
- Select, develop and present details of their preferred solution.

More broadly, the module aims to prepare students for similar projects which they will potentially be working on after they have graduated. Hence, the module also helps students to develop a diverse range of employability skills, such as (but not limited to) project management, working in teams and communication skills. These are a part of the 'Guidelines for Developing Degree Programmes (AHEP4)', which are a requirement of the Joint Board of Moderators (2025) and the Engineering Council (2023). It was felt that the best way to achieve this was to make the project as realistic as possible, within the confines of the university environment/constraints.

4.2 *Assessment*

The module is assessed by group coursework. Typically working in groups of six, students are asked to develop proposals for a vertical extension to an existing building, with a choice between Canada House, a Grade II* listed Victorian loadbearing masonry structure with jack arch floors and the Broad Lane Building, a 1950s reinforced concrete frame (with original drawings for both buildings made available to students), as shown in Figures 1 and 2 respectively.

In addition to producing a concept design for the extension, students appraise the existing structure, with recommendations for any testing required, as well as identifying load paths and producing calculations to justify critical elements. Students also produce (and critically assess) construction methods/sequences and embodied carbon calculations (ideally the amount of embodied carbon saved in comparison with demolishing the existing building and constructing an equivalent building from new). Further, students learn the different approach to working with new and existing buildings, including the unknowns/complexities often associated with the latter.

In hindsight, adding a vertical extension to a Grade II* listed building with a pitched roof was unrealistic. Consideration has been given to using an alternative building, but it has been decided to continue with Canada House due to the availability of drawings and site access.

4.3 *Output*

Each group's proposals are presented in the form of a nominally 50-page long report, which includes associated calculations and drawings. Sample drawings produced by groups of students, for both of the existing buildings used in the coursework, are provided in Figures 5 to 7.

4.4 *Feedback to students*

Feedback was provided to students at various stages, and in various formats, as noted below.

In additional to formative feedback from the weekly tutorials and the ongoing online-discussion boards, students were required to submit a number of documents during the course of the module, to ensure consistent engagement. This includes:

- Submission of a Gantt chart on Friday of week 3, listing the key activities identified by each group, who will carry them out, and when. Formative feedback is provided in the week 5 tutorial sessions.
- 10-minute long presentations of load-path sketch drawings (in the form of well annotated hand marked up drawings, which can be pinned to the wall) during the tutorial sessions in week 7. This helps to ensure each group understands (in principle) how the building they are considering for their coursework works structurally, in terms of both gravity and lateral

