

# Controlled Reuse of Screws in Timber Lifting: Mechanical, Operational, and Environmental Assessment



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## ABSTRACT

Lifting operations in timber construction are high-consequence activities in which the integrity of the lifting interface directly affects worker safety, operational reliability, and the handling of prefabricated elements. In screw-fastened lifting systems, screws are generally prescribed as single-use components, while field practice often reuses them without traceability or objective screening criteria. This work investigates whether screw reuse in lifting applications can be technically assessed and managed in a controlled way.

The research program was structured to separate the effect of reuse itself from the effect of installation and use-induced damage. Single-screw testing showed that repeated controlled use did not meaningfully affect the main mechanical parameters of the screw. System-level testing on RAPTOR lifting assemblies then showed that repeated use alone had limited influence on ultimate resistance under tension, shear, and combined tension-shear loading. A subsequent damage-mechanism campaign identified and quantified the effect of the main representative damage states introduced by real use, including plastic hinging beneath the head, over-torque, and thread abrasion. The results showed that reuse itself is not the dominant driver of resistance loss; rather, performance is governed by whether significant damage has been introduced during installation, lifting, removal, or reinstallation.



Figure 1. Lifting of a CLT-floor panel on site.

The experimental results were interpreted within the lifting safety framework using both the rated working load limit (WLL) and the  $4\times$ WLL certification-level limit condition associated with the Machinery Directive. For the tested configurations, the mean force at the end of the linear branch of the load-displacement curve remained above WLL, indicating that correct operation within the declared working range corresponds to elastic-range behavior. On this basis, the work supports the technical possibility of limited reuse, provided that installation is correct, damage is excluded through objective screening, and reuse remains bounded and traceable.

The study then translates the experimental evidence into a conservative reuse protocol and into product development logic, including JIG REUSE and the conception of VGS PLATE as a lifting-oriented screw designed to support bounded reuse and practical traceability. In parallel, a life-cycle assessment showed that controlled reuse can significantly reduce the global warming potential per use, with the most relevant decrease occurring within the first reuse cycles and an asymptotic trend emerging from around 25 cycles onward. Overall, the work does not support uncontrolled reuse. It defines the conditions under which reuse can move from an informal site practice to a bounded, objective, and technically defensible process, with benefits in terms of safety, cost efficiency, and circularity.

## INTRODUCTION

Lifting timber elements is one of the most critical operations in timber construction, both in prefabrication plants and on site. Unlike most permanent structural connections, lifting systems operate in a short time window in which temporary conditions, installation tolerances, handling effects, moving loads, and operator decisions act simultaneously. The severity of the operation does not depend only on the mass of the element, but on the fact that any local failure immediately becomes a system failure: if the lifting interface fails, the load is no longer retained.



Figure 2. RAPTOR MINI with VGS PLATE on a real CLT-floor-panel lifting application.

This general risk profile is reflected in recent safety communications from the sector. In Germany, for example, *Holzbau Deutschland*, the professional association representing the German carpentry and timber construction sector, reported several very serious accidents during the installation of timber elements and stated that three fatal occupational accidents had been recorded in recent years. The cases discussed were linked to force- or friction-based lifting devices, that is, systems in which the load is carried through magnet, suction, friction, or comparable force-based principles. Rothoblaas does not commercialize lifting systems of this type, precisely because of the inherent risks associated with such operating principles, and instead focuses on mechanically fastened or sling-based lifting solutions. These episodes nevertheless remain clear evidence of the criticality of timber lifting operations as a whole.

Within this context, the role of screws in lifting applications becomes a particularly sensitive issue. The market already operates around a clear contradiction: technical documentation from screw manufacturers generally prescribes single use for lifting applications, while field practice often involves the reuse of screws. This naturally raises concerns across the whole chain, from manufacturers and designers to contractors, insurers, and the wider industry. Those concerns are well founded, and they are shared by Rothoblaas as part of the industry. For this very reason, the issue could not simply be ignored. The objective was therefore not to normalize reuse as such, but to understand its actual implications, quantify its effects, and determine whether a controlled, technically supported, and objectively verifiable reuse pathway could exist.

This contradiction has a further implication: Where reuse takes place informally, the associated risk is effectively assumed only by the operator, typically the prefabricator or the contractor. In other words, screws are already being reused in practice, but without an objective screening

method, without traceability, and without a shared technical framework aligning manufacturers' assumptions, insurance logic, and field operations. This leaves end users alone in taking a decision that directly affects both safety and liability. It also helps explain why, in more insurance-sensitive markets, such as the US and the UK, the most rigorous operators increasingly default to single use, despite the resulting increase in cost and material waste.



Figure 3. Installing the chain hook on a RAPTOR MINI prior to lifting.

A further reason for addressing the issue is sustainability in the economic sense of the lifting process. The lifting devices themselves are already reusable, while the screws used to fix them to the elements are still treated as single-use components. This creates an evident imbalance: one recurring site operation still relies on a consumable component. If reuse can be demonstrated to be feasible under safe and controlled conditions, current practice may involve higher screw consumption, higher costs, and more waste than technically necessary. Reducing that consumption would not only improve site efficiency but also reduce the carbon footprint associated with lifting operations by lowering the quantity of steel fasteners required for the same handling function.

## **INTERPRETATION FRAMEWORK FOR THE CAMPAIGNS**

Before reading the campaigns, it is necessary to define the framework used to interpret the results. The work does not assess reuse only by comparing the peak load of a used-screw assembly with that of a new-screw assembly. In a lifting application, that comparison alone is insufficient. What matters is not only how the system behaves at failure, but whether it remains within a safe operating range under repeated use and under realistic damage conditions.

For this reason, the campaigns are interpreted against two distinct domains. The first is the declared maximum operational load capacity of the lifting system, WLL, that is, the rated working load used as the maximum allowable lifting load in practice. This value is obtained by dividing the characteristic resistance of the relevant configuration by a safety factor of 4 ( $WLL = R_k/4$ ). The second is a safety limit domain corresponding to  $4 \times WLL$ . The latter is not an arbitrary multiplier; it reflects the certification-level safety framework associated with the Machinery Directive (2006/42/EC) and is used in the work as the reference limit condition for Rothoblaas certified lifting systems, such as RAPTOR.

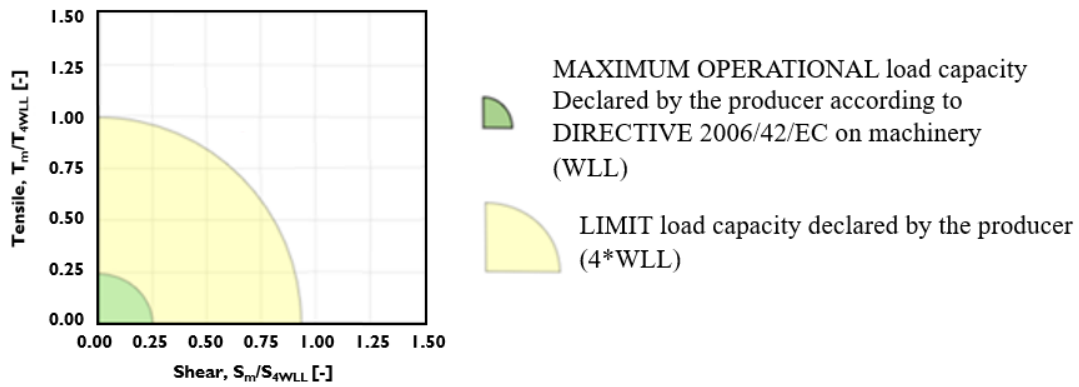


Figure 4. Graph with the domains of the maximum operational load capacity (WLL) and Limit load capacity declared by the producer (4xWLL)

A second parameter used throughout the campaigns is the mean force at the end of the linear branch of the load-displacement curve, referred to as the elastic limit. This value is important because it identifies the point up to which the connector can be interpreted as operating in the elastic range. If a lifting operation is carried out in compliance with the provided WLL values, the screws and the system will remain within the elastic domain, and is not expected to accumulate use-induced damage, provided installation is correct and no abnormal event occurs. This is one of the reasons the work does not stop at ultimate-load comparisons. It is not only asking whether a reused screw can still fail at a high load, but whether it can continue to work inside a range compatible with lifting practice.

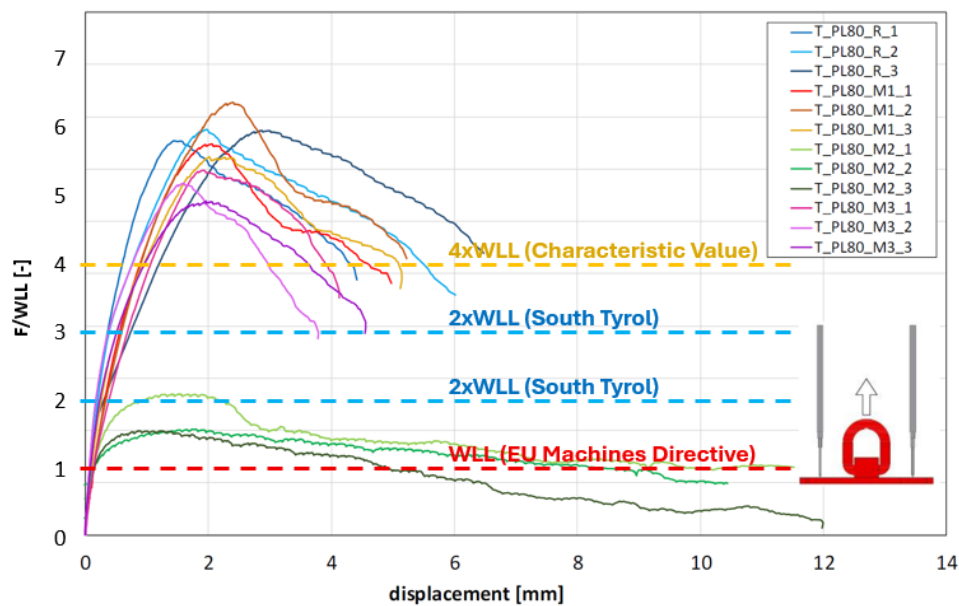


Figure 5. Load-displacement curves from the pure-tension (90°) tests of the Bologna campaign, with reference load limits used as benchmarks in the different test phases.

This interpretive framework is also consistent with the broader technical background of steel-to-timber screw behavior. In thick steel-to-timber connections, the screw is not loaded only by the design force considered in structural verification. It may also carry unintended prestressing introduced during installation and additional force generated later by swelling of the timber if moisture increases.

# SOUTH TYROL – PROGRAM STRUCTURE AND PROBLEM DEFINITION

The work carried out at the Rothoblaas headquarters in South Tyrol (Italy) was the phase that gave the whole path its structure.

The project was preceded by a preliminary phase focused on the regulatory framework and on the current state of the art regarding screw reuse in timber applications. This phase highlighted the absence of consolidated data, guidelines, or established testing and assessment methodologies specifically addressing reuse in lifting applications. A dedicated multi-phase methodology therefore had to be defined and then developed experimentally. On that basis, the project was structured in three phases: first, single-screw analysis under repeated use; second, system analysis on RAPTOR with reused screws; and third, system analysis on RAPTOR with intentionally damaged screws. The work focused on Ø10 mm (0.40") HBS PLATE screws, primarily the newer HBSPL version and the older HBSP version, while considering variables such as screw length, number of screws, wood species, and load direction. The emphasis on HBSPL is also relevant in view of the later development of VGS PLATE, which adopts the same underhead concept.

This sequencing reflects the actual engineering question. Before assuming that reuse is dangerous in itself, it was necessary to determine whether repeated use alone causes a relevant degradation, or whether the main issue lies instead in the damage introduced during installation, lifting, disassembly, and reinstallation. In practice, these conditions are often mixed together. Here they were deliberately separated.

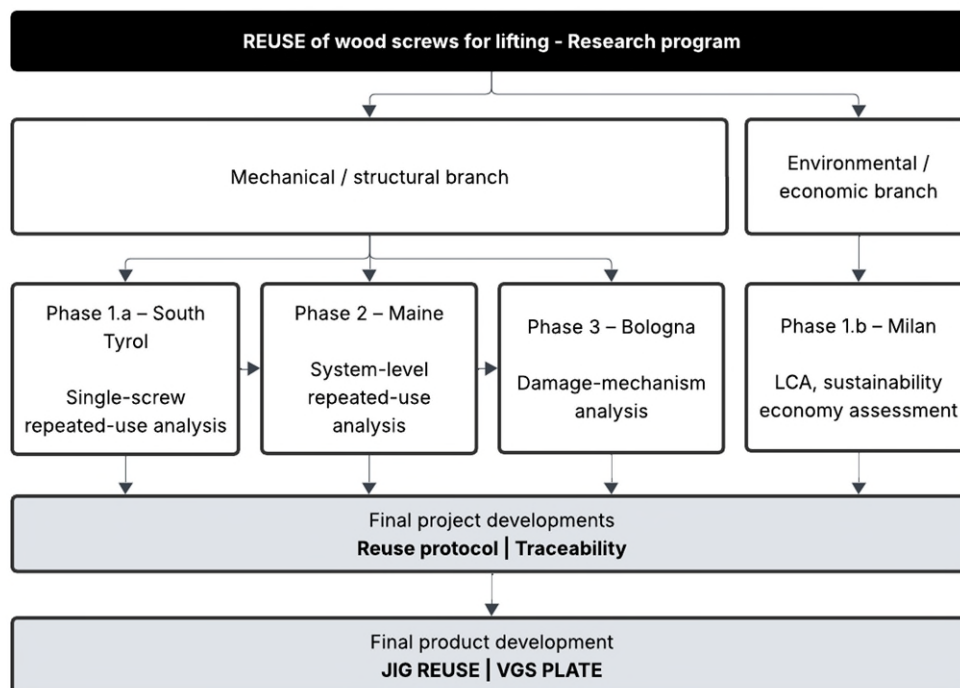


Figure 6. Program structure developed within the Rothoblaas research project. The white phases represent the initial structure of the experimental program, while the gray phases indicate the subsequent research phases that emerged from the later development.

That distinction was not automatic at the beginning. Market practice often treats a reused screw as suspect simply because it is no longer new. The concern is valid. But instead of stopping there, the work split the problem into two parts. First: what happens to the screw if it is used

multiple times under controlled conditions? Second: what happens when realistic damage or misuse mechanisms are introduced? That separation is what allowed the work to move from a generic concern about reuse to a technically grounded method for assessing it.

