Proceedings of IASS-IWSS 2026 — September 14-18, 2026, Turin, Italy
"R-Evolution of Shapes: Sustainability, Re-Use, and new Design Paradigms"
Annual Symposium of the International Association for Shell and Spatial Structures
3rd Italian Workshop on Shell and Spatial Structures
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REUSE STEEL IN THE DELIVERY OF OPTIMISED PUBLIC INFRASTRUCTURE.

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Abstract

This paper presents an innovative 60 m-long public footbridge spanning a live railway. It was developed at the intersection of digital design tools, new embodied-carbon datasets, evolving UK regulations on steel reuse and the growing industrial ecosystem for structural steel reuse. The project serves as a demonstrator for integrating reuse-led design within the context of national infrastructure. A stock-led design approach was adopted. The structural typology was not solely derived from the conventional approach of first engineering intuition, then specification of material, but worked initially from establishing an inventory of readily available unused circular hollow section (CHS) steel tubes. This reverses conventional design practice, where form is typically established prior to material selection, often limiting opportunities to incorporate reclaimed components. Multi-objective optimisation techniques supported an iterative and flexible process, testing multiple configurations, quantities, and inclinations of the available tubes to satisfy structural performance requirements for a pedestrian bridge while minimising material use. Embodied carbon metrics were continuously evaluated and embedded within the design decision-making process. It is believed that the reuse of steel components is a first for the rail network bridge in the UK. It emerged as a robust solution, one where many valuable lessons were learnt along the way with regard to design methodologies, structural utilisation, procurement and testing.

Keywords: reuse, multiple objective optimisation, form finding, steel, bridges

Figure 1- Tan House Footbridge Elevation from allotment plots. @FormatEngineers

1. Introduction

The project brief was defined by two objectives: delivering a high-quality architectural solution while serving as a pilot for advanced low-carbon design. Supported by the client, the intention was to integrate original research and unconventional engineering typologies. The scheme was to have high standards of sustainable practice. Central to this approach is the adoption of PAS 2080:2023, representing a shift from voluntary 'best practice' to a structured, auditable commitment to carbon management within the built environment. The design life expected for this type of infrastructure is 120 years with low maintenance cycles to minimise train traffic disruption. Designed to replace two ageing temporary structures, the footbridge was conceived as part of a wider urban regeneration project. By providing a permanent crossing to replace an ageing concrete bridge and a temporary scaffolding structure, the scheme secures a connection between the new residential and leisure district and the existing urban landscape. This link is fundamental to the area's permeability, connecting the new development to parks, allotments, housing, and commerce. Balancing the rigid constraints of railway design standards, the scheme balances security with openness. The client asked for some visual transparency, even within the context of the mandatory and conventionally solid 1.8m parapets. This ambition for lightness extended to the structural form; a minimised deck thickness was specified as a strategic spatial solution to reduce the approach footprint and facilitate future ramp upgrades. This also directly influenced the structural typology. The primary spatial constraint was also influenced by the delivery of the bridge, by rail, under an existing Grade II listed structure. This imposed tight volumetric limitations, directly governing the bridge's overall envelope. To maximise the effective clear width for pedestrians within this envelope, the design typology was selected specifically to minimise the lateral profile of structural members, ensuring that the primary load-bearing elements did not encroach upon the user environment.