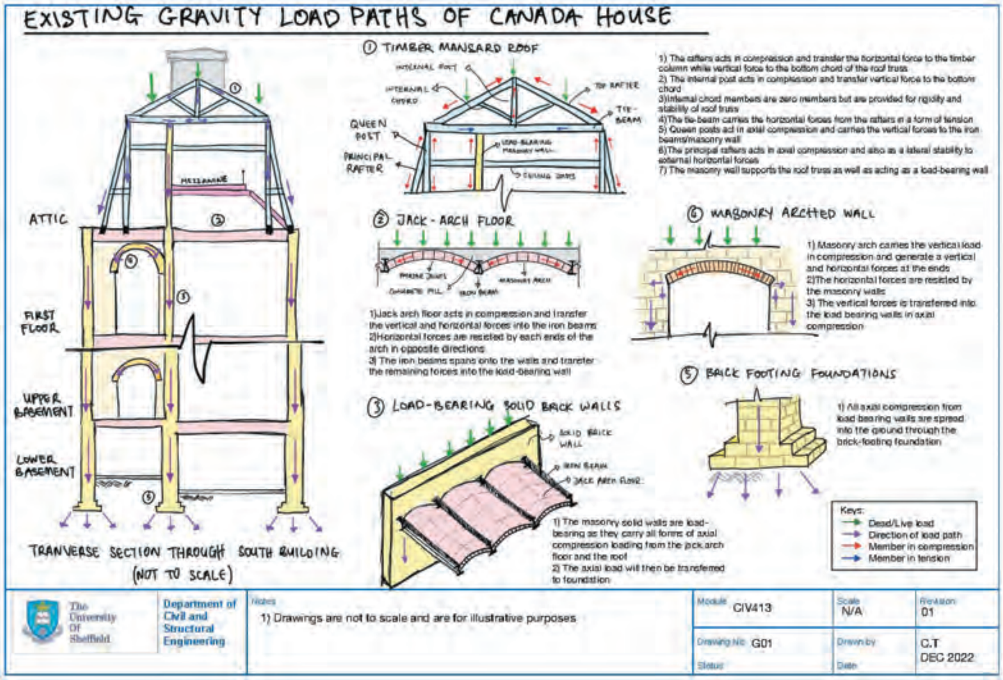

Figure 5. Cross section through Canada House, showing proposed vertical extension and load paths, as well as typical construction details (CIV413 Module Students, University of Sheffield).

loads. As well as the formative feedback provided verbally during this session, students are encouraged to view/learn lessons from presentations given by other groups.

At the end of the module, each group submits their written report, calculations and drawings. Detailed written feedback is provided on each of these three components, taking into consideration the Intended Learning outcomes listed earlier. Marking takes approximately 2.5 hours per group, which sounds relatively resource intensive, but is probably less time than it would take to mark a similar open ended/design-based project if done individually by students.

A peer assessment system is also adopted when marking, again to try and ensure all students engage consistently with the group. This system, introduce in response to feedback from the first year of running the module, ensures that students are rewarded for the work they do individually, whilst ensuring they support other members of their group and make meaningful contributions to the overall submission. The percentages shown in Table 3 are multiplied by the raw grades for each of the three components (i.e. written report, calculations and drawings) to determine individual students' overall grades for the module.

5 FEEDBACK FROM STUDENTS

The module proved very popular, with 60% of the 2022/23 student cohort choosing it, which was very encouraging for the first year of an optional module. This trend has continued, with 80% of the cohort signed up for the module in the 2023/24 and 2024/25 academic years.

The quality of the work submitted in the 2022/23 and 2023/24 academic years was excellent, suggesting a high level of engagement. Student feedback for the 2022/23 was very positive overall (Figure 8) and a representative sample of text comments is presented in Table 2.

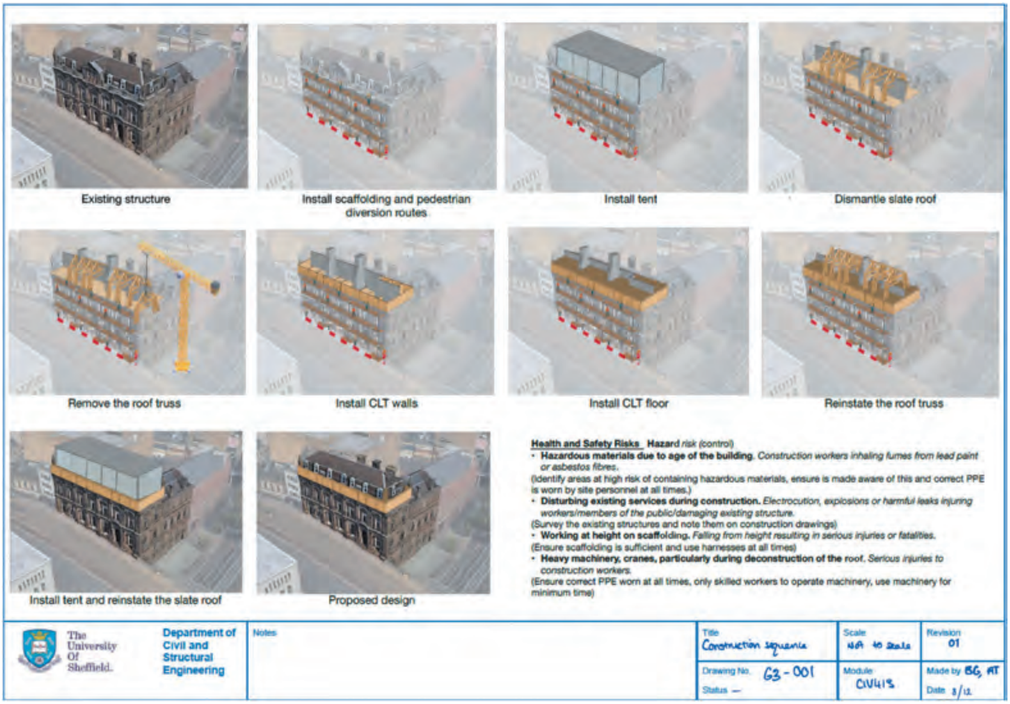

Figure 6. Cross section through Canada House, showing proposed vertical extension and load paths, as well as typical construction details (CIV413 Module Students, University of Sheffield).