This preliminary work also brought installation method into focus. In the single-screw campaign, an additional series using an impact driver was started but then stopped because the driver caused excessive damage to the bit recess, making installation problematic. Even though that path was not completed, the observation remains relevant because it aligns with the related installation-risk evidence: in steel-to-timber applications, impact and impulse drivers can generate torque values above twice the recommended insertion moment and intensify damage to the recess, coating, and timber counter-thread.

## SOUTH TYROL – REPEATED-USE BEHAVIOR AT SCREW LEVEL

The first experimental question was intentionally narrow. Before studying the behavior of the full lifting system, it was necessary to establish whether repeated controlled use changes the basic mechanical properties of the screw itself.

A reference batch of screws was first characterized through torsional, withdrawal, and tensile tests (see table 1).

Table 1. Mean values of the reference screw batch, as obtained from the initial torsional, tensile and withdrawal characterization tests.

	<b>Torsional</b>	<b>Tensile</b>	<b>Withdrawal</b> ( $\rho=430\text{kg/m}^3$ )
	<b>F<sub>tor</sub></b> [Nm]	<b>F<sub>tens</sub></b> [kN]	<b>F<sub>ax</sub></b> [kN]
<b>Mean value</b>	59,00	41,98	26,59
<b>Standard deviation</b>	0,47	0,28	0,88
<b>CoV [%]</b>	0,8	0,66	3,32

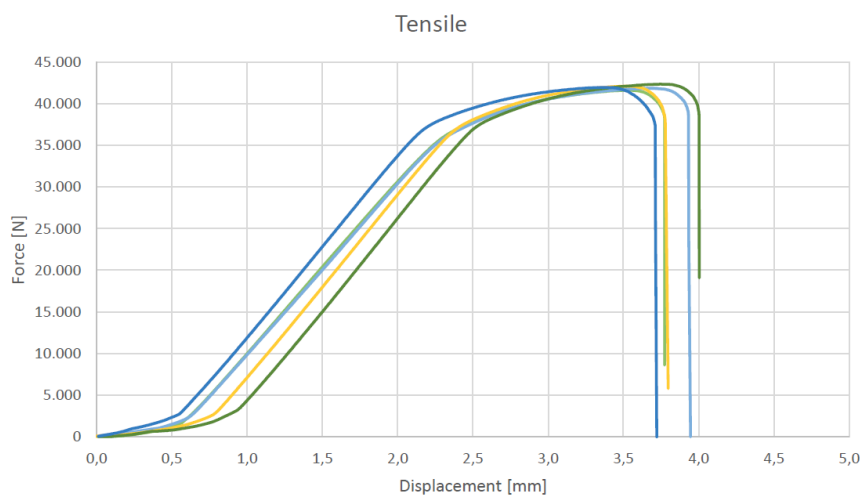


Figure 7. Load-displacement curves obtained from the tensile tests on the reference screw batch

After that, other screws from the same batch were subjected to 25 use cycles. In each cycle, the screw was installed into the loading plate, loaded, removed, and then reinstalled into a new timber member. Every five cycles, nominal diameter, insertion moment, and plate deformation were measured. At the end of the use cycles, the screws were removed from the assembly and tested individually in torsion, withdrawal, and tension.

## ■ REUSE-CYCLE PROCEDURE



Figure 8. Photo of the test rig used for the repeated-use screw-level tests at Rothoblaas.

The repeated-use protocol itself is worth stating explicitly. The loading sequence followed an EN 26891-type protocol with  $F_{est} = 2 \times WLL$  (equivalent to 50 kN), load to  $0.4 F_{est}$  in 2 minutes, hold, unload to  $0.1 F_{est}$ , hold, reload to  $0.7 F_{est}$  in 3 minutes, then load to  $1.0 F_{est}$  in 3 minutes. Two full test series were completed. The third series, using an impact driver and over torquing, was stopped because of the recess damage mentioned above.

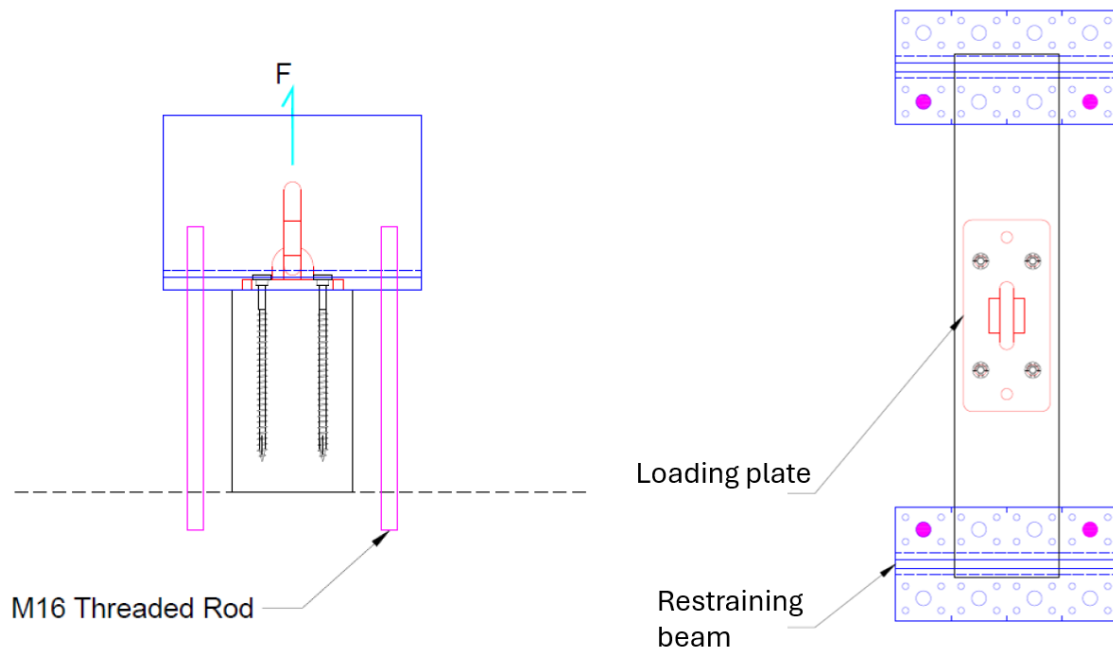


Figure 9. Layout of the test rig used for repeated-use screw-level tests at Rothoblaas.

## MECHANICAL RESPONSE AFTER 25 USE CYCLES

The results showed that the main screw-level parameters were not meaningfully affected by repeated controlled use. After 25 cycles, the mean torsional strength was 1.33 Nm lower than the reference value, corresponding to a decrease of about 2.3%. The mean tensile strength was 0.11 kN lower than the reference value, corresponding to a decrease of about 0.3%. Finally, the mean withdrawal resistance was 0.32 kN higher than the reference value, corresponding to an increase of about 1.2%. These differences are of the same order of magnitude as ordinary statistical fluctuation within the test series and, taken together with the similar load-displacement behavior, support the interpretation that no meaningful variation in these parameters was observed between new and used screws.

Table 2. Mean values after 25 use cycles in the repeated-use screw-level tests, compared with the reference screw batch, for torsional strength, withdrawal resistance, tensile strength, and insertion moment.

	<b>Torsional</b>		<b>Tensile</b>		<b>Withdrawal</b> ( $\rho=430\text{kg/m}^3$ )		<b>Insertion Moment</b>	
	<b>F<sub>tor</sub></b> [Nm]		<b>F<sub>tens</sub></b> [kN]		<b>F<sub>ax</sub></b> [kN]		<b>R<sub>tor</sub></b> [kN]	
	<b>REF</b>	<b>C25</b>	<b>REF</b>	<b>C25</b>	<b>REF</b>	<b>C25</b>	<b>C1</b>	<b>C25</b>
<b>Mean value</b>	59,00	57,58	41,98	41,87	26,59	26,91	17,16	17,30
<b>Standard deviation</b>	0,47	0,55	0,28	0,42	0,88	1,04	2,37	2,42
<b>CoV [%]</b>	0,80	0,96	0,66	1,00	3,32	3,85	13,80	14,00

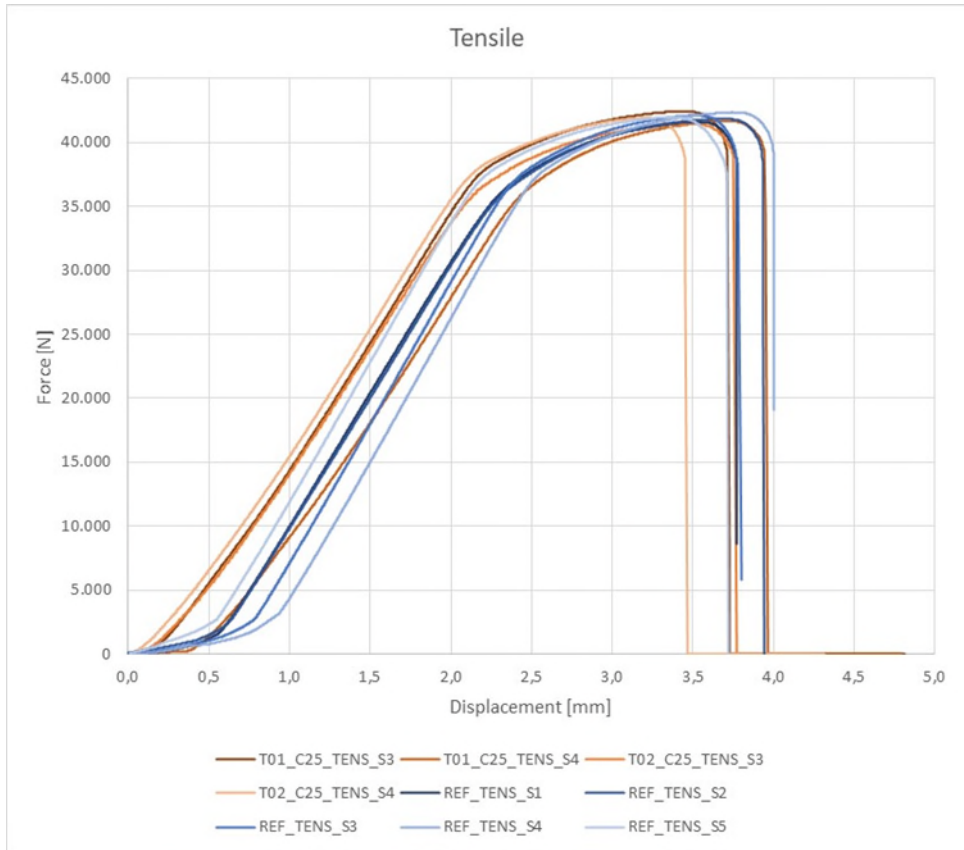


Figure 10. Load-displacement curves from the tensile tests, showing together the curves of the reference screw batch and those of the repeated-use screw-level tests after 25 use cycles.

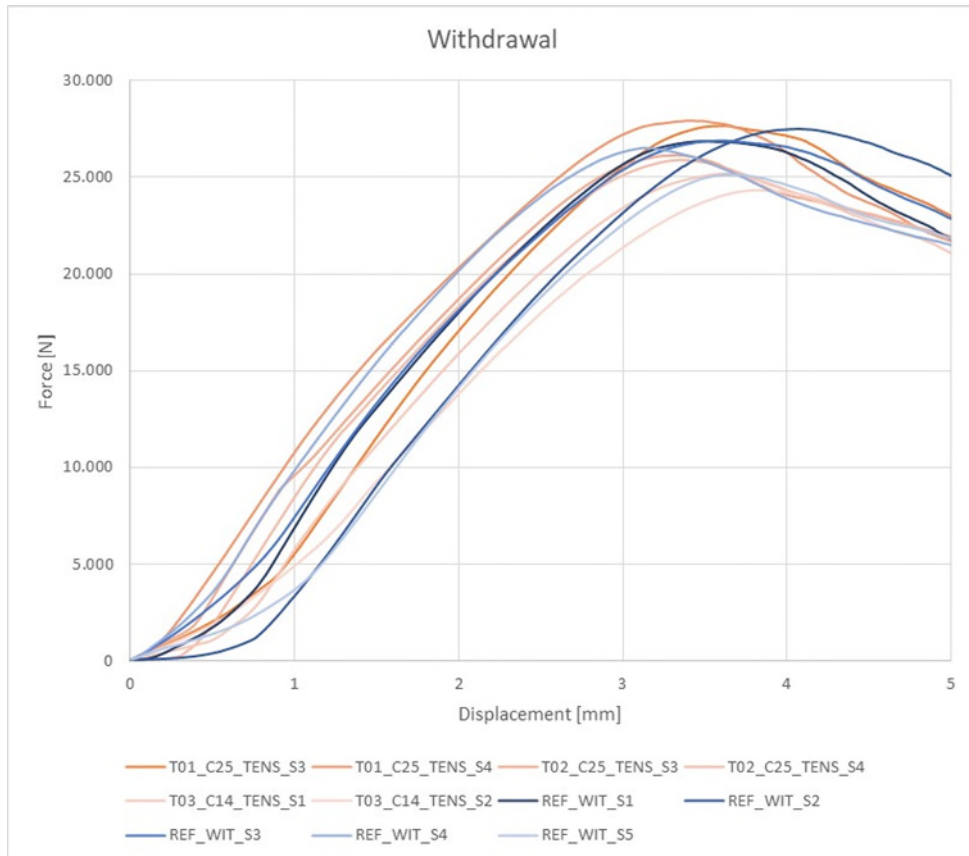


Figure 11. Load-displacement curves from the thread withdrawal tests, showing together the curves of the reference screw batch and those of the repeated-use screw-level tests after 25 use cycles.

