



Research paper

Evaluating the fitness for reuse of earth blocks reclaimed from load-bearing masonry: The case for compressive strength

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ABSTRACT

Retrieving masonry units for reuse is a promising circular strategy to reduce environmental impacts, yet their technical suitability for reuse remains insufficiently understood. Earth blocks are relatively easy to reclaim, and this study is the first to assess whether they retain adequate performance after reclamation from load-bearing structures. Fitness for reuse was evaluated by comparing the compressive strength of blocks before and after sustained loading. The effect of sustained loading was isolated in the laboratory through a controlled testing sequence that comprised sustained loading of masonry columns, deconstruction and cleaning of blocks, and testing of both new and reclaimed blocks. Columns were built using commercially available nonstabilised moulded earth blocks (MEBs) and cement-stabilised compressed earth blocks (CEBs), combined with thick-bed earth mortar (EM) and thin-layer earth-adhesive mortar (EAM). Blocks were reclaimed using a hammer drill and cleaned with a joint knife. Large sample sizes of both new and reclaimed blocks were tested, and inferential statistics, including independent *t*-tests and General Linear Models (GLMs), were applied to detect changes in compressive strength. Results show that sustained loading affects compressive strength differently across block-mortar combinations. MEBs consistently exhibited increases of 6% and 11%, depending on mortar type, whereas CEBs showed either a reduction of 6% or no change, depending on block orientation. The findings demonstrate the fitness for reuse in both block types based on compressive strength, but highlight the need to assess whether CEB strength reductions stabilise or worsen under prolonged loading and to investigate the underlying mechanisms driving these changes.

1. Introduction

This study is situated at the intersection of earth construction and circular construction, focusing on the reuse potential of earth blocks. By placing earth block masonry in its historical context and outlining its environmental and circular advantages, we clarify why reclaimed blocks warrant investigation and how this study addresses key gaps in evaluating their fitness for reuse.

1.1. Environmental benefits of using earth blocks

For millennia, hand-moulded unfired earth blocks, commonly known as adobes, have been employed in load-bearing masonry structures. While their primary application has been in lightly loaded single- and two-storey residential buildings, adobes have also historically been

utilised in multi-storey structures such as the tower houses in Shibam, Yemen [1]. The Industrial Revolution introduced mass production of fired bricks and concrete blocks, whose superior technical performance rendered earth materials largely obsolete in construction, particularly in highly industrialised nations [2,3]. In recent decades, renewed interest in earth as a building material has grown as a response to the environmental burdens of the construction sector [4,5]. Since the 1950s, compressed earth blocks have gained traction in South America as a more performant and faster-to-produce alternative, and their adoption has gradually expanded to other continents, including Europe [6–8]. Simultaneously, adobes, recognised today as moulded or extruded earth blocks, have experienced a revival and are progressively improved by industrial manufacturing [7,9].

The environmental impact of conventional masonry units, such as fired bricks and concrete blocks, is considerably higher than that of non-stabilised earth blocks, largely due to their higher embodied energy,

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Nomenclature	
n	Sample size
f_c	Compressive strength
f_b	Normalised compressive strength
t	t -statistic from t -distribution
p	p -value (probability)
d	Effect size (Cohen's d)
S^2	Variance
R^2	Coefficient of determination
\bar{X}	Arithmetic Mean
\bar{X}_{adj}	Adjusted Mean (Least Squares Method)
β	Regression coefficient
Abbreviations	
CDW	Construction and Demolition Waste
MEB	Moulded Earth Block (non-stabilised)
CEB	Compressed Earth Block (cement-stabilised)
EM	Earth Mortar (thick-bed, non-stabilised)
EAM	Earth Adhesive Mortar (thin-layer, cellulose-bound)
CEBH	CEB tested in the horizontal plane (pressing bed faces)
CEBV	CEB tested in the vertical plane (pressing stretcher faces)
MEB-EM	Masonry column of MEBs laid horizontally with EM
MEB-EAM	Masonry column of MEBs laid horizontally with EAM
CEBH-EM	Masonry column of CEBs laid horizontally with EM
CEBV-EM	Masonry column of CEBs laid vertically with EM
CEBH-EAM	Masonry column of CEBs laid horizontally with EAM
R-MEB-EM	Reclaimed MEBs from MEB-EM columns
R-MEB-EAM	Reclaimed MEBs from MEB-EAM columns
R-CEBH-EM	Reclaimed CEBs from CEBH-EM columns
R-CEBV-EM	Reclaimed CEBs from CEBV-EM columns
R-CEBH-EAM	Reclaimed CEBs from CEBH-EAM columns
GLM	General Linear Model
SD	Standard Deviation
SE	Standard Error
CI	Confidence Interval
AIC	Akaike Information Criterion