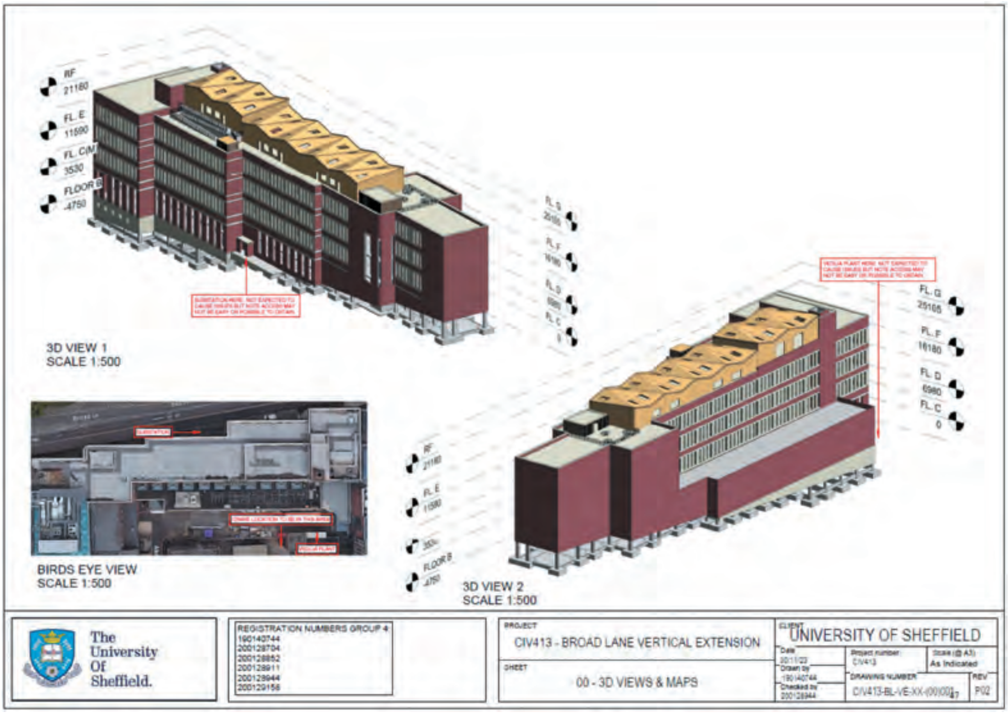

Figure 7. Vertical extension to Broad Lane Building (CIV413 Module Students, University of Sheffield).

Table 2. Sample of the contributions made by each group member to the final submission.

Student	Report	Calculations	Drawings	Total
Fred	70%	30%	0%	100%
Holly	30%	35%	35%	100%
Sarah	10%	65%	25%	100%
Johnny	50%	10%	40%	100%
Shan-Shan	0%	30%	70%	100%
Alessandro	60%	40%	0%	100%

Table 3. Student Feedback on module.

'I found this topic very interesting, and I also like how the content is extremely important in the field of sustainability. Having this module feels like an asset to talk about in job applications.'
'I like the topic covered in this module, and how we were able to visit the buildings that the project was based on.'
'The module is really relevant to the current issues in the built environment. Up to now, I've only learnt about designing new structures, so it was really helpful and interesting to learn about how we can repurpose and retrofit existing structures.'
'I liked the variety of lectures and the inclusion of guest speakers. I think it is a module unlike any other and is crucial to take before going into practice.'
'I am glad there is finally a module on this topic as it is very important in industry to meet carbon goals. I liked the guest lectures and especially liked the site visit, as well as the tutorial sessions where guests from industry were invited.'

Table 4. Lecture Topics 2024-25.