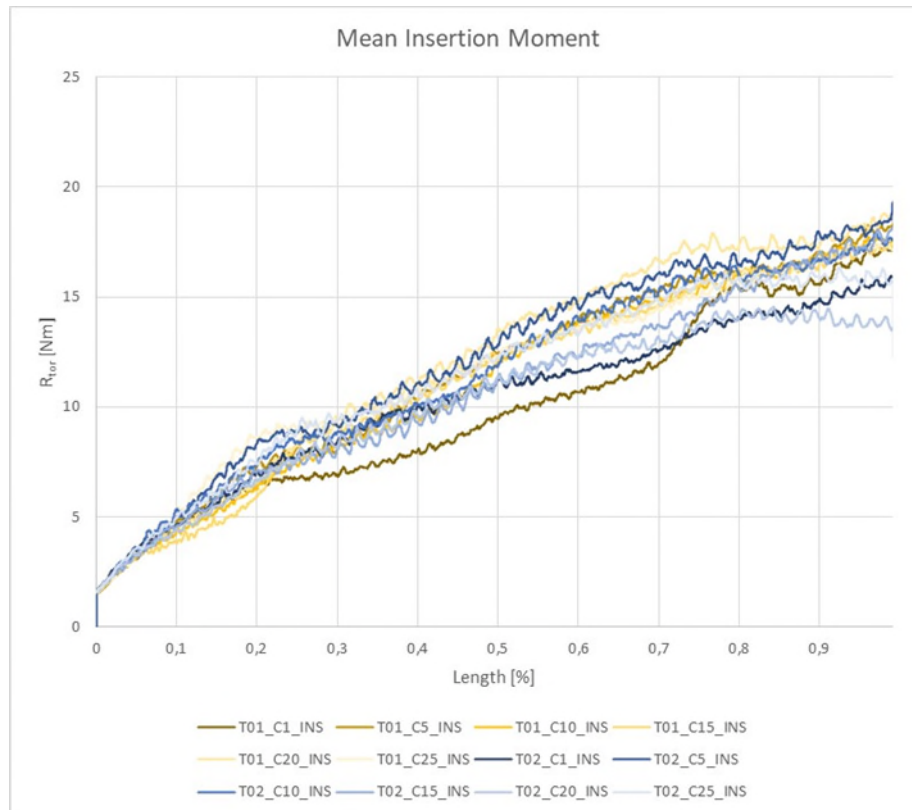


Figure 12. Insertion moment curves from the tensile tests, showing together the curves of the reference screw batch and those of the repeated-use screw-level tests after 25 use cycles.

## ■ SCREW-LEVEL INTERPRETATION OF RESULTS

Nominal diameter variations remained very low, and insertion moment showed scatter but not a monotonic deterioration with increasing cycle count. The conclusion is, therefore, that the analyzed parameters were not affected by multiple use of the screws.

	Measured external thread diameter		
	$d_1$ [mm]		
Load cycle	C1	C10	C25
Mean value	9,854	9,851	9,851
Standard deviation	0,01		
CoV [%]	0,14		

Figure 13. Measurements of the external thread diameter after each use cycle.

This does not mean that every reused screw is acceptable. It means something more precise: at screw level, repeated controlled use did not emerge as the factor governing the main mechanical parameters. Once that had been clarified, there was still an essential intermediate step before moving to damage mechanisms. It was first necessary to verify whether, at system level, reuse could interact with factors such as load eccentricity, screw number, and screw positioning in a way that affected the final resistance of the system-scale assembly. Only after addressing that question did the focus shift from reuse itself to the specific damage or misuse mechanisms that could actually result in the performance losses that may occur in practice.

## MAINE – SYSTEM-LEVEL RESPONSE UNDER REPEATED USE

The Maine campaign was the first full-system answer to that revised question.

At the University of Maine (USA), RAPTOR assemblies fastened with HBS PLATE screws were tested in pure tension, pure shear, and combined tension-shear. The tests were performed by loading the lifting system from the hook at 90° to the panel surface for pure tension, 0° for pure shear, and 45° for combined tension-shear, using custom rigs developed specifically for the campaign. New screws were installed at 90° with a standard drill, left slightly proud, and then tightened with a torque wrench to avoid overdriving. The cyclic series were loaded, unloaded, removed, and reinstalled into new CLT members for repeated cycles before the final destructive test.



Figure 14. Test setups for pure tension (load applied at 90° to the panel surface), pure shear (load applied at 0° to the panel surface), and combined tension-shear (load applied at 45° to the panel surface).

This campaign moved the discussion from the isolated screw to the lifting assembly. In a real lifting device, the screw does not work alone. It interacts with the plate, the timber, the number of fasteners, the load direction, and the redistribution of forces within the system.

### TENSION, SHEAR AND COMBINED RESPONSE UNDER REPEATED USE

The Maine results showed that, across many tested configurations, repeated use alone had limited influence on ultimate resistance. In combined tension-shear with the shorter 80mm (3 1/8") screws on standard CLT, the average maximum load of the reference specimens was 29.86 kN, while the cycled specimens reached 30.53 kN.



Figure 15. Combined tension-shear tests at 45° after failure. Most specimens with L=80mm (3 1/8") screws failed by withdrawal of the downhill screws, causing timber splitting and plate rotation, which then led to deformation of the uphill screws and further splitting.

In tension, the 80mm (3 1/8") screws reference-tests averaged 40.94 kN and the cycled series 41.69 kN. For the longer 180mm (7 1/8") screws in tension, the reference series averaged 99.24 kN and the cycled series 103.70 kN.

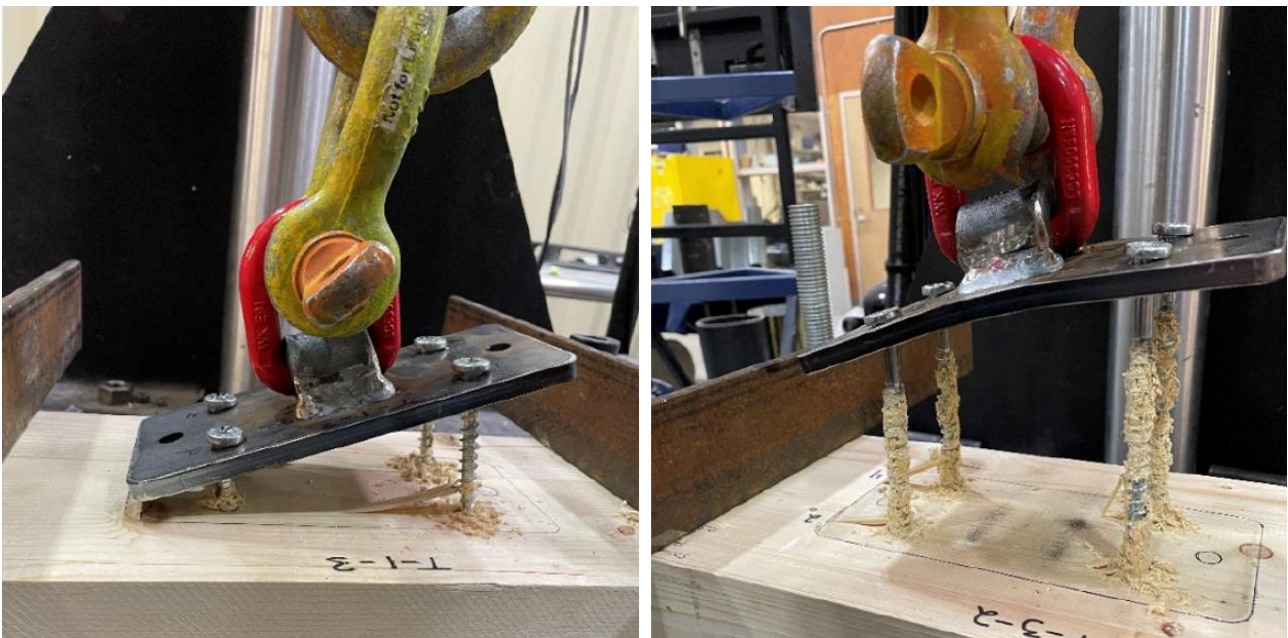


Figure 16. Pure tension tests at 90° after failure. Specimens using L=80mm (3 1/8") screws ultimately failed by withdrawal, both in the cycled and non-cycled conditions. For specimens with 180mm (7 1/8") screws, the observed failure modes included plate bending followed by screw withdrawal, screw-head rupture, or a combination of the two.

In shear with the 180mm (7 1/8") screws on standard CLT, the reference series averaged 70.61 kN and the cycled series 60.17 kN, showing that shear was the more variable case.

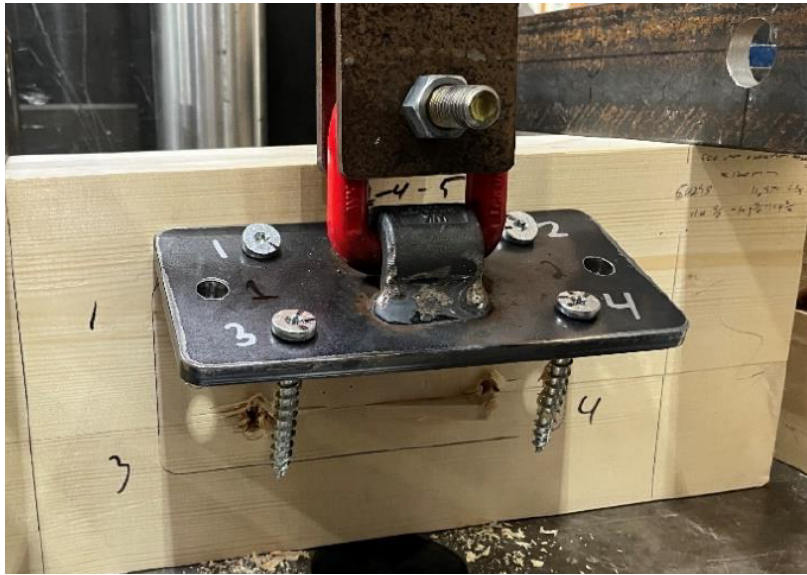


Figure 17. Pure shear tests at 0° after failure. Most specimens with HBSP1080 screws failed by withdrawal of the two lower screws, allowing the plate to rotate and the upper screws to deform.

## ■ ROLE OF LOADING HISTORY AND ACCUMULATED DAMAGE

The interpretation is therefore not that repeated use has no effect under any circumstance, but that repeated use alone did not emerge as the dominant driver of resistance loss in the lifting system. In this context, the simulated reuse was carried out under a load level equal to 3 times the declared WLL, which proved to be particularly influential on shear resistance, since it operated in the order of magnitude of yielding, and highlighted the critical role of the accumulated damage/loading history. The issue was thus no longer “used versus new,” but “used under what conditions, and with what damage history?”

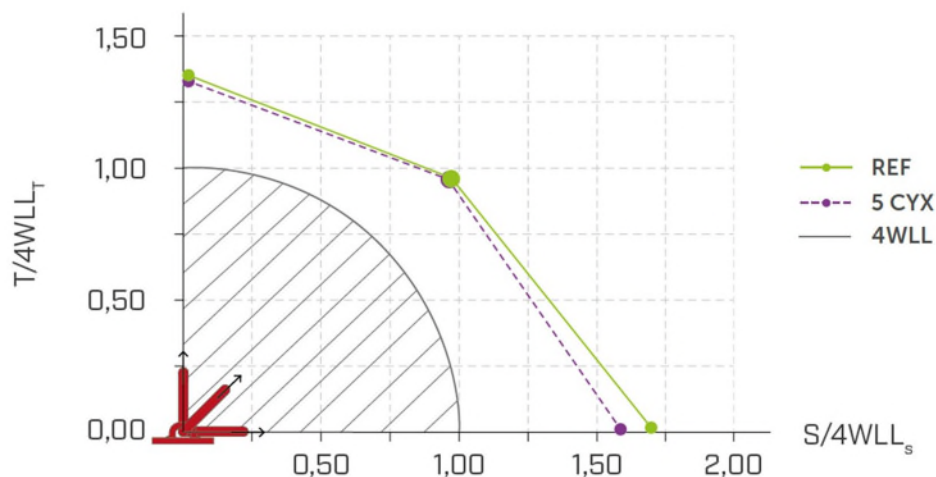


Figure 18. Non-dimensionalized final resistance domain based on the mean values obtained from all tests under the different loading-angle configurations.

Another relevant aspect of the Maine work is that it broadened the sensitivity analysis. The tests did not remain limited to one timber density or one screw geometry. They included short and long screws, different screw counts, and both standard and higher-density CLT conditions. Even where some sub-configurations had limited repetition, the direction of the evidence was sufficiently clear: controlled repeated use does not, by itself, explain the reductions that practitioners fear.

# BOLOGNA – REPRESENTATIVE DAMAGE MECHANISMS AND TEST METHODOLOGY

The University of Bologna (Italy) campaign is where the work becomes fully damage-sensitive and method-driven.

The workplan was structured as three steps: definition of representative damage mechanisms, experimental tests on RAPTOR plates fastened with damaged screws, and analysis of the resulting structural response. The main contribution of this phase was to determine which specific damage states are realistic, how they can be reproduced in a controlled way, and how they affect the system in different loading directions.

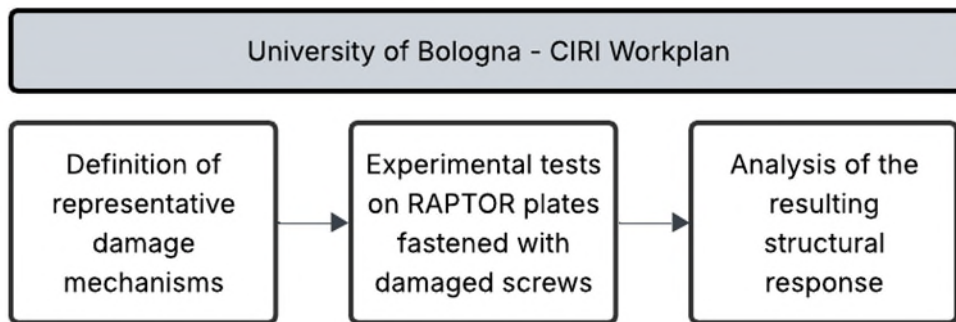


Figure 19. Workplan of the Bologna campaign, structured in three main steps.

## DEFINITION OF REPRESENTATIVE DAMAGE MECHANISMS (MECH)

The first mechanism (MECH 1) was plastic hinging beneath the screw head. This mechanism can arise either from incorrect installation or from plate bending under excessive loading, with the screw head following the plate deformation.