global warming potential, and depletion of abiotic resources [10–12]. In contrast, earth blocks offer a lower-impact alternative, particularly because they can be produced without energy-intensive firing processes and can use locally available soils, including those excavated from construction sites, underground passageways, or even landslide areas, rather than quarried materials [13–17]. At the same time, the construction sector is the largest generator of waste in Europe, creating a strong incentive to develop waste-based building materials [18,19]. Unlike most masonry units, earth blocks are particularly well-suited to incorporate construction and demolition waste (CDW), such as crushed brick or concrete, as recycled content. This practice has demonstrated clear technical, economic, and environmental benefits in recent studies [20–23].

1.2. Environmental benefits of reusing earth blocks

Nevertheless, the environmental footprint of earth block masonry is not insignificant. Its primary contributors are the transportation of raw materials and the use of stabilisers such as lime or cement, particularly in compressed earth blocks, which are added to enhance strength, durability, and water resistance [12–25]. In some cases, especially where building heights or wall spans are increased, the embodied energy of stabilised earth block masonry can even surpass that of conventional concrete block masonry [26]. Additionally, conventional cementitious stabilisers hinder the recyclability of earth blocks [27]. Although bio-stabilisation methods offer promising alternatives [28–33], they still face considerable technical and practical barriers to broader adoption in mainstream construction [34]. As a complementary or alternative circular end-of-life strategy, reuse can help further reduce environmental impact by extending the service life of earth blocks. Doing so ensures that the embodied energy invested in their production remains in use for as long as possible, thereby improving their overall environmental performance [35,36].

Reusing masonry units can substantially reduce the environmental impact of buildings, primarily by avoiding the production of new units [37–39]. A key prerequisite for reuse is the successful reclamation of these units, which is strongly influenced by the type of mortar used and the bond characteristics between the unit and the mortar [40]. Previous studies by the authors have demonstrated promising reclamation rates across various earth block-mortar combinations [41,42]. However, the ability to recover units without visible damage does not guarantee that critical mechanical properties, such as compressive strength and durability, remain intact. To ensure the safe and effective reuse of salvaged

units in new construction projects, it is essential to re-evaluate their performance after reclamation [43,44].

1.3. Evaluating fitness for reuse

Evaluating the fitness for reuse of masonry units involves verifying whether their technical performance is sufficient for reimplementation in construction [43]. Reclaimed masonry units must therefore meet quality requirements comparable to those of new units, demonstrating adequate suitability for their intended function, whether this matches or differs from the original application. Cascade use is one established strategy to facilitate reuse, whereby components are applied in progressively less demanding roles, such as repurposing structural materials in non-structural functions [44,45]. To assess whether reuse in similar or less demanding applications is technically feasible, a range of properties must be evaluated to ensure that structural and functional requirements can be met. For bricks, these properties include density and dimensional stability, compressive strength, flexural and shear bond strength, porosity and water absorption, water vapour permeability, frost and fire resistance, and efflorescence, among others [40].