Week(s)	Lecture topic (2 x 1 hour lectures per week)
1	Intro and overview of module, including coursework brief The appraisal process part 1
2	The appraisal process part 2 Vertical extensions (guest speaker)
3	Site visits (no lectures)
4	The desktop study and masonry Iron and steel
5	Concrete Timber
6	Investigations and testing Case study (external guest speaker)
7	Canada House calculations Broad Lane calculations
8-11	Case studies (guest speakers)
12	No lectures

Overall, student feedback for 2023/24 was similarly positive. However, it was apparent that the 3-hour long lecture sessions had worked less well than in the previous year, probably as a result of changes to the schedule (afternoon instead of morning) and location.

6 FEEDBACK FROM GRADUATE ENGINEERS

In the course of writing this paper, a number of Graduate Engineers who took this module (and have the benefit of having worked for one or two years in industry) provided feedback on its benefits (as well as some ideas for further improvement). One such example is presented over.

"The CIV413 (Reuse of Existing Structures) module has been essential in my early career in the way that I approach existing buildings and services. I am able to replicate the desk top study that I first completed in CIV413 across preconstruction projects of various scopes and complexities to quickly determine feasibility and the key questions that need answering before my company can proceed with a retrofit project. The module combined lectures with on-site visits that gave me the introductions and what to look for that have allowed me to succeed in my role. An essential part of the module was to evaluate how a structure might work which has directly translated to fast evaluations needed in a fast-paced environment with great accuracy and success".

7 ONGOING DEVELOPMENT OF MODULE/STAFF REFLECTIONS

In response to negative feedback relating to the original 3-hour long lecture slots, the schedule has changed to 2 no. 1-hour long lectures and 2 no. 1-hour long tutorial slots per week (see Table 4 for further details). Initial feedback on this change has been positive.

In addition, the order of the lectures has been revised to ensure a better balance between ensuring students understand the bigger picture before diving into detailed design, whilst at the same time ensuring they have sufficient time to carry out the design/produce the necessary calculations and drawings in the time available.

8 DISSEMINATION

The module has been recognised as best practice by the Institution of Structural Engineers for teaching reuse of existing structures, leading to an invitation to present at the Annual Academics Conference 2023 and a paper in The Structural Engineer (Carr & Harpin 2023).

9 CONCLUSION

In response to the Climate Emergency and the needs of industry, the University of Sheffield introduced a new 'Reuse of Existing Structures' module in September 2022, to help equip final year students with the skills needed to work on existing structures with competence and confidence.

The quality of the work produced, positive student feedback, increased student numbers in the following academic years and recognition from the Institution of Structural Engineers, alongside other Civil Engineering departments, all suggest the module is a welcome addition to the curriculum.

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Structures and Architecture. REstructure REmaterialize REthink REuse - Rinke & Frier Hvejsel (Eds)

M127: Re-reading and re-writing a structure

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ABSTRACT: The paper describes five strategies collected from the adaptation of a modernist concrete building in Antwerp. It argues that reading the existing structure prevails towards optimizing the building for its new uses. It also suggests that seeing the shortcomings of this structure triggers the most meaningful interventions to extensively extend the lifetime of a building. At the same time, it acknowledges the fragility of these modernist structures and recommends carefulness when intervening. What is seemingly a local intervention in the structure, often effects far beyond this local area. Being aware of this domino effect allows for precise actions, limited to essential locations. The article concludes by synthesizing the structural events in M127 and distils abstract notions from them. Embracing a structure and its necessary modifications leads to its proper tectonics. It is a celebration of a seriously pleasurable handling of the preservation of structures. In this way, we can use existing structures for a long time to come.

1 INTRODUCTION

The restoration and repurposing of historical heritage is socially acquired, valued and often heavily subsidized (Jokilehto, 1999). For young patrimony, the matter is more complicated. The recognition of the architectural value of buildings from the 1950s and later is not as evident. It seems to take more generations to provoke a nostalgic argument for preservation. This creates noise in the conversation about more recent buildings. The drive for the completely new is always lurking. However, a turning point is occurring (Ledent et al. 2025). With materials and energy becoming scarcer, this parameter is weighing more and more heavily on the balance. Besides quoting architectural quality, an ecological theme is coming to the fore. Preserving building components because of their intrinsic grey energy is for the time being little valorised by support measures, while societal support for hybrid solutions has grown (Kockerols, 2024).