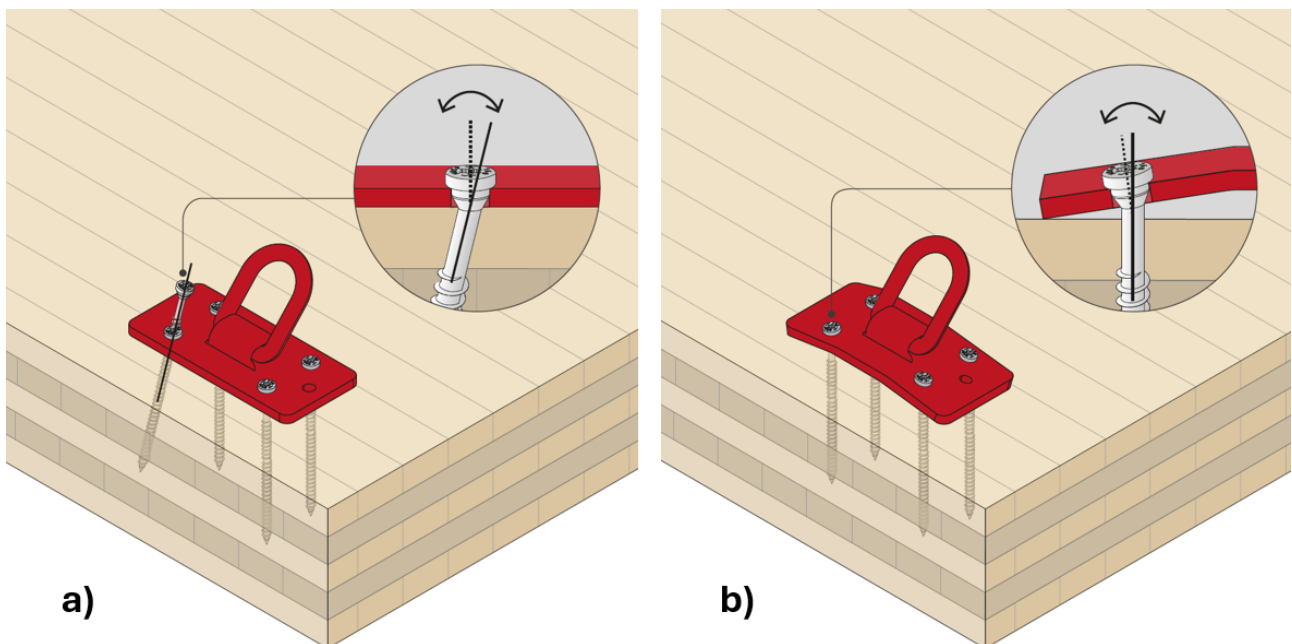


Figure 20. Damage mechanism #1 (MECH 1) induced by: a) incorrect installation and b) screw head deformation due to excessive loading and plate bending.

A formal 10° rotation threshold was adopted in the study, not as an admissible installation condition, but as a detectable limit case beyond which correct installation would no longer be possible and the screw would clearly no longer be acceptable for reuse. The report also notes that in real applications plastic rotations may add up with opposite signs, visually cancelling part of the deformation while leaving the stem plasticized.

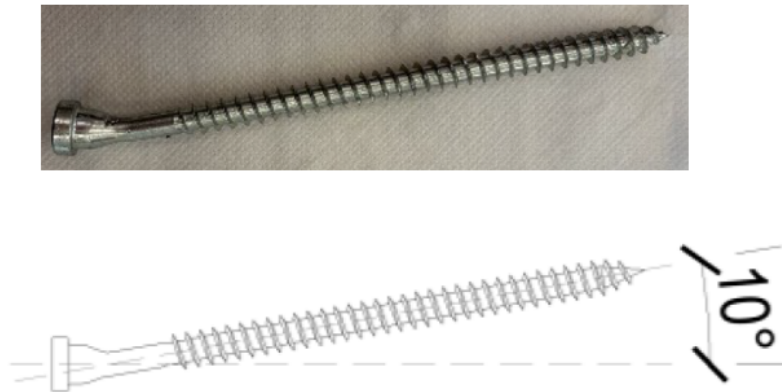


Figure 21. Damage mechanism #1 (MECH 1) applied on HBSPL10180, before straightening.

The second mechanism (MECH 2) was over-torque. This mechanism is especially relevant in thick-plate steel-to-timber conditions, where the screw can continue to rotate after the head has already seated against the plate. Tightening tests were therefore carried out both in a rigid-thread bench setup and in a real installation configuration with the thread clamped in wood and the head reacting against a thick plate. The report also states that the ultimate torque values were approximately twice the recommended installation torque and that, in the real thick-plate condition, the failure torque increased further because of local friction under the head.

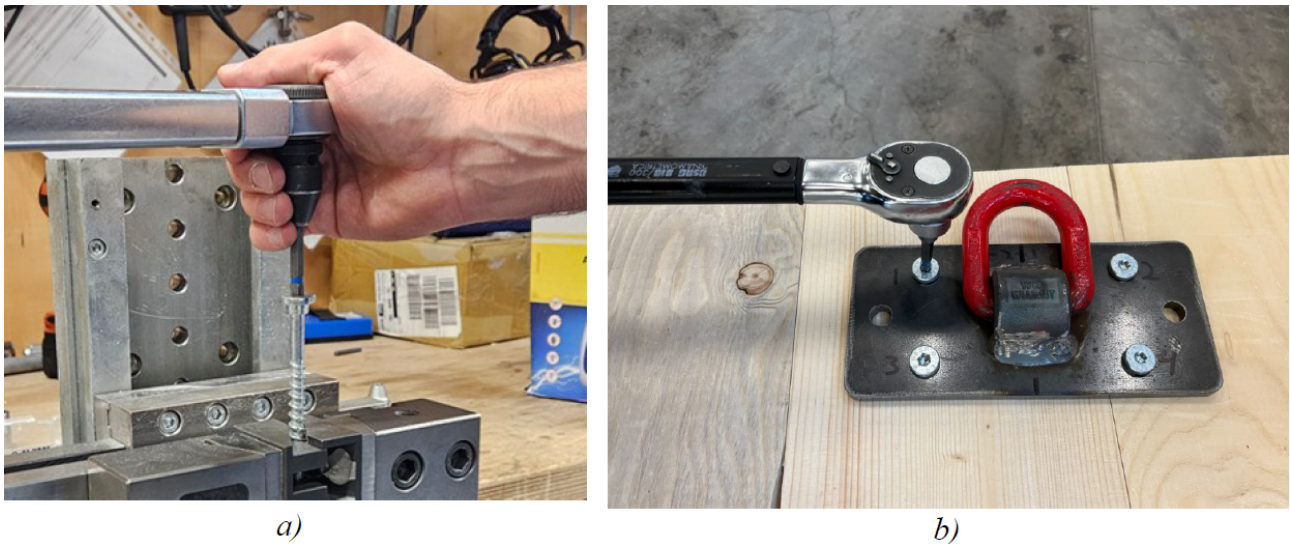


Figure 22. Tightening tests of HBS P10 screws: a) rigid thread fixing (pure screw torsional strength) and b) real installation condition using a thick steel plate (applicable torque in-use).

The third mechanism (MECH 3) was thread abrasion. Since the thread governs axial resistance and also contributes to lateral resistance through rope effect, damage to the thread directly affects the connection in more than one load direction. In real applications thread damage can occur from incorrect insertion, especially when the screw is not perpendicular to the fixing plane and abrades against the plate edges (MECH 4), or from hidden metal elements or knots inside the timber.

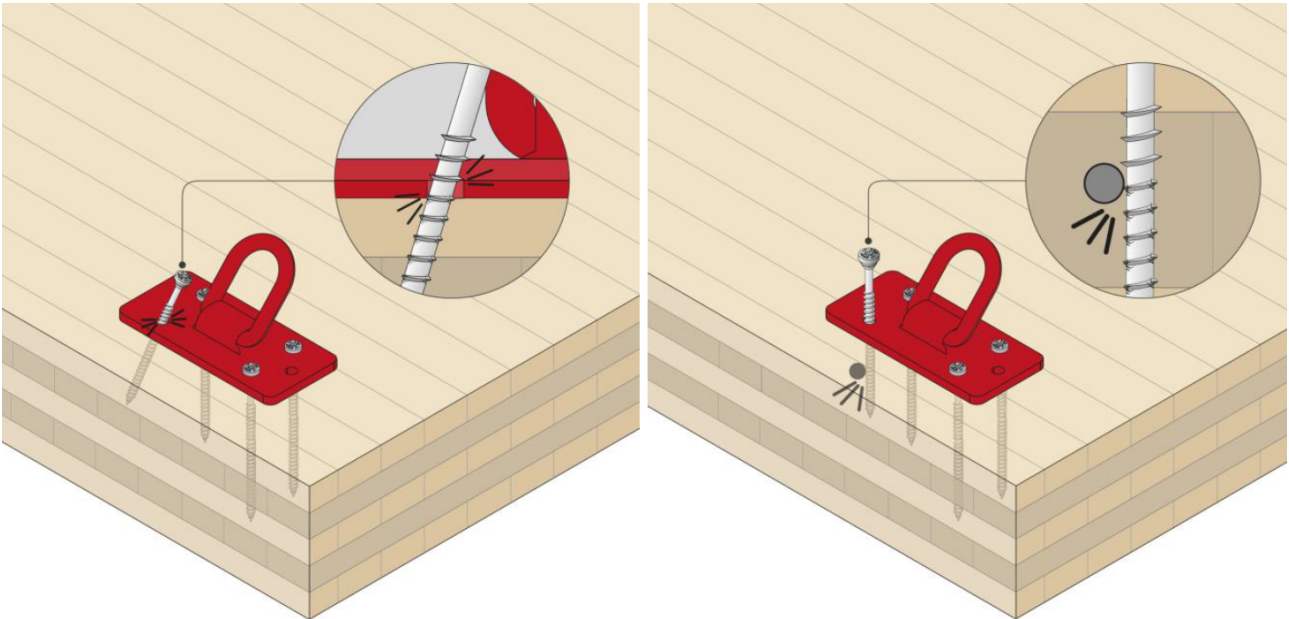


Figure 23. Damage mechanism #3 (MECH 3) induced by: a) incorrect installation and b) intersection with hidden plates inside the wooden element.

Experimentally, the mechanism was imposed by passing the screw through a hardened steel pin drilled with 9.5, 9.0, and 8.5 mm holes until the final net diameter was about 8.7 mm.

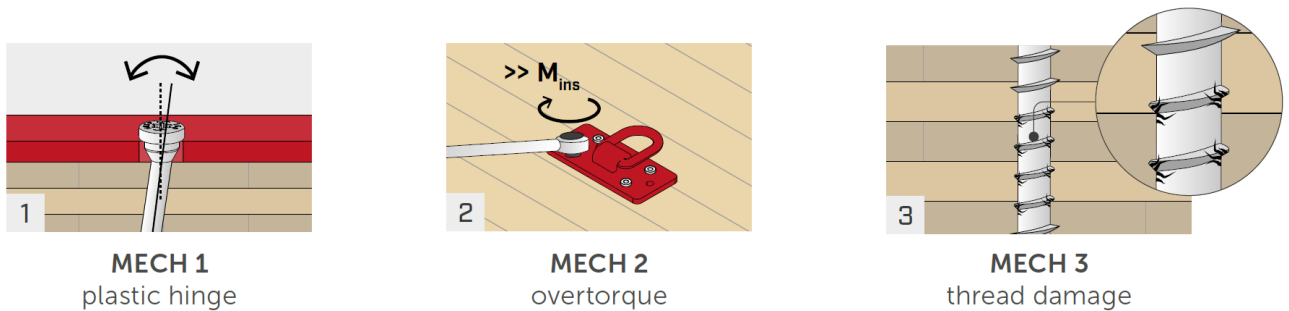


Figure 24. Representation of the three main damage mechanisms investigated.

As discussed, altered screw inclination (MECH 4) is more appropriately interpreted not as an independent governing category, but as a condition that can induce or amplify other damage states. Accordingly, the study also considered cumulative cases, since the investigated mechanisms do not necessarily occur in isolation in real conditions. Two combinations were selected for experimental assessment: MECH 1 + MECH 2 at screw level, and MECH 4 + MECH 2 at connection level.



Figure 25. (a) Insertion of the screw at an inclination of  $10^\circ$  using a dedicated jig; (b) Screws in place after installation, inclined at  $10^\circ$  (MECH 4).

Dedicated procedures were developed to impose each mechanism in a repeatable way. Plastic hinging was introduced through angulation and straightening plates (see Figure 21a); over-torque was imposed directly during fastening (see Figure 18), with different procedures for short and long screws; and thread abrasion was induced through the hardened-pin sequence described above.

The screw-level MECH 1 + MECH 2 tests showed that prior plasticization did not significantly affect the torsional resistance of the screws, while the MECH 4 + MECH 2 combination was assessed at connection level in the subsequent structural tests. In this respect, it is worth noting that the influence of imposed screw angulation had already been investigated by Denz et al. at KIT, who showed that altered insertion angle can reduce tensile capacity, in severe cases by more than 30%, although for more realistic deviations, such as  $10^\circ$ , the reduction was much smaller, on the order of 4–5%.

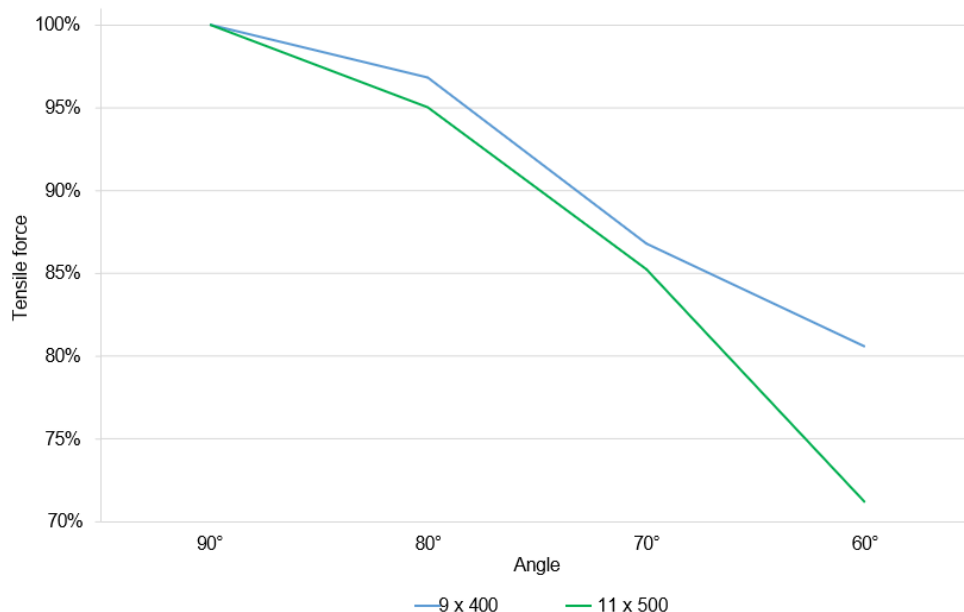


Figure 26. Graphic representation of the decrease in the tensile load-bearing capacity of the deliberately misaligned wood screws. C. Denz, Bestimmung möglicher Einflüsse auf die Tragfähigkeit von Stahlblech-Holz-Verbindungen mit Vollgewindeschrauben durch unsachgemäße Montage, KIT, 2023.