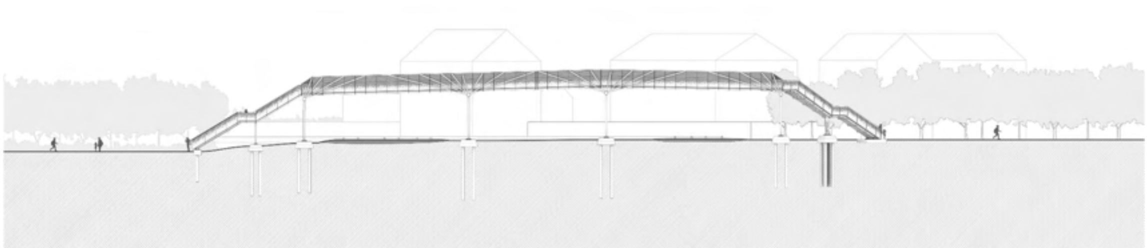


Figure 2- Tan House Elevation - @FormatEngineers

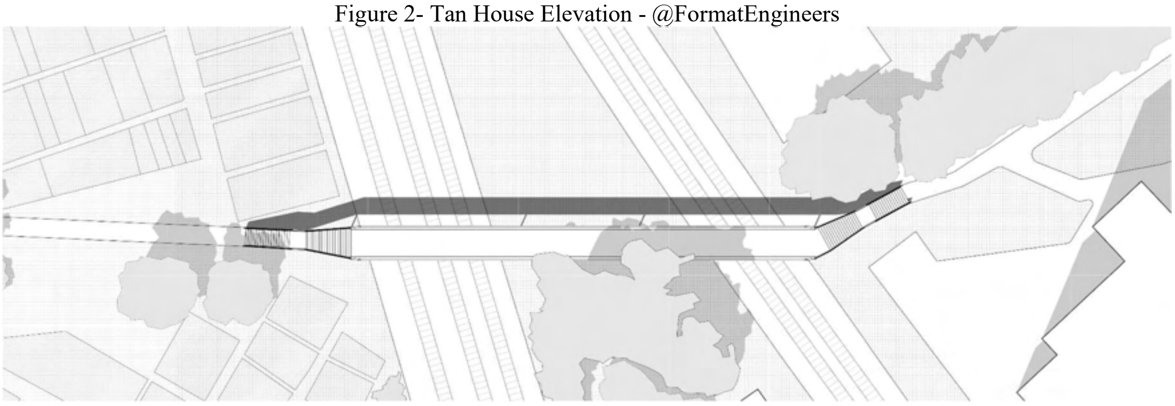


Figure 3- Tan House Plan - @FormatEngineers

2. Optimisation of Repurposed Steel

2.1 Repurposed Steel vs Recycled Steel

To satisfy the three requirements: low-carbon performance, Durability (120-year service life), and minimal maintenance, the design team decided to focus on the use of repurposed steel. This non-extractive, circular design strategy eliminates the need for primary resource depletion. By using existing material stock, the project significantly reduces the embodied carbon associated with raw material extraction, long-distance transport, and high-energy transformation processes. This approach has secondary ecological benefits by mitigating the biodiversity loss typically associated with mining and industrial processing [1].

In this context, a distinction is made between repurposed steel and traditional reused or recycled variants. Unlike recycled steel, which requires energy-intensive electric arc furnace (EAF) or basic oxygen furnace (BOF) smelting, or reused steel, which often carries the uncertainty of prior structural loading, repurposed steel refers to surplus industrial stock. These are high-quality, unused resources that are frequently downgraded to scrap. Utilising this material stimulates a circular market while removing reprocessing emissions.

For infrastructure, repurposed steel offers a specific technical advantage: traceable provenance and unloaded history. This ensures the material is free from antecedent fatigue damage, a critical assurance for structures over active rail lines. While fatigue is rarely the governing limit state for a footbridge of this scale, the virgin nature of surplus stock provided a low-risk entry point for the client to adopt a circular procurement. The reused/repurposed steel industry is expanding and responds to the rising demand from clients and designers for second-hand materials. By specifying repurposed steel, a low-risk conduit for circularity, this project did more than satisfy a local brief; it validated the economic feasibility and technical viability of circular procurement for a major national stakeholder. The success of this delivery has served as a proof of concept, leading to a direct shift in the client's long-term procurement strategy. Since the delivery of this project, the client has been looking at reused steel for other projects and encourages/imposes second-hand steel as a primary resource. Guidance has also been written to provide a useful insight to clients or designers who would wish to incorporate this practice: Steel Reuse in Bridges[2]. This covers in more depth the subjects linked to: standards, testing, fatigue, and CE marking.