Not seldom, it is more specifically the structure that provides the framework for reuse. Preserving a structure, however, does not stop at speaking out. It is accompanied by intensive reading and triggers a carousel of design research in a still relatively unknown field of thought. Thorough renovations are the time to question and make structural corrections.

In project M127 in Antwerp the ambitious client brings a diverse design team together (consisting of an architect, interior designer, landscape architect and artist) who were asked to design in close collaboration, irrespective of their disciplines. The 7-story building perpendicular to the street is an exception in the streetscape but creates an intriguing relationship with the adjacent church. Only the concrete structure has any (economic and ecologic) value since façade, interior layout and technical installations are completely outdated. The 1967 modernist office building underwent a thorough energetic refurbishment alongside a programmatic turnover. The monofunctional office became an attractive workplace welcoming the new way of working and inviting exchange with visitors and neighbourhood on the public floors with a coffee bar and meeting places.

The building previously behaved hermetically towards the surroundings and its facades were uninsulated. It lacked porosity towards the city and its own private outdoor spaces. Every open area and roof on the building plot was asphalted or paved. Solid ground was

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Figure 1. Top left: At M127, a '60s office building behaved hermetically towards its surroundings; Bottom left: The concrete structure was hidden behind wafer-thin coverings. Daylight hardly entered in the deep ground floor level; Right: The outdoor space was fully asphalted and intended for access with vehicles. The only strip without parking underneath was filled with storage volumes from the adjacent church. (©ono architectuur).

absent. Furthermore, the building was missing spatial hierarchy. Low stacked floors without variation lead to monotonous usage of the building and dark spaces on the wide lower floors. The lack of spatial variation prevents multifunctional use and decreases encounter and publicness. On top of that, the vertical stair cores were closed off from the rest of the building, dark and little used unlike the elevators.

Figure 2. M127 front facade on Mechelsesteenweg, Antwerpen. (©Filip Dujardin).

2 STRUCTURAL STRATEGIES

Several interventions and corrections occur in the project. M127 provides the case for a diverse catalogue of seemingly separate interventions that at the same time all work together towards a common goal.

2.1 *A hybrid of old with new concrete or steel*

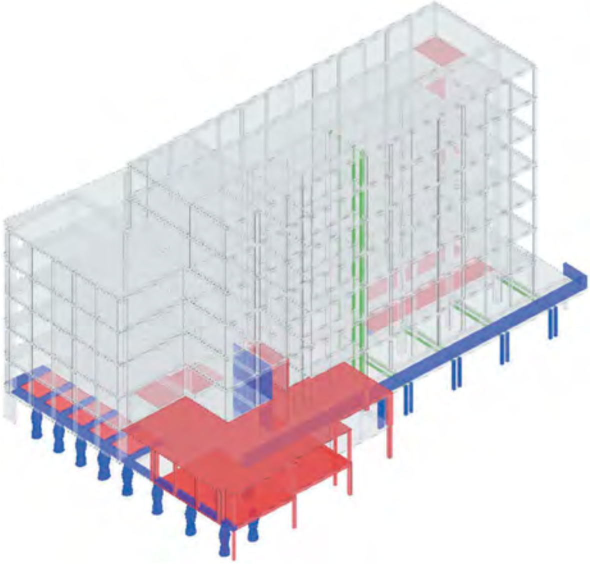


Figure 3. Types of structural interventions; Removed parts (red); Concrete reinforcements (blue); Steel bracings (green). (©ono architectuur).