# BOLOGNA – EFFECT OF DAMAGE MECHANISMS ON LOAD-CARRYING CAPACITY

The Bologna phase showed that the damage mechanisms do not act with the same relevance, and that their influence depends strongly on screw length and load direction.

## PLASTIC HINGING BENEATH THE HEAD

Plastic hinging beneath the head turned out to be the least penalizing mechanism overall. This may appear counterintuitive, because visually it is one of the most evident damage states, but mechanically it was not the mechanism that most strongly governed the loss of resistance across the tested load cases. In the RAPTOR system, plastic hinging primarily affects local deformation and prying behavior but does not necessarily suppress the withdrawal contribution governing several of the tested configurations.

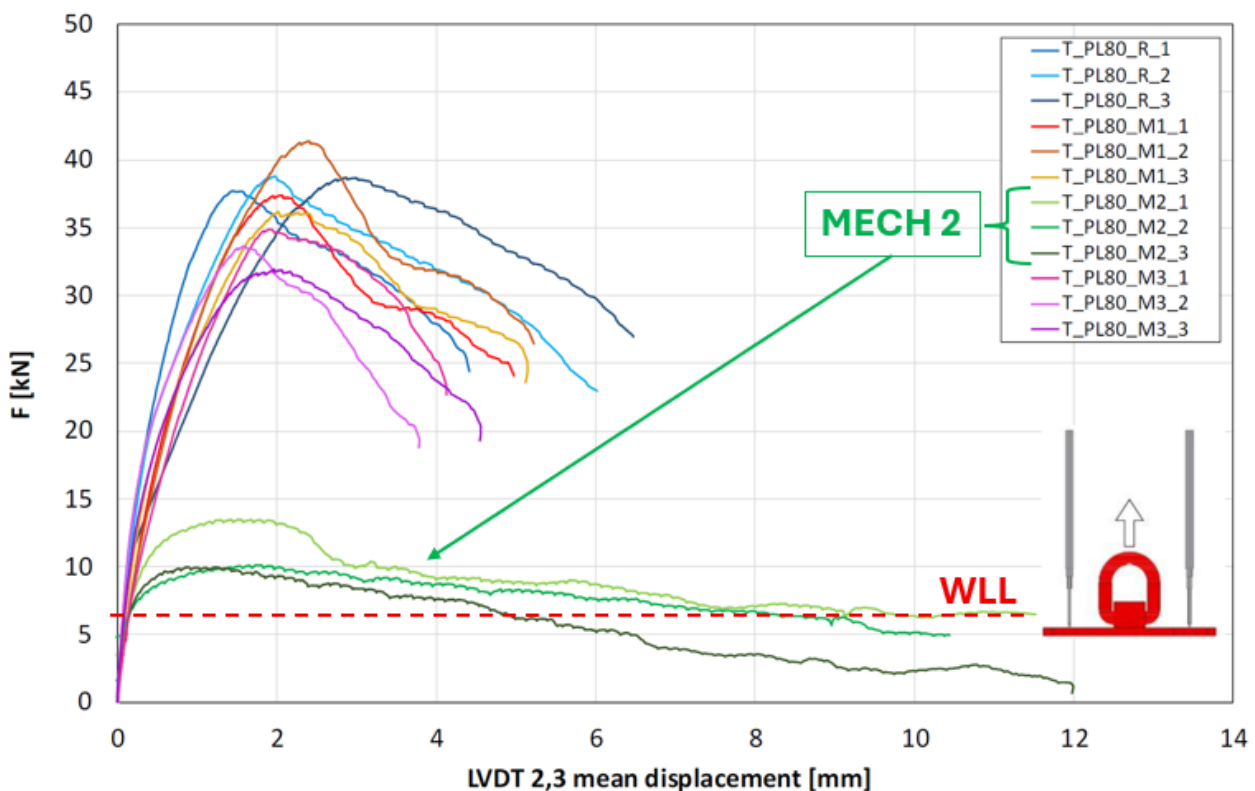


Figure 27. Load displacement graph for shorter screws in pure tension (90°).

## OVER-TORQUE AND TIMBER COUNTER-THREAD DAMAGE

Over-torque was more complex and, for short screws, clearly more critical (see Fig. 27). The dominant effect was not torsional failure of the steel itself, but damage to the timber counter-thread. Once that happens, the screw may no longer develop the intended withdrawal resistance, and the capacity of the connection can decrease sharply. MECH2 was, indeed, the most critical mechanism for short screws ( $L=80\text{mm}$ ,  $3\frac{1}{8}''$ ) reducing resistance by more than 50% in many cases, while the effects on 180 mm ( $7\frac{1}{8}''$ ) screws were negligible (see Fig. 29). For short screws, MECH2 produced elastic-limit values very close to WLL (see Fig. 27).

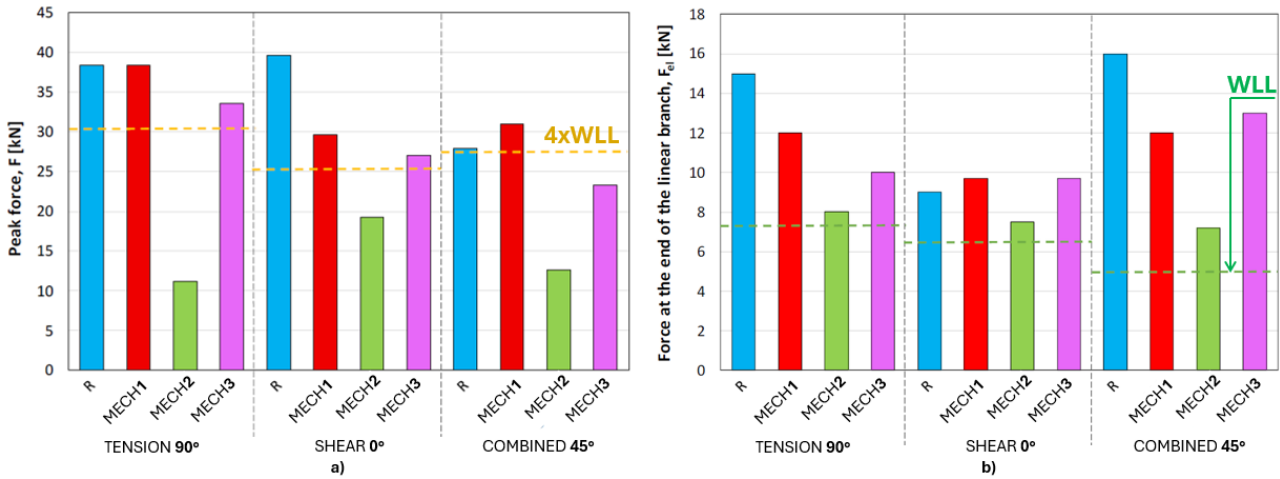


Figure 28. Bar chart of the mean peak force (a) and of the mean force for each damage mechanism at the end of the linear branch (b) for L=80 mm (3 1/8") screws (HBSPL1080). The yellow line represents the limit load capacity declared by the producer (4xWLL = R<sub>k</sub>). The green lines represent the maximum operational load capacity declared by the manufacturer (WLL).

## THREAD ABRASION AND LOSS OF AXIAL ENGAGEMENT

Thread damage (MECH 3) proved to be the broadest and most influential mechanism. This is not because it always gives the largest numerical reduction in every configuration, but because it affects the largest number of structurally relevant mechanisms: axial resistance in tension, withdrawal contribution in combined loading, and rope-effect contribution in shear-sensitive behavior. MECH3 was critical for all around lengths and screw types, showing that the strength contribution provided by the screw thread is susceptible to damage (see Fig. 29).

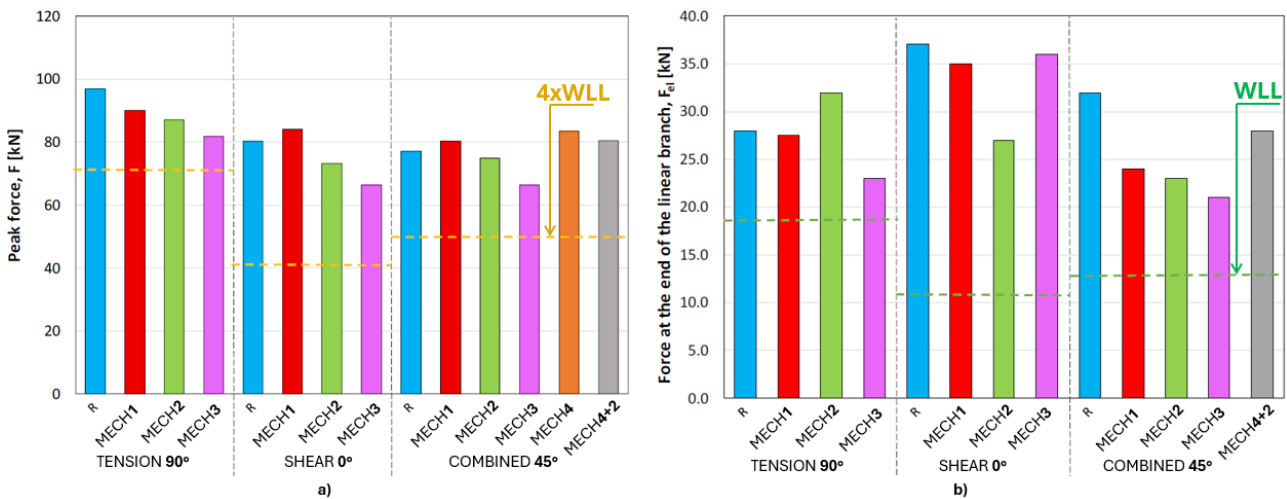


Figure 29. Bar chart of the mean peak force (a) and of the mean force for each damage mechanism at the end of the linear branch (b) for L=180 mm (7 1/8") screws (HBSPL10180). The yellow line represents the limit load capacity declared by the producer (4xWLL = R<sub>k</sub>). The green lines represent the maximum operational load capacity declared by the manufacturer (WLL).

## ■ INTERACTION DOMAINS AND SAFETY INTERPRETATION

At the level of the overall safety interpretation, for all damaged configurations the mean force at the end of the linear branch remained above WLL. It also states that all experimental interaction domains lay outside the WLL operational domain and that all remained outside the  $4 \times WLL$  limit condition except for M2 in the short screws and M3 in the tension-shear condition of HBSPL1080. On that basis, the report concludes that if installation is carried out correctly and the screws operate within the elastic range, a limited number of reuses does not compromise the system's strength.

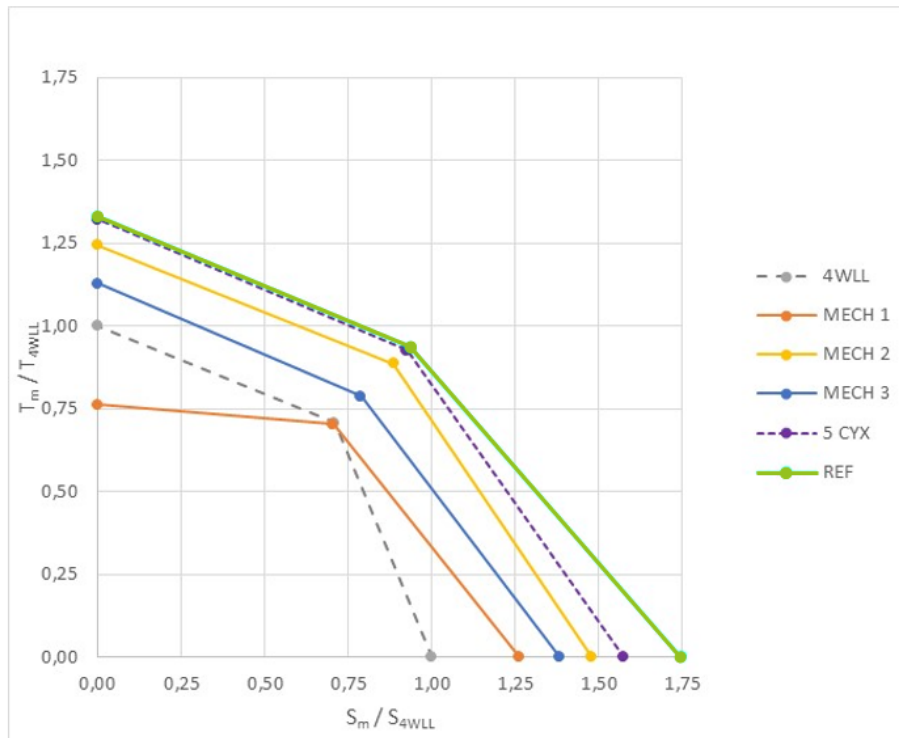


Figure 30. Aggregate non-dimensionalized resistance domain based on the mean system response of all investigated HBS PLATE screw types and lengths, for each damage mechanism (MECH 1, MECH 2, MECH 3), including the reused-screw condition (5CYX).

This is where one of the clearest conclusions emerges. A reused screw cannot be judged primarily by how many cycles it has undergone. Its acceptability depends mostly on whether those cycles introduced any of the damage states that actually matter.

# FROM CAMPAIGN RESULTS TO THE REUSE PROTOCOL

Once the work showed that reuse alone was not the dominant issue, whereas certain damage mechanisms were, the next step was to translate those findings into a procedure that could in principle be applied outside the laboratory.

Mechanical evidence alone could not be treated as a permission to reuse. It could only define the boundaries within which reuse might be considered. The practical challenge was that the most consequential damage states were not always obvious on site, and some of them could accumulate over repeated installation and removal cycles. For that reason, any reuse procedure would have to be developed as a conservative decision framework.