2.2 A stock-led design approach

This project utilises a stock-led design approach, using an established UK source of reclaimed structural steel rather than traditional procurement. The available inventory comprises repurposed circular hollow sections (CHS) ranging from 40mm to over 1,000mm in diameter. Because steel can be easily cut and rewelded, the design was not restricted by the fixed lengths of the reclaimed members. The bridge typology was specifically engineered to maximise the use of these sections within a structurally efficient pattern. While other materials were considered, repurposed steel was selected for its proven durability and predictable mechanical properties, which simplified the assembly process for the design team and contractor. To manage fluctuations in stock, a parametric computational framework was used to link the design geometry directly to live inventory data. Stock was added as a parameter like any other. By integrating performance metrics into this digital workflow, the project maximised the use of repurposed steel while significantly reducing the infrastructure's total embodied carbon.

Despite the constraints of a stock-led approach, the design primarily focused on the user experience and the bridge's integration into its surroundings. While the material availability set the technical framework, the architectural quality and attention to detail remained as high as any bespoke infrastructure project. The goal was to ensure that the logic of reuse did not compromise the aesthetic or functional value of the public crossing. The bridge typology consists of a fan-like column supporting a continuous triangular top chord, with a series of U-frames partially suspended from it. This triangular geometry was designed to minimise the visual bulk of the structure, creating a sense of lightness. To avoid the 'closed-in' feeling typical of railway bridges with high safety parapets, the U-frames splay outward. This cross-section design creates a more open and expansive environment for pedestrians. The parapet system uses perforated stainless steel panels, chosen for their durability and low maintenance. A gradient perforation pattern was applied to these panels to provide 'visual porosity,' ensuring the bridge feels open on the inside rather than solid. By varying the design between the internal walkway and the long external elevation, the bridge creates a changing atmosphere for the user. The result is a journey that feels both open and light, yet safely enclosed. Structurally, the bridge was built in two segments. The splice joint connecting them was hidden behind the parapet cladding to maintain a clean, seamless appearance. In elevation, lateral stability is provided by braced tubular columns, complemented by the west staircase, which provides longitudinal stiffening. The stairs were designed to fit within a very tight site boundary. Ramp solutions have also been designed and could be installed retrospectively once funding is available.

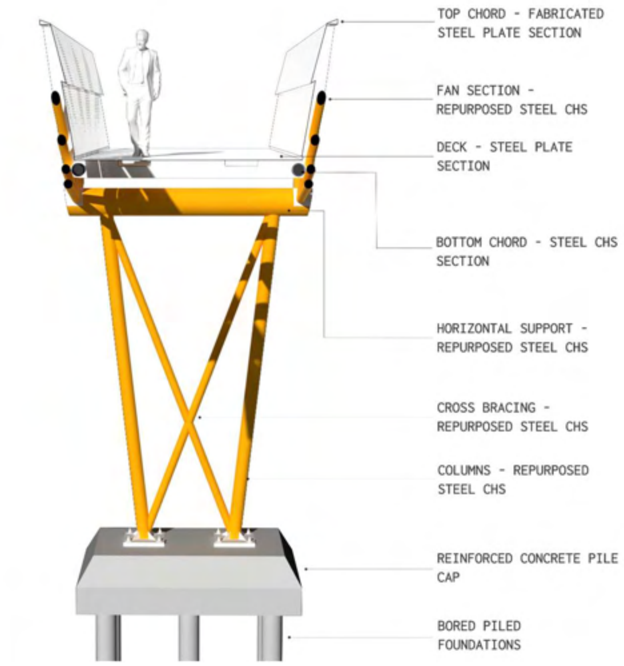


Figure 4 - Tan House Section - Repurposed Steel - @FormatEngineers

2.3 Parametric workflow and optimisation of an existing stock

The design was developed through a systematic, iterative process focused on carbon reduction and material efficiency:

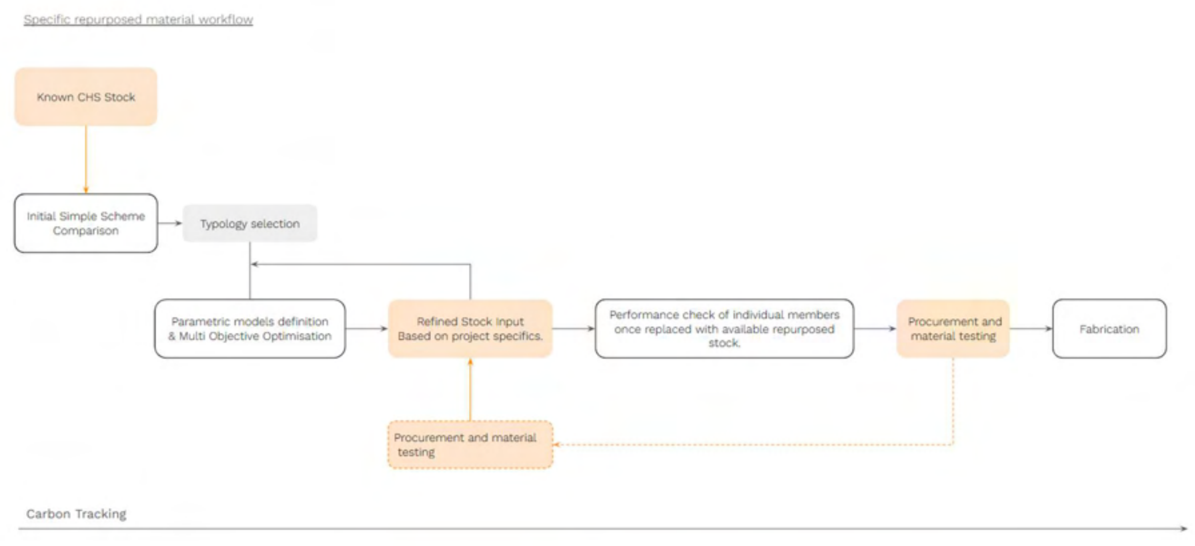


Figure 5 - Optimisation of Repurposed Steel Workflow

- Comparative Analysis: Several design schemes were evaluated to determine the impact of span configurations (two-span vs. three-span, Typology) on overall embodied carbon, including the requirements for the substructure and foundations.
- Typology Selection: The "fan" typology was chosen by the design team and contractor as the most effective structural form to accommodate the repurposed circular hollow sections (CHS) while maintaining architectural elegance and buildability.
- Design Parameters: Key variables were established for optimisation, including the number and geometry of the fan supports, the spacing of the U-frames, and the height of the parapets.
- Multi-Objective Optimisation (MOO): A computational workflow was developed within the Grasshopper environment using Karamba3D and Design Explorer. Initial 2D simulations focused on:
  - Deflection limits and Ultimate Limit State (ULS) utilisation.
  - Total structural mass.
  - Aesthetic proportions and engineering feasibility.
- 3D Structural Refinement: The selected 2D solution was evolved into a comprehensive 3D model. Additional performance outputs were integrated into the optimisation loop, specifically vertical and horizontal natural frequencies and detailed carbon auditing.
- Stock Input: Based on the optimum models developed above, a list of cross sections was provided to the supplier, and the team received the closest matching sections available.
- Dynamic Inventory Synchronisation & Optimisation: After receiving a list of available alternative sections from the supplier, the MOO process was re-run. This ensured that substituting the specified sections with available stock did not lead to unnecessary weight

increases, maintaining an optimal strength-to-weight ratio. The overall model and sections were constantly optimised, the U frame thicknesses vary depending on their use, the bottom chord thickness also varies, and similarly, the bottom and top parapet panels are 2 different thicknesses. The optimisation wasn't capped at the repurposed elements.