Releasing and revealing the concrete immediately makes the structure the defining theme. The rough functional concrete was embraced as a material quality that could complement the often sleek elements of contemporary offices. That being said, damaging this structure was to be avoided. Hence, new functional loads, a rooftop extension in combination with an existing structure that did not entail any margin in structural strength quickly lead to needed reinforcements. Where initially confronting, these interventions were finally welcomed as complementary tectonic expressions of the adaptations conducted in the building. The reinforcements result in bas-reliefs of old and new concrete, almost pedagogically explaining the structural behaviour of the structural elements. The smooth new concrete contrasts with the rough texture of the existing that was not meant to be visible before. Often, the surfaces are not aligned, but the new concrete overtakes the

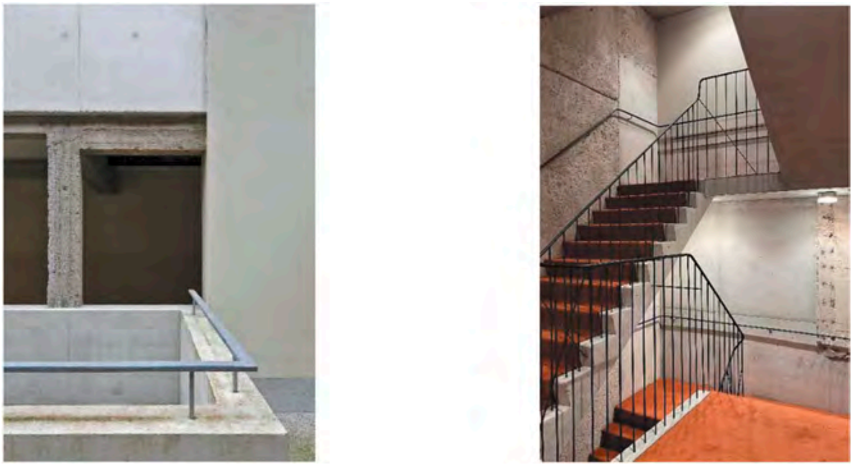


Figure 4. Left: A time composition of new concrete overtaking the old concrete; Right: The widened stairs display a patchwork of newly poured concrete parts amidst the locally cut-through original concrete structure. (©Filip Dujardin).

old. The cold technical grey of the new concrete fuses with the warm grey aged columns and beams into a new concrete conglomerate.

At other locations steel bracings were required. The concrete beam is sandwiched between two UPN profiles. They form a structural exoskeleton for the beam, a hybrid solution where concrete and steel hold each other, at the same time strengthening the structure as a whole. At other locations, extra reinforcement is needed for the lower columns in the building: steel strips are glued onto the column, creating a structural-aesthetic striped pattern. Again, the technical solution is accepted in its incorporated beauty. Only the choice of contrasting cold grey paint brings the pattern of stripes in tension. Old and new concrete, together with the steel reinforcements, exist next to each other in a re-used and renewed hybrid structure as a new composition, with stronger chances for preserving its grey energy over time.


Figure 5. Left: The concrete core is reinforced by adding steel strips and profiles; Right: On lower floors, the needed glued-on steel strips seem almost-intentional decorative stripes. (©ono architectuur).

2.2 *A city loggia*


Figure 6. Left: A polystyrene mould and reinforcement nets around an exposed concrete column; Right: The sheltered terrace in front of the building. (©ono architectuur, Filip Dujardin).

The elements mentioned above are related to showing the concrete structure as a quality. More invasive interventions follow new ambitions that were not present before. The impermeable façade along the street was inappropriate for a welcoming building. The façade is pushed backwards, bringing the front row of columns to the outside of the building. The so created colonnade becomes an in-between between public and private. The original columns lack concrete reinforcement cover and need protection. In line with the other reinforcements an extra layer of concrete is added. The location along the busy street demands more than this technical solution. A barrier between the traffic of the street and the sheltered terrace in front of the building is desirable. Instead of creating a screen, the thickness of the columns is increased above the technical needs. Artist Philip Aguirre y Otegui developed the shape of the columns. He proposes a stacked volumetry holding the middle between a statue and a classical column. In the perspective along the street the columns shield off the terrace completely. Also from the terrace, only a perpendicular view provides visual contact to the street. By integrating art at this specific location, a new public place is poured into possible permanence. Publicness is consolidated.