## SCREENING PRINCIPLES

At this stage, the reuse procedure could already be outlined around three main screening principles:

- 1. Visual** **screening**  
Any screw showing corrosion, visible bending, head damage, cracked or flaking coating, or visible thread damage would have to be rejected.
- 2. Straightness** **check**  
A go/no-go gauge would be needed to verify whether the screw remained within the admissible tolerance for bending and plastic deformation.
- 3. Thread-wear** **check**  
A dedicated control feature would be needed to verify whether the external thread diameter remained within tolerance, and thus whether thread wear or damage had reached a level requiring discard.

Only if all three checks were satisfied could the screw be considered for reuse.

## NUMBER OF USES AND OTHER CONDITIONS FOR REUSE

At the same time, one part of the protocol was still not fully resolved at that stage: the control of the admissible number of uses. The campaigns had made it possible to identify unacceptable damage states and define screening criteria, but they did not yet provide, on their own, a practical way to determine on site how many times a screw had already been reused, nor how that number should be kept within a bounded and traceable range. This point was already

recognized as necessary, but its practical investigation and implementation would come in a subsequent phase of the work.



Figure 31. Real examples of visual inspections of used screws. Screw to be discarded due to visible corrosion (left). Screw to be discarded due to visible deformation (right).

The protocol would also need to be conservative in a second sense. It could not be limited to a simple pass/fail check of the screw itself. It would also have to be paired with process rules: controlled installation and removal torque, dry and segregated storage of used screws, and immediate discard after any abnormal event such as suspected overload, impact, or loss of control of the suspended load. In that sense, reuse would not be merely a property of the screw, but the outcome of a controlled process.

# FIELD-IMPLEMENTATION OBJECTIVE CONTROL TRACEABILITY

# REQUIREMENTS: TOOLS AND

At that stage of the work, the logic of field implementation was already clear, even if the practical means to make it robust and usable on site had not yet been fully developed.

The campaigns had shown that controlled reuse could not rely on visual judgment alone. Even where the acceptance criteria were conceptually clear, a field-applicable method was still needed to make those criteria objective, repeatable, and usable on site.

## JIG REUSE AS AN OBJECTIVE INSPECTION TOOL

This is the point at which the work moved from requirements to implementation. The need for an objective field check led to the development of JIG REUSE, conceived as an inspection template for reusable lifting screws and designed around the geometry of VGS PLATE, the screw later developed for controlled reuse in lifting applications. Its role was to make the verification of residual straightness (see Fig. 32) and admissible thread wear (see Fig. 33) practical, repeatable, and immediately applicable on site: screws that do not satisfy the defined control conditions are rejected, while screws that pass the checks can proceed within the reuse procedure. In this sense, JIG REUSE should not be read as an accessory, but as the first practical bridge between the laboratory campaigns and a controlled reuse procedure in the field.

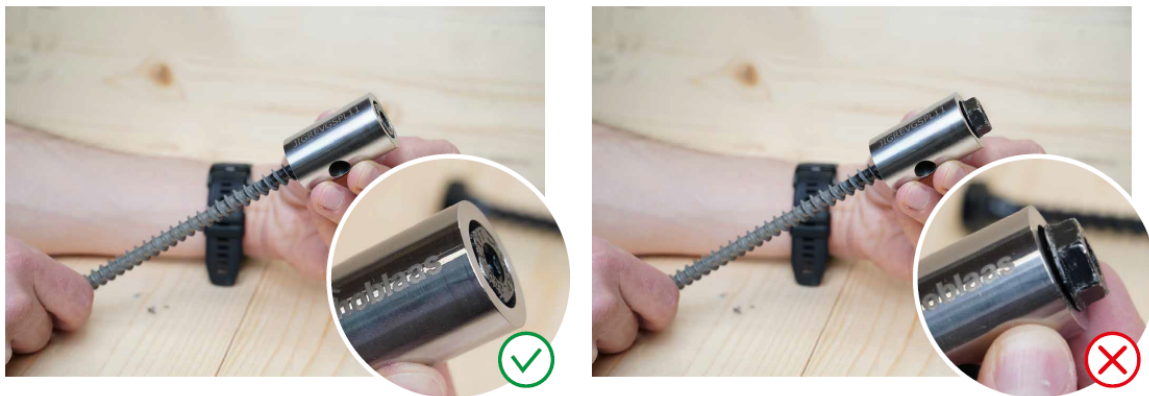


Figure 32. Real examples of visual inspections of used screws with gauge JIG REUSE. Straightness check passed, thus absence of significant plastic deformation (left). Straightness check NOT passed, screw to be discarded (right).

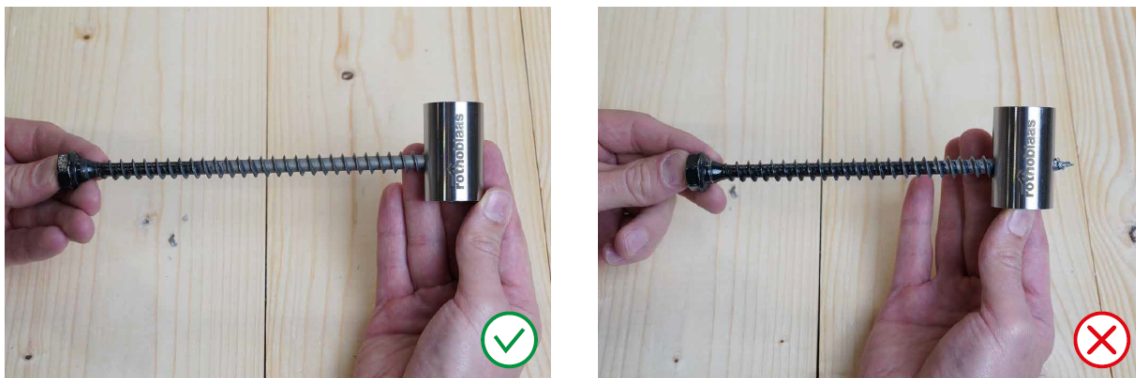


Figure 33. Real examples of visual inspections of used screws with gauge JIG REUSE. Thread wear check passed (left). Thread wear check NOT passed, screw to be discarded (right).

## ■ TRACEABILITY REQUIREMENT

A second issue remained, however, even once an inspection tool had been developed: traceability. The point was not only procedural, but technical. Even though the experimental campaign was extensive, it could not be assumed to cover every possible damage scenario that may occur in practice, nor to exclude the possibility that additional effects might emerge after a number of use cycles greater than those investigated. For this reason, inspection alone could not be considered sufficient. A traceability method was still needed to keep reuse within a bounded and known range, limiting the uncertainty associated with cumulative effects, unobserved damage histories, or mechanisms not fully captured within the tested envelope.



Figure 34. Rendering showing the on-site separation of new, used, and discarded VGS PLATE screws after inspection with JIG REUSE.

The practical conclusion was therefore that a traceability method was still necessary. Even if a limited number of reuses could be justified mechanically, a way was needed to keep that number bounded on site without introducing so much time, effort, or procedural burden that operators would simply revert either to uncontrolled reuse or to blanket single use.

## FROM PROTOCOL TO VGS PLATE

If JIG REUSE addressed the need for an objective field check, it still did not resolve the second requirement that had emerged from the work: bounded and practical traceability. Inspection could identify screws that should be discarded, but it could not by itself control how many acceptable use cycles a screw had already undergone, nor reduce the residual uncertainty associated with cumulative effects beyond the tested envelope.



Figure 35. VGS PLATE and RAPTOR MINI in real application conditions.

## A SCREW CONCEIVED FROM A LIFTING PERSPECTIVE

The move toward VGS PLATE was therefore not an isolated product exercise, but the continuation of the same technical logic. Once the campaigns had identified the governing mechanisms, and once the field procedure had made clear the need for objective inspection and bounded reuse, the next step was to develop a screw conceived from the outset for lifting and controlled reusability. In that sense, VGS PLATE is not simply a structural screw adapted to lifting, but the product-development response to the requirements that emerged from the project.

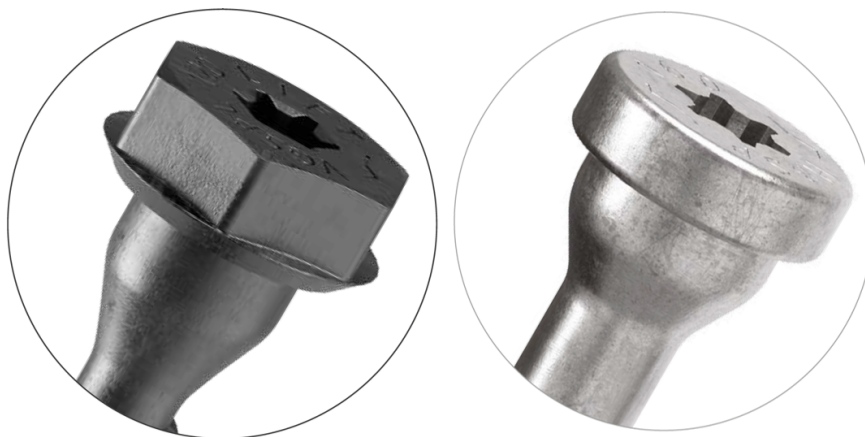


Figure 36. VGS PLATE and HBS PLATE head design.

This development also created an opportunity to reconsider the screw from a lifting perspective rather than only from a structural one. The resulting concept combines a full-thread geometry, to enhance withdrawal-related performance, with a reinforced plate-type head and underhead zone, drawing on the experience developed with HBS PLATE. It also incorporates a hexagonal head, alongside the internal drive, so that repeated installation and removal remain possible even if the drive recess progressively wears.

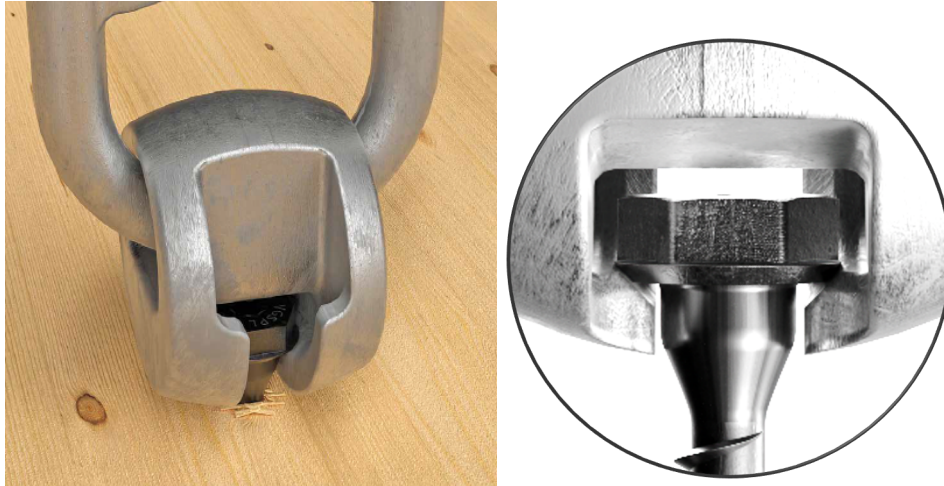


Figure 37. Renderings of VGS PLATE in application with the WASP lifting hook (left). Front view showing how the conical washer beneath the hexagonal head allows the screw to seat perfectly in the countersunk slot of the hook (right).

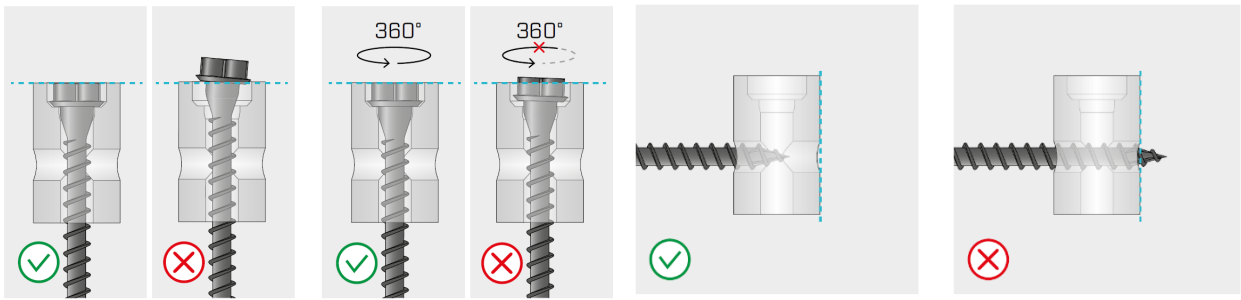
In addition, the conic washer below the hex-head makes the screw compatible both with plate-based lifting systems and with hook-based solutions that normally require countersunk-head compatibility, extending its field of use across Rothoblaas lifting devices.



Figure 38. Rothoblaas mechanically fastened lifting systems.

## ■ JIG REUSE AND VGS PLATE

The product is explicitly presented as reusable for transport under specific conditions and is paired with JIG REUSE as the inspection template for field verification. The connection between the two developments is direct: the geometry of JIG REUSE was developed specifically around the geometry of VGS PLATE, so that the inspection procedure and the screw concept form parts of the same controlled-reuse system.



The screw head must be fully seated within the jig.

When inserted in the jig, the screw must rotate freely while the head remains fully seated.

The tip of the screw must not protrude from the jig.

Figure 39. Straightness and thread wear check showing the fit between JIG REUSE and VGS PLATE geometry. From VGS PLATE+JIG REUSE INSTRUCTIONS AND CRITERIA.

## COATING: PROTECTION, IDENTIFICATION, AND USE INDICATOR

This last point is particularly relevant because it addressed the traceability challenge more directly. The need for immediate distinguishability on site suggested a further development question: could the coating itself serve not only as protection, but also as a visible indicator of accumulated use? That question led to a dedicated development phase in which different coating systems were compared through repeated insertion and withdrawal tests on different screw lengths and timber substrates in order to quantify their wear-off behaviour. The final concept adopted for VGS PLATE combines a chrome-passivated electroplated zinc base layer, a black e-coating topcoat, and an additional wax layer. Beyond corrosion protection, reduced insertion friction, and easy identification as a lifting screw, this solution provided the most balanced result between wearing off too quickly and remaining too unchanged after a number of cycles greater than those investigated.



Figure 40. Screws after 1, 3, 5, and 10 insertion-withdrawal cycles, showing the progressive wear-off of the Ecoat + Wax coating.

The wear-off factor depends on both screw length and timber conditions. The longer the screw, the faster the coating wears relative to its full length; likewise, the denser or more layered the timber, the faster the visible wear. In the more demanding cases, this leads to roughly 3–5 cycles, while in less aggressive conditions it may extend toward roughly 20–25 cycles.