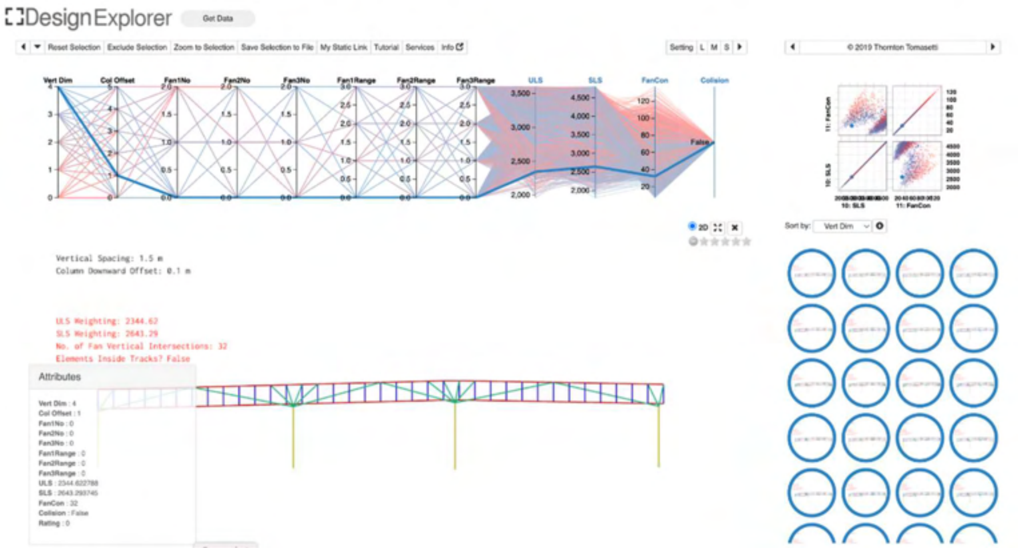


Figure 6 - Multiple Objective Optimisation - MOO in Design Explorer

- Reclaimed vs. Virgin Steel: A comparative performance analysis was conducted between repurposed and new steel sections. It was observed that the repurposed bottom chord required a significantly larger wall thickness than structurally necessary due to limited stock availability. Following recent publications, it was determined that if a repurposed member's mass exceeded the optimised design weight by more than 30%[3], the embodied carbon benefit would be negated. For this reason, the bottom chord was specified as new steel to ensure overall material efficiency. This decision was part of a wider debate around the circular economy: whether to prioritise immediate reuse or to preserve reclaimed material for projects where its capacity is more appropriately utilised.
- Procurement and Material testing: Due to contractual and liability frameworks, the reclaimed stock was not formally reserved until the construction phase. This delay meant that material testing, essential for verifying the properties of the steel, occurred immediately before fabrication, creating a sudden schedule pressure. However, the testing duration was relatively brief (10 days). This experience suggests that for in the futur projects, testing should be integrated in the framework agreement to be conducted in parallel with the design phase to mitigate delivery risks. Details on the list of the recommended tests can be found in the guidance Steel Reuse in Bridges.

3. Direct and Indirect Impact on Embodied Carbon

3.1 Carbon Tracking

To ensure rigorous carbon management, the project utilised the SCORBS rating system and guidelines from the Net Zero Bridges Group[4]. Embodied carbon was monitored throughout the design and construction phases using a bespoke carbon calculator developed within the Grasshopper (Rhino 3D) parametric environment. This tool integrates IStructE calculation methodologies [5], allowing for real-time feedback on the carbon implications of structural, buildability, and aesthetic decisions. A significant challenge in infrastructure projects is the latency between initial design and final delivery, which often precludes the integration of evolving industry guidance. The parametric nature of the carbon calculator mitigated this risk, enabling the team to update carbon models as new data became available. This was particularly vital during the fabrication phase; while the scheme was developed in collaboration with the fabricator, minor adjustments were required to optimise production. By maintaining a dynamic carbon model during the fabrication phase, the team was able to produce an as-built model. This is a rare practice in the industry due to limited access to primary fabricator data and to contractual frameworks.