2.3 *Voids*

The low ceilings in the building are not suitable for a public program. In addition, in the centre the wide and deep floor plans are very dark. To harbour a communal function, part of the concrete floor behind the terrace is cut away. Its form follows the muddled shape of the structure, having a structural logic at the same time as raising spatial questions. To avoid that this shape plays a too important role in the space, the balustrade ignores the specific form and surrounds a rectangular shape. This way, a layered scene mixes impossible ambitions with structural coincidences. The complexity adds to the versatile experience of this new double-high space, where light penetrates in the heart of the building.

Figure 7. Left: Low stacked floors are cut away at precise locations at ground floor; Right: New cuts through the building are left in their raw state. (©ono architectuur, Filip Dujardin).

Figure 8. The adapted structure can house uses that were not possible before. (©ono architectuur).

Also in the back of the building a new cut-out alters the space. Meeting rooms connect to the company's library. The new void adds hierarchy to the space, elevating its presence in the building. The central space is surrounded by glazed meeting rooms that connect to the new garden. The previously introvert space opens up to the surroundings and allows for multifunctional and shared use. By taking away part of the building we get more building in return. The structure can house uses that were not possible before.

2.4 *Vertical circulation*

The three main spatial interventions, as mentioned above, lead to a public double high ground floor. At the same time the functional closed off staircase cannot support this public function. Hence its importance for the structural rigidity of the whole building, the stairwell has nevertheless been enlarged on the two lowest levels. The balance here tilts from doing nothing in order to maintain structural rigidity towards increasing the degree of public permeability for the long term. To repair the existing rigidity a new substitute structure is inserted in the building. At the same time, the existing elevator shafts are strengthened with steel bracing along the full height of the building to sit in for the lost rigidity. This time, a set of consequential interventions create a technical complexity in addition to the challenging spaces and forms. This example shows that certain local design choices lead to interventions on a broader scale or even in a completely different area in the building.

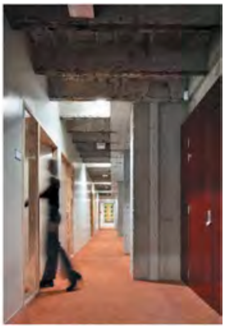


Figure 9. An adaptation of the lower levels of the staircase (left) leads to additional steel strips, embracing the central core (right) with elevator and stairs. (©Filip Dujardin).

2.5 *A self-carrying garden*

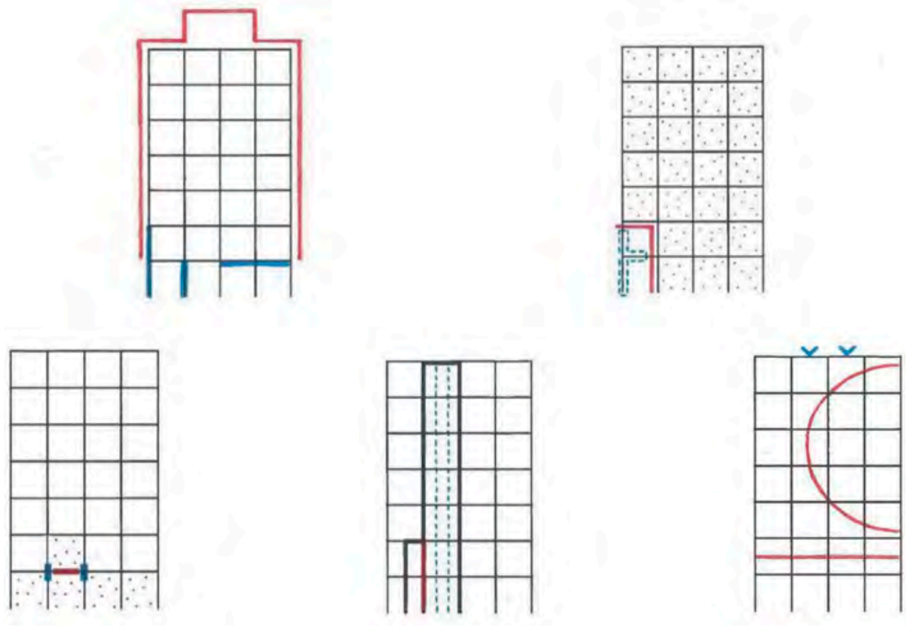
The outside space sits largely on top of an existing underground parking. The structure here is too weak to carry the extra load of a garden. The design of the garden was conceived as such that all new elements contain extra structure to carry the new loads. A curved bench is conceived as an upward beam and carries a mass of earth behind it. A small pond is surrounded by concrete beams and thus becomes self-carrying. A set of stairs conceal a transversal beam, allowing the ground package towards the back of the garden to increase. The constructions in the garden both preserve the underlying structure and make a green outdoor space a reality.