In this way, without requiring each use to be manually counted and logged, the screw itself can carry part of the traceability information, since the coating becomes the visible threshold indicating whether the screw has already been used beyond the acceptable range. When linked to predefined acceptance criteria, coating consumption therefore becomes an objective visual threshold to control the maximum reuse count.

The same coating logic was also checked from the durability side through salt-spray testing according to ISO 9227. The final selection of three coating systems were compared after repeated insertions in CLT panels, and the e-coating + wax solution showed the best overall balance, maintaining better integrity after repeated insertion and providing the most robust corrosion resistance among the alternatives tested.

In this sense, the coating system is not only a durability feature, but part of the broader reuse concept. It contributes simultaneously to corrosion protection, to visual identification of approved lifting screws on site, and to a bounded reuse logic in which the screw itself provides part of the information needed for field control.

The enhancement of the corrosion protection is relevant also for the broader structural use of the product. VGS PLATE is not only conceived for controlled reuse in transport and lifting but also belongs to the family of Rothoblaas structural timber screws.



Figure 41. VGS PLATE in a structural application.

In the product documentation, it is presented for permanent metal-to-timber structural connections and associated with ETA-11/0030 in Europe, ESR-4645 in the United States, and ELC-4645 in Canada. More broadly, Rothoblaas structural timber screws are described as complying with EAD 130118-01-0603 in Europe, while in North America AC233 provides the US acceptance framework and CSA O86 the Canadian design framework.



Figure 42. Certifications, assessments and approvals for Rothoblaas VGS PLATE Structural timber screws.

In this sense, VGS PLATE is not simply another screw developed for structural use and then adapted to lifting. It is the product-development outcome of the whole line of reasoning: the robustness expected from structural fastening, combined with the specific needs of lifting and controlled reuse.

## FULL REUSE-CONTROL PROCEDURE

With this step, the reuse protocol is completed. Besides visual screening, straightness control, and thread-wear verification, the procedure also includes control of the maximum admissible number of uses.

1. **Visual screening**
2. **Straightness check**
3. **Thread-wear check**
4. **Maximum-use check**

The coating transition zone (wear area) on the VGS PLATE must be identified. The screw must then be inserted into the main hole of JIG REUSE with the head fully seated. The wear area must remain completely outside the body of JIG REUSE. If the wear area enters the body of the jig, the screw is rejected.

NUMBER OF USES [screws with  $L > 80$  mm]



NUMBER OF USES [screws with  $L \leq 80$  mm]



Figure 43. Real examples of visual inspections of used screws with gauge JIG REUSE. Number of uses check passed (left). Number of uses check NOT passed, screw to be discarded (right).

This adds a fourth acceptance criterion to the protocol, allowing the procedure to control not only the damage state, but also bounded cumulative use.

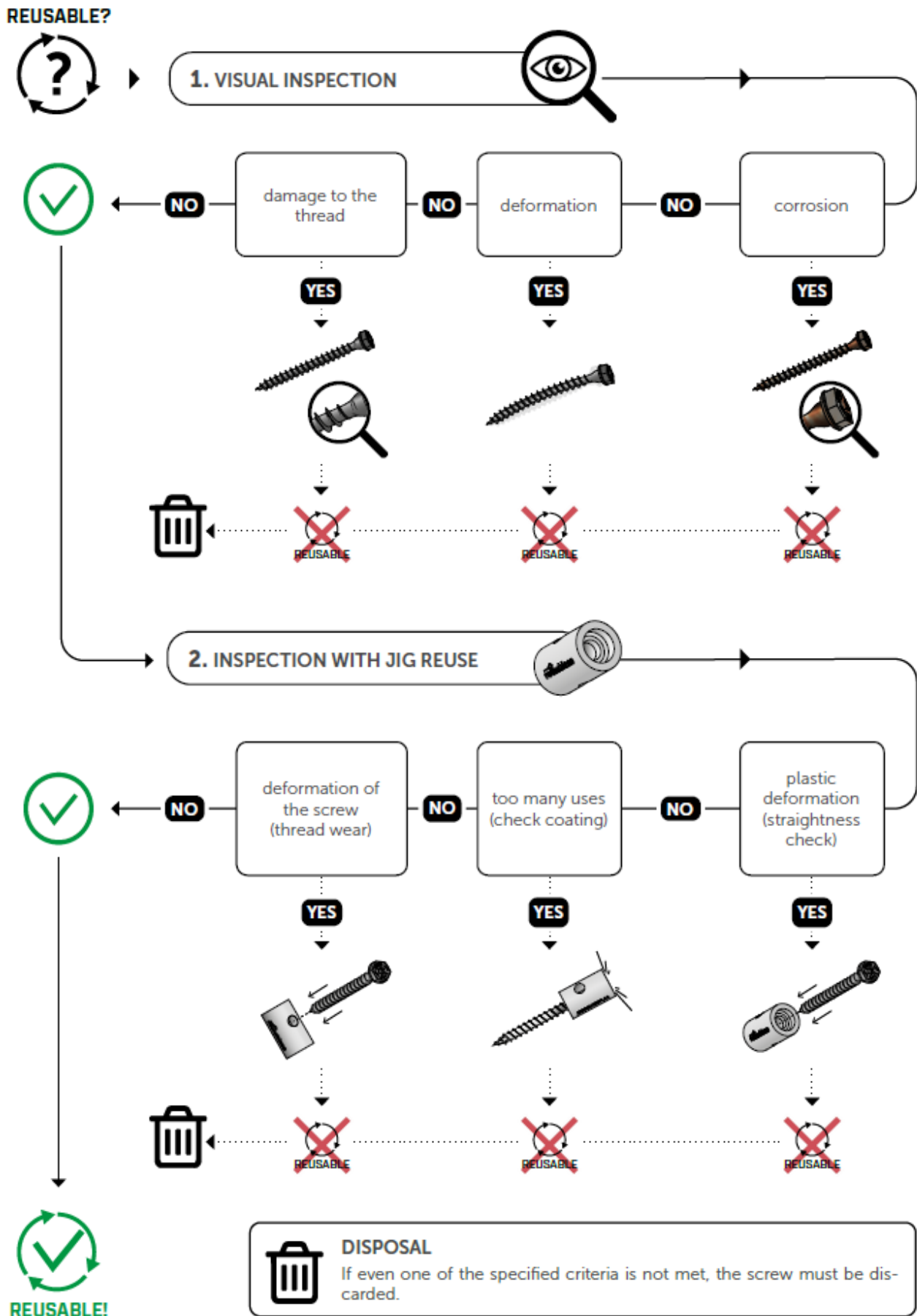


Figure 44. Final full reuse-control procedure, as defined in the VGS PLATE + JIG REUSE instructions and criteria for reuse in lifting systems. Rothblaas.

# MILAN – BUILDING-SCALE ENVIRONMENTAL AND ECONOMIC ASSESSMENT

The work at Politecnico di Milano (Italy) addresses a question that belongs in the opening motivation of the document, not only at the end: if a lifting screw can be reused in a controlled way, is the gain relevant not only from the standpoint of waste, but also from the standpoints of carbon footprint and cost?

## LCA FRAMEWORK AND BENCHMARK ASSUMPTIONS

The analysis starts from the asymmetry already mentioned: RAPTOR and WASP are reusable lifting devices, while the screws used with them are still treated as single-use items. The lifting devices themselves are reusable, while the screws are currently intended for a single use, so the development of the LCA comes precisely to assess the environmental advantage of reducing the quantity of screws consumed during the construction phase.

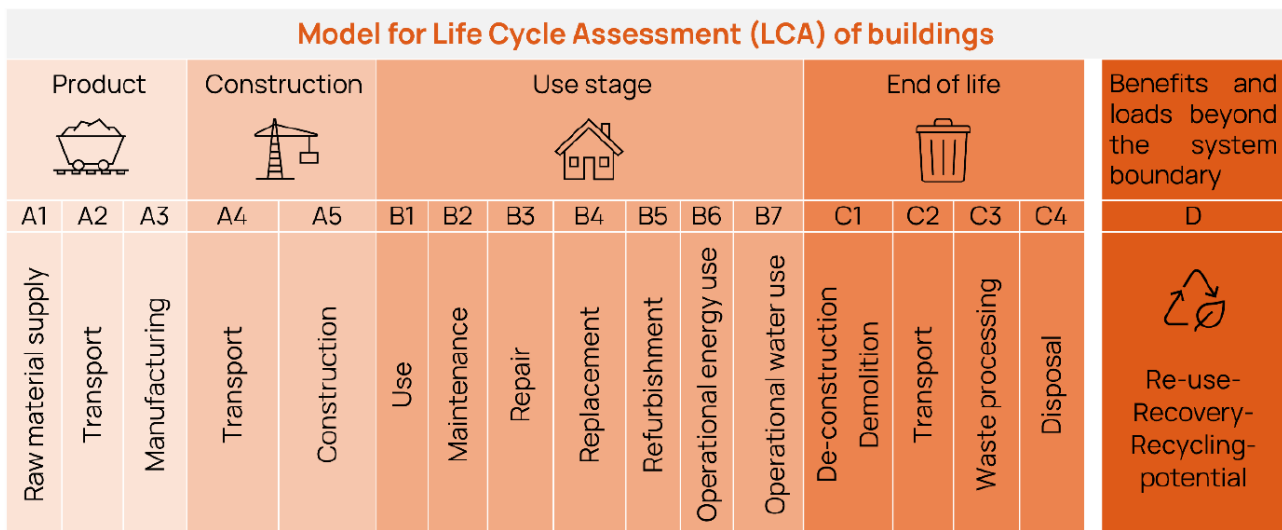


Figure 45. Life Cycle Assessment stages according to ISO 15804.

The benchmark was built from an available EPD for a comparable steel screw and translated into the lifting-screw context. The analysis adopted ISO 15804 logic and focused on GWP. The most impactful stages were identified as the upstream production stages A1–A3, while stage D provides a reduction through recycling credits. Three main end-of-life scenarios, plus three mixed scenarios intended to better reflect real practice, were defined:

Table 3. End-of-life scenarios, main and combined.

Scenario	End-of-life composition
A	100% recycling
B	100% landfilling
C	100% reuse
D	33% reuse / 33% landfilling / 33% recycling
E	50% reuse / 50% landfilling
F	20% reuse / 40% landfilling / 40% recycling

Using HBS PLATE 10x120 mm (0.40 x 4 ¾") as a representative screw, and weight 45 g, the cradle-to-cradle GWP values reported by the study are:

Table 4. GWP impact of 1 screw (HBSP10120) per established scenario.

Scenario	End-of-life composition	GWP <sub>TOT</sub> (kg CO <sub>2</sub> eq.) for 1 screw
A	100% recycling	0.118
B	100% landfilling	0.312
C	100% reuse	0.118
D	33% reuse / 33% landfilling / 33% recycling	0.184
E	50% reuse / 50% landfilling	0.215
F	20% reuse / 40% landfilling / 40% recycling	0.196

An important conceptual distinction is made. In the first reuse scenarios, "reuse" initially means one single lifting use followed by permanent structural use of the screw in the building. But the wider objective is different: reuse should mean repeated lifting use of the same screw before final disposal or incorporation. To model that, the study applies the following equation:

$$GWP_n = GWP_{TOT} + (n - 1) \times GWP_{C1}$$

where n is the number of reuses, and evaluates 1, 5, 25, and 50 uses because, at the time of the study, it was not yet possible to establish definitively how many cycles would lead to resistance loss. The stated purpose was to reach an asymptotic behavior and identify a maximum number of cycles capable of optimizing both structural and environmental outcomes.

Table 5. Screws LCA scenarios with different numbers of uses.

Scenario and # use for each screw	GWP total (kg CO <sub>2</sub> eq.) for 1 screw
Scenario C, 1 use	0.118
Scenario C, 5 uses	0.124
Scenario C, 25 uses	0.162
Scenario C, 50 uses	0.210

The total impact of a single screw reused 50 times is greater than in case of single use; however, when considering all the screws which should be used in a real situation (e.g., in lifting timber panels during building construction phase), a global lower environmental impact is immediately noticeable if screws are re-used.

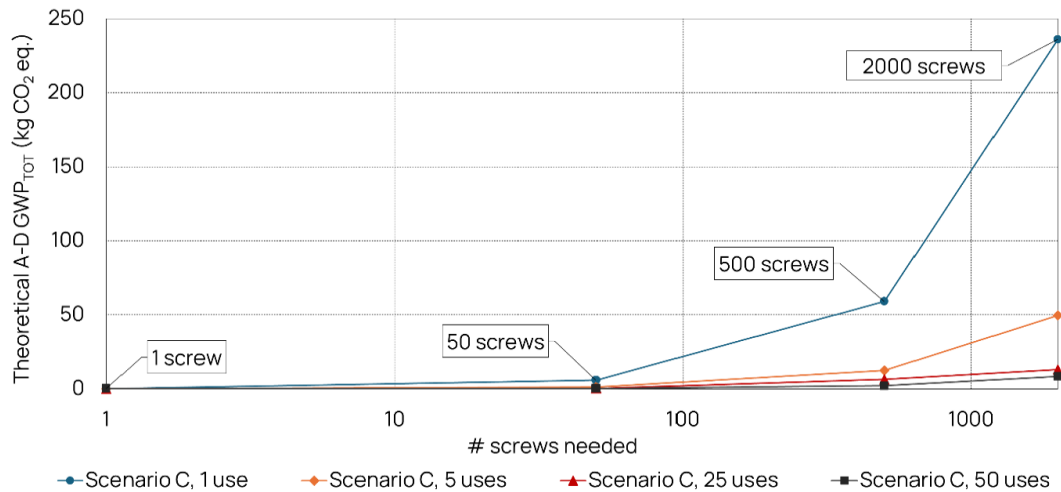


Figure 46. GWP<sub>TOT</sub> for different # of uses (1, 5, 25, 50 uses) and different # of screws (50, 500, 2000 screws).

## THE 4-STOREY BUILDING CASE STUDY

The study does not stop at the impact of one screw as an isolated product, but moves to a real construction case: a 4-storey timber building with a gross floor area of 360 m<sup>2</sup>, focusing on slab lifting, since slabs are the heaviest elements and represent the largest timber volume in the building.