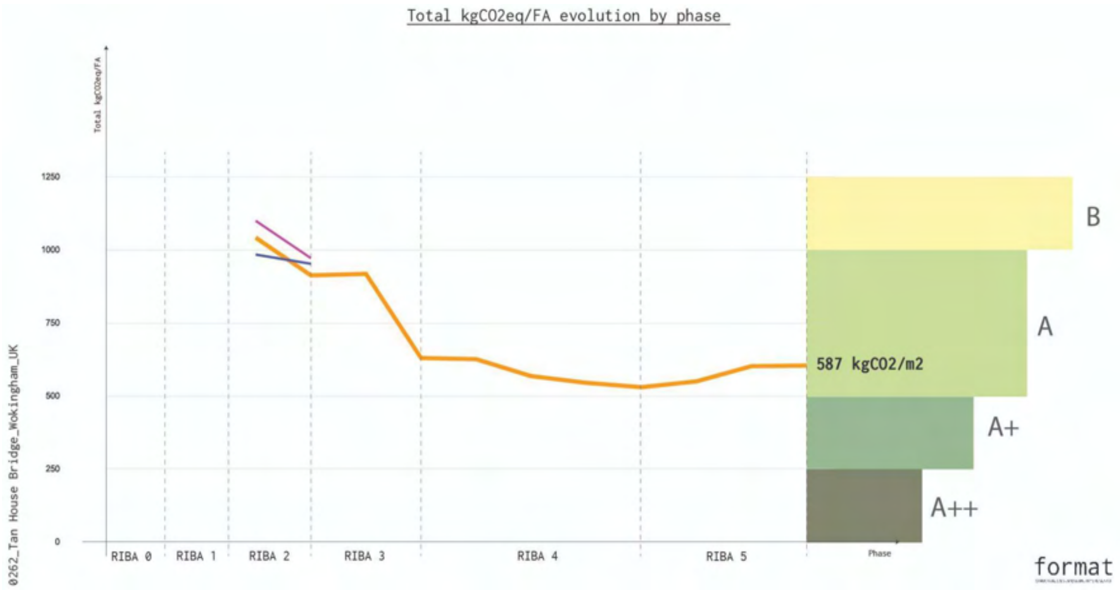


Figure 7- Carbon Tracking (A1-A3) from design stage to delivery.

3.2 Carbon Performance

The project set an ambitious benchmark: to meet or exceed a SCORBS Rating A (defined as 500-1,000 $kgCO2e/m^2$). The as-built footbridge successfully realised this aspiration, achieving an upfront embodied carbon (Stages A1–A5) of 677 $kgCO2e/m^2$. This comprehensive figure encompasses the superstructure, substructure, finishes, and the 1.8m parapets. This performance was driven by the strategic procurement of repurposed steel and the iterative optimisation process. Based on contemporary research, a 95% carbon saving was applied to the repurposed steel components compared to primary steel equivalents[6]. This substantial reduction served as a primary driver in overcoming institutional inertia and fostering a culture of circularity within the project team. The design team also reflected on the carbon numbers, and in this scheme, a high proportion of the carbon was also located in the parapet (20%), as this was an essential element to provide the necessary safety, but was not part of the overall structural design. Using the parapet plate would have led to a different structural solution and may have resulted in a heavier overall bridge; we have kept this in mind in more recent work without clear conclusions on a right or wrong strategy.