Although the reuse of reclaimed bricks constitutes a small but established market [40–45], the scientific literature on evaluating the fitness for reuse of masonry units remains limited. Existing studies have examined the performance of reclaimed fired clay bricks and limestone in both contemporary and historical masonry [46–51]. Within this modest body of work, two main research directions can be identified: studies that explicitly evaluate fitness for reuse [49–51], and studies that assess or predict material properties during service life for durability analysis [46–48].

Despite their contributions, most of these studies have three important limitations: First, they rely on *in situ* reclamation of bricks retrieved from buildings that have been in service for many years or decades, often under unknown or unquantifiable long-term structural and environmental conditions [46–50]. Second, they focus predominantly on evaluating non-destructive testing methods, such as the ultrasonic pulse velocity test or the Schmidt rebound hammer test for estimating compressive strength, which frequently show limited predictive accuracy for actual performance [46–48,50]. Third, they typically examine a wide variety of brick types, each represented by relatively small sample sizes, which increases the risk of overestimating performance differences that are not real or failing to detect subtle but meaningful changes [46,48–50].

None of these studies has attempted to simulate long-term use in

controlled laboratory conditions based on compressive strength tests on large sample sizes. Such an approach could enable manufacturers to demonstrate the reusability of newly developed masonry units and support designers in understanding early performance gains or losses during service life.

1.4. Key contributions of this study

This study is the first to evaluate the fitness for reuse of reclaimed earth blocks by examining their compressive strength after sustained loading of the masonry. Compressive strength is a critical indicator of technical feasibility for reuse in load-bearing masonry applications and remains central to quality control in non-load-bearing contexts, particularly given the higher variability of earth materials compared to conventional masonry units [52,53].

A second contribution is the replication of long-term stresses under controlled laboratory conditions, which enables a direct and reliable comparison between new and reclaimed earth blocks without relying on *in situ* retrieval. Since earth block masonry is predominantly used in interior applications, this study isolates sustained loading from weathering effects to ensure that performance changes can be attributed exclusively to mechanical stresses. This controlled approach also addresses two challenges in the field: the limited availability of existing buildings from which earth blocks can be reclaimed, and the mismatch between older, manually produced blocks and modern, industrially manufactured blocks.

A third contribution is the development of a replicable testing sequence that simulates real-world reclamation from load-bearing structures. Masonry columns were constructed and subjected to sustained loading using an established setup for long-term structural behaviour, including creep deformation [54,55]. Following unloading and careful deconstruction, the recovered blocks were cleaned and tested alongside new blocks. This sequence offers a transferable

framework that could be further developed into a standardised method that can be utilised to verify the reusability of newly developed products.

Finally, the study applies robust inferential statistical methods, including independent *t*-tests and General Linear Models (GLMs) [56, 57], to compare reclaimed and new blocks. Whereas previous studies have relied largely on descriptive statistics from small sample sizes, this approach enables more reliable detection of subtle strength changes and reduces the risk of misinterpreting apparent differences.

1.5. Aim and structure of the paper

This study advances circular construction by investigating the feasibility of reusing earth blocks manufactured primarily from secondary raw materials, thereby promoting resource efficiency at both the origin of the materials and their end-of-life (Fig. 1). The blocks and mortars used in the experiments were produced using revalorised loam and sand from construction excavations, incorporating recycled construction and demolition waste. By examining commercially available non-stabilised and stabilised earth blocks paired with two mortar types, the study offers insights that are directly applicable to current market products and reveals how different block-mortar combinations influence reuse potential. These findings provide an early basis for circular design recommendations in earth block masonry.

The remainder of this paper is structured as follows. Section 2 describes the experimental campaign, including the characterisation of the earth blocks, mortars, and masonry columns, as well as the testing sequence comprising sustained loading of columns, their deconstruction, retrieved block cleaning and compressive strength testing. Section 3 presents the comparison between new and reclaimed blocks, first through descriptive statistics and then through inferential analysis to assess the statistical significance of the observed strength changes. Section 4 synthesises the results of the compressive strength assessment