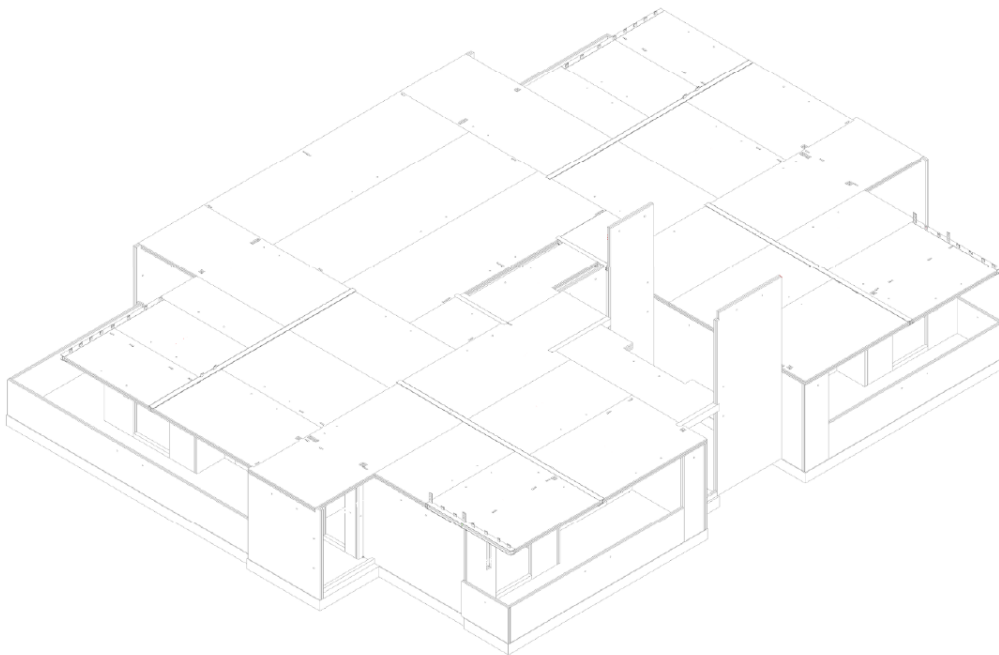


Figure 47. Ground storey slabs of the case study building.

In the case study, each of the first three storeys is composed of 33 CLT slab panels, while the fourth storey includes 22 panels. For each panel, the number of screws per RAPTOR was calculated using HBSP10120 screws. The 4-screw configuration applies to 30 panels, while the remaining 3, the heaviest ones, require 6 screws per RAPTOR. Under the benchmark assumption of single use, the total number of screws required for lifting all slab panels of the building is 2112.

At this scale, the difference between end-of-life scenarios becomes immediately legible. Scenario B, that is 100% landfilling, is the most penalizing one, reaching 659.05 kg CO<sub>2</sub> eq. for the slab-

lifting procedure of the benchmark building. More broadly, the study shows that the main dividing line is not between the various mixed scenarios, but between “no reuse” and “reuse”. Once reuse is introduced, even under mixed end-of-life assumptions, the impact drops sharply compared with the one-use case.

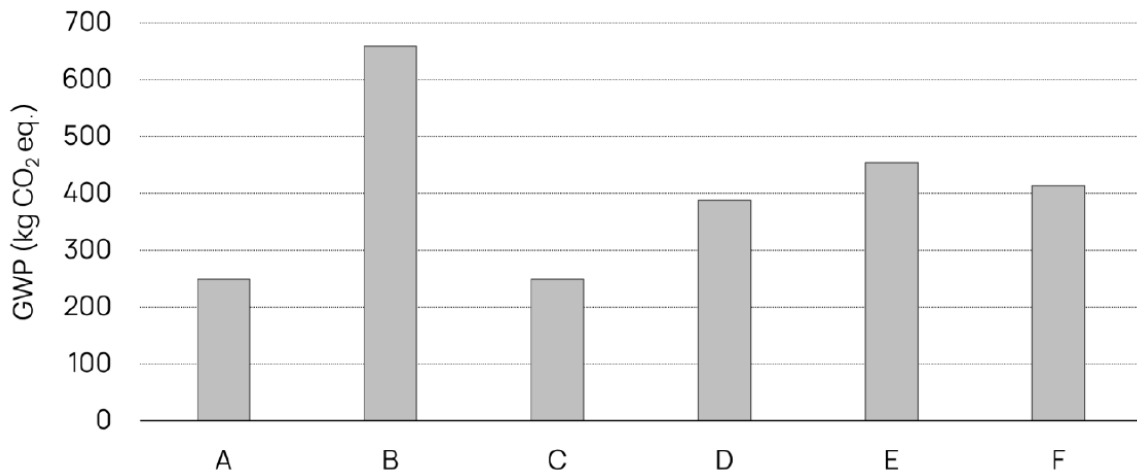


Figure 48. GWP impacts of screws for lifting procedure of CLT slab panels with each screw used once.

This is where it becomes clear that the dominant variable is the number of uses assigned to each screw. The results cluster into two groups: the first is the single-use condition, while the second includes all the multi-use conditions. Within that second group, the largest reduction is already achieved in the first reuses, while the environmental benefit then tends progressively toward an asymptote. In the Milan analysis, that asymptotic behaviour becomes evident from about 25 uses onward, meaning that pushing the reuse count far beyond that point yields only limited additional environmental benefit.

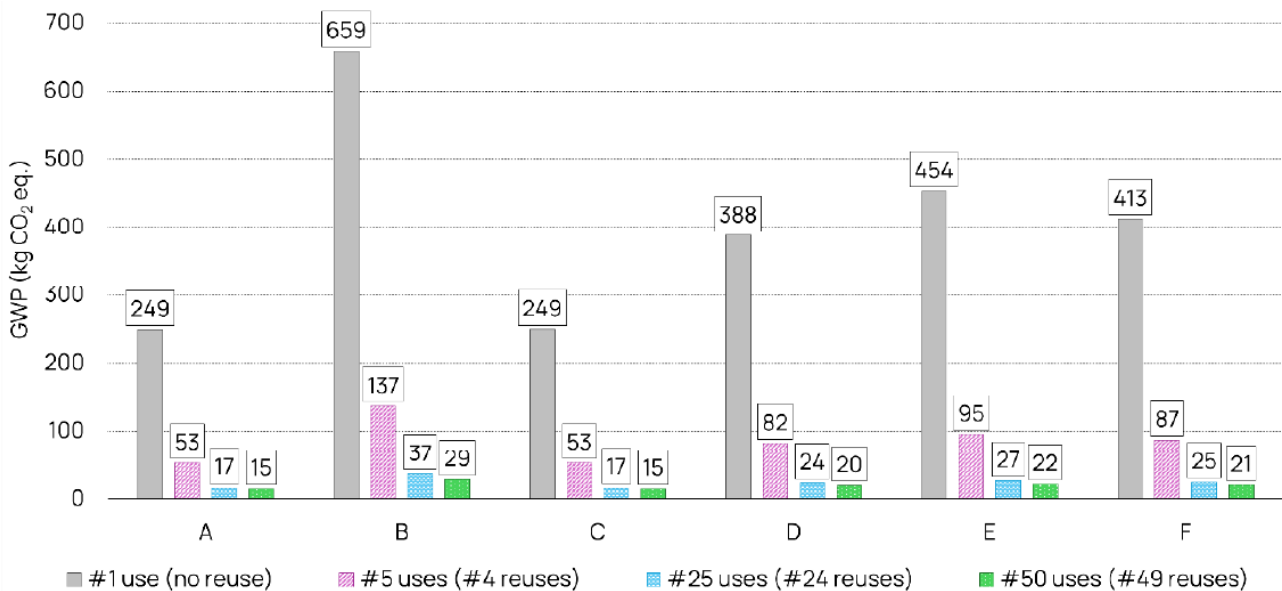


Figure 49. GWP impacts calculated for assessed scenarios and different numbers of screws uses for all slabs of the 4-storeys building.

This is important because it aligns well with the mechanical logic of the project. The goal is not to maximize reuse abstractly, but to identify a bounded range in which reuse remains both technically credible and environmentally meaningful. From the Milan perspective, the key point is precisely that very large environmental gains are obtained well before extreme reuse counts would become necessary.

For the 4-storey benchmark under scenario C, the study also derives an empirical relationship showing that GWP decreases rapidly with the first reuse cycles and then tends toward asymptotic behaviour. This is important because it confirms that the largest environmental gains are obtained at relatively low numbers of reuse, while the marginal benefit decreases as the number of cycles increases. The same logic is then generalized as

$$GWP_{n,scenario\ x} = \frac{GWP_0}{n^{0.85}}$$

where  $GWP_0$  becomes the scenario-specific one-use benchmark.

This analytical step is more than a mathematical fitting. It turns the study into a practical decision tool, because it allows the impact of lifting screws to be estimated quickly for other real buildings once the one-use benchmark is known. In other words, the Milan work does not only say that reuse is better in principle; it provides a scalable way to quantify how much better it becomes as the number of uses increases.

## ■ STOREY-BASED SENSITIVITY AND BUILDING-SCALE INTERPRETATION

Finally, the reasoning can be extended beyond the 4-storey benchmark to buildings with the same floor area but 8 and 16 storeys. The result is consistent with the general logic of the project: if no reuse is foreseen, the GWP of lifting screws increases with the number of storeys, whereas for high reuse counts the curves become much closer to each other. This means that the environmental relevance of controlled reuse becomes even more pronounced as the scale of the building and the number of lifting operations increase.

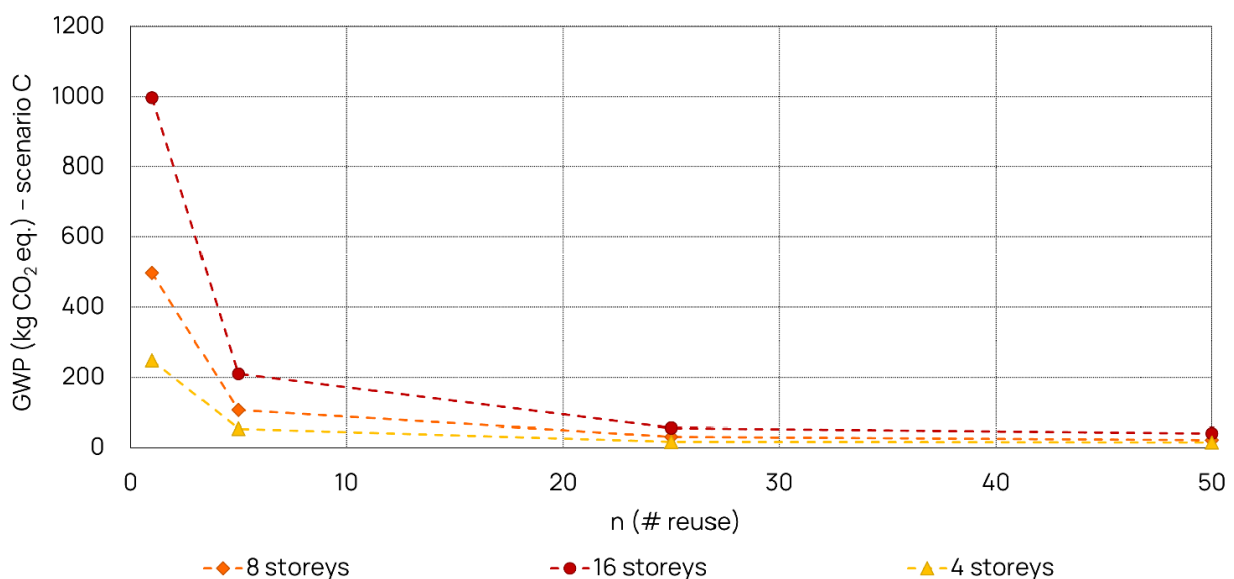


Figure 50. GWP impact of screws for lifting CLT slab panels in buildings with different number of storeys: 4 (benchmark case study), 8, and 16.

From the project standpoint, this is the real contribution of the Milan phase. It shows that the question of reuse is not only whether waste can be reduced, but whether a repetitive site function can be decoupled from the linear logic of one screw per lifting cycle. Once that possibility is opened, the consequences are simultaneously environmental and economic: fewer screws purchased, fewer screws discarded, lower material consumption, and therefore lower embodied carbon for the same lifting work. The economic side is thus not treated through an isolated market-price calculation, but through the more structural relationship between reuse, reduced material demand, and reduced waste generation.

## CONCLUSION

The work starts from a reality that the market already knows, even if it rarely addresses it openly. Screws are being reused in lifting operations, while manufacturers generally prescribe single use. In that gap, the risk is often being assumed only by the operator, without manufacturer-backed screening rules, without traceability, and often in tension with insurance logic.

The response developed here was not to normalize that gray zone, nor to ignore the concern behind it. The concern is real. If anything, the results confirm why it is real: improper installation and damage can markedly reduce resistance, especially in short screws affected by over-torque and in configurations where thread damage suppresses withdrawal-related strength. At the same time, the work also shows that reuse alone is not the dominant driver of performance loss. Under correct installation and operation in the elastic range, a limited number of reuses does not, by itself, compromise the strength of the lifting system.

This is the central technical distinction established by the campaigns. The question is not simply whether a screw has already been used. The decisive question is what happened to it during that use. South Tyrol answered that at screw level. Maine answered it at system level. Bologna identified the damage states that actually govern performance loss. Milan showed why solving this technical problem is worthwhile also from the standpoint of carbon footprint, cost, and material efficiency.

From there, the work could not stop at test results. If the intention was to move from informal reuse to controlled reuse, then the evidence had to be translated into a conservative field procedure. That is why JIG REUSE, thread-wear checking, bounded reuse, and traceability are not secondary aspects of the document. They are the practical condition that allows the mechanical results to become usable outside the laboratory.

The same is true for VGS PLATE. It is not a generic new screw, nor simply a structural screw adapted for lifting. It is the product-development outcome of the whole line of reasoning: a screw conceived from a lifting perspective, combining robust structural design, compatibility with lifting interfaces, ease of removal and reinstallation, and a coating system that also acts as a visible traceability marker.

Seen in this way, the broader significance of the work becomes clear. It is not merely a study on reuse. It is an attempt to transform a practice already occurring in the field from something informal, one-sided, and difficult to insure into something bounded, objective, and technically defensible. That has value from the standpoint of safety, because it shifts the discussion from assumption to evidence. It has value from the standpoint of responsibility, because it reduces the extent to which the operator is left alone carrying the decision. And it has value from the standpoint of circularity, because it opens a realistic path for reducing waste and the per-use environmental burden of lifting operations.

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