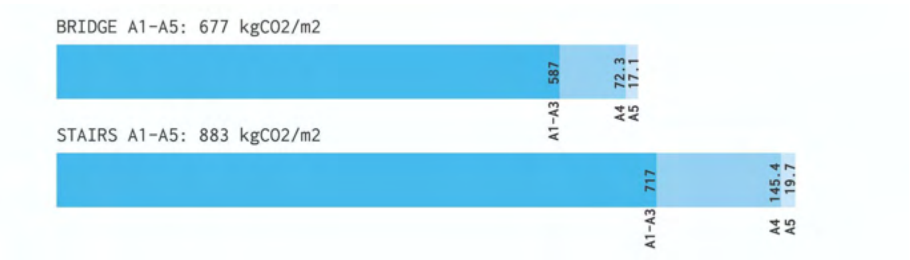
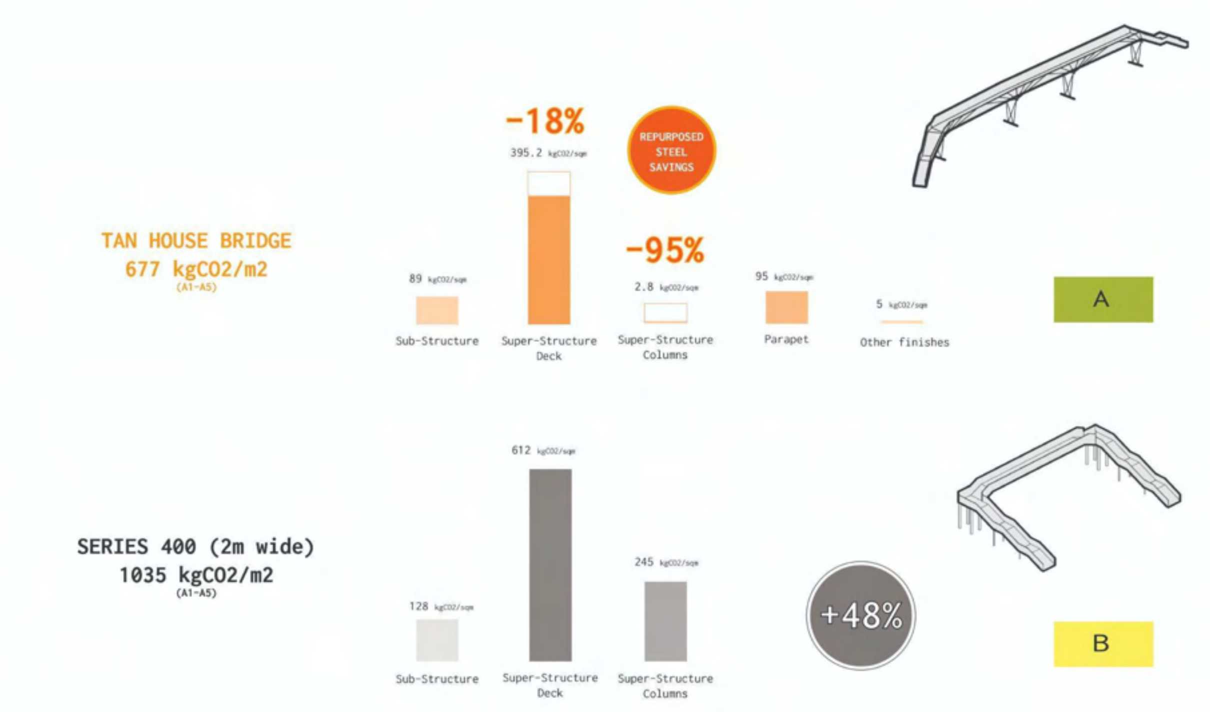


Figure 8 - As Built carbon A1-A5

3.3 Comparative Analysis: Bespoke vs. Catalogue Solutions

To contextualise the project's performance, a comparative analysis was conducted against the client's existing numbers for their standardised catalogue bridges. Using data from the client's design guide appendices [7], carbon numbers by functional area were compared. While standard designs, such as the Series 400 steel plate U-frame bridge, are often deployed for efficiency, they typically offer limited width (up to 2m) and do not meet the aesthetic or spatial requirements of this site. The Series 400 baseline is rated at 1,035 $kgCO2e/m^2$ (A1–A5). By contrast, the bespoke, repurposed design achieved a 48% carbon reduction while delivering a superior, context-specific outcome. Out of these 48%, we have found that 25% are directly associated with site-specific optimisation and a further 23% are linked to the carbon reduction due to the use of CHS sections.



4. Conclusion

By delivering a project which from the outset doesn't look different to any other infrastructure project, centered around user experiences and contextual connection, this project humbly showcases the economic and practical feasibility of circular principles without compromising timeline, durability or aesthetics. This also act as an example that circular principles can be scaled up to large pieces of infrastructure, designed to be as durable as any other projects using the same standards and same constraints.

This project has been used in the UK as a case study to support other projects and second hand materials within the infrastructure and construction industries, and we hope to see other projects built in the future.

While using repurposed materials, this project did not cover the end-of-life cycle and disassembly process. As built data cataloguing and storage discussion was unfortunately not pursued due to the liquidation of the fabricator just after the installation of this bridge and would be an important next step to ensure future reuse of elements or spans.

5. Acknowledgement

Thanks to Network Rail for their support and determination, which enabled this ambitious change in material procurement.

Thanks to WSP for their engineering collaboration and openness in this unusual but efficient iterative structural design exercise.

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