Figure 10. Left: Freeing the church of the added storage volumes gives some air to the public garden-to-be and allows for a strip of fertile soil; Right: Reinforced concrete beams are disguised as garden elements such as a pond, stairs and a bench, creating the possibility for heavier loads (greenery). (©ono architectuur).

3 CONCLUSION

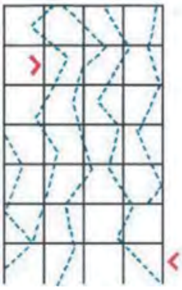
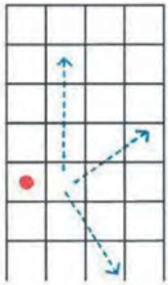
The responsible momentum of a substantial design brief for renovation can perpetuate the encapsulated grey energy by not only preserving the structure, but by doing so in a corrected manner. Adaptations steered by e.g. urban, social, cultural and spatial themes make construction more meaningful and further extend their lifespan. Precise physical actions can permanently embed new qualities into the structure, which is thus ushered into a new era. The specificity of the assignment is leveraged to encapsulate qualities that extend further beyond the assignment itself.

The paper describes how a concrete building structure dating from the '60s is adapted. We show a cut-out of five selected (groups of) interventions. M127 acts as the source project for abstracted schemes that offer generalizing strategies for architectural design with existing concrete structures. The original construction is shown as a regular framework (black) with the indication of action/intervention (red) and reaction/outcome (blue).



Figures 11-12-13-14-15. From left to right. 11: Adding extra loads to an existing construction generally leads to the need for reinforcements at other locations throughout the building; 12: Changing the perimeter between in- and outside ask for detailed study of reinforcement covers and thermal behaviour of building details. This could be an invitation for specific design solutions; 13: Creating voids can improve public realm and allow more diverse programs. By removing floor slabs selectively, structural modifications can be reduced; 14: Modifying rigid (circulation) cores locally may require reparative interventions over the entire height; 15: Adding reinforcing structures can make the existing structure more load bearing and enable qualities that were previously absent. (©ono architectuur)

We synthesize by adding two overarching metaphors, illustrated with similar abstract schemes and expressed more physically with photographs of art works by Fischli & Weiss. The first metaphor states that these constructions could be seen as delicate equilibriums. This creates the awareness that any intervention (red, action) can be very impactful (blue, reaction) for integral stability. The second metaphor states that these structures could be regarded as a balloon. When you push it at a certain place (red, action), it is visible at another location (blue, reaction). But one should not push too hard.

Figures 16-17. From left to right. 16: Metaphor of a delicate equilibrium; 17: Metaphor of a balloon. (©onoarchitectuur).

Figures 18-19. From left to right. 18: Fischli & Weiss, Image "Quiet Afternoon" (1984-1986) (Matthew-Marks Gallery, 2020); 19: Fischli & Weiss, Still of video "Small Questions Big Questions 3 Films by Peter Fischli & David Weiss" (Athènes & Papadopoulos, 2015).

Where the program and ambitions of the brief give rise to possible adaptations, it is the building itself – and more specifically its structure – that will determine the interventions to be made. Reading this structure, seeing its potential and problems, but also reading what the structure does not offer yet, leads to more meaningful changes that prepare the building for the future. The program will insert itself into the new qualities that were created, as will future programs. Moreover, it allows to intervene without disrupting the often-fragile structural capacities of this modern heritage. Only this way the ambition to reduce climate impact to a minimum can be achieved. But evenly important is acknowledging the shortcomings of this existing structure and intervening here as required. Not doing so would lead to redoing similar changes in the further future. Reading the structure makes one appreciate its qualities, allows to embrace its disorders and to rewrite its disabilities. Re-reading carefully, Re-writing precisely, Re-using longer.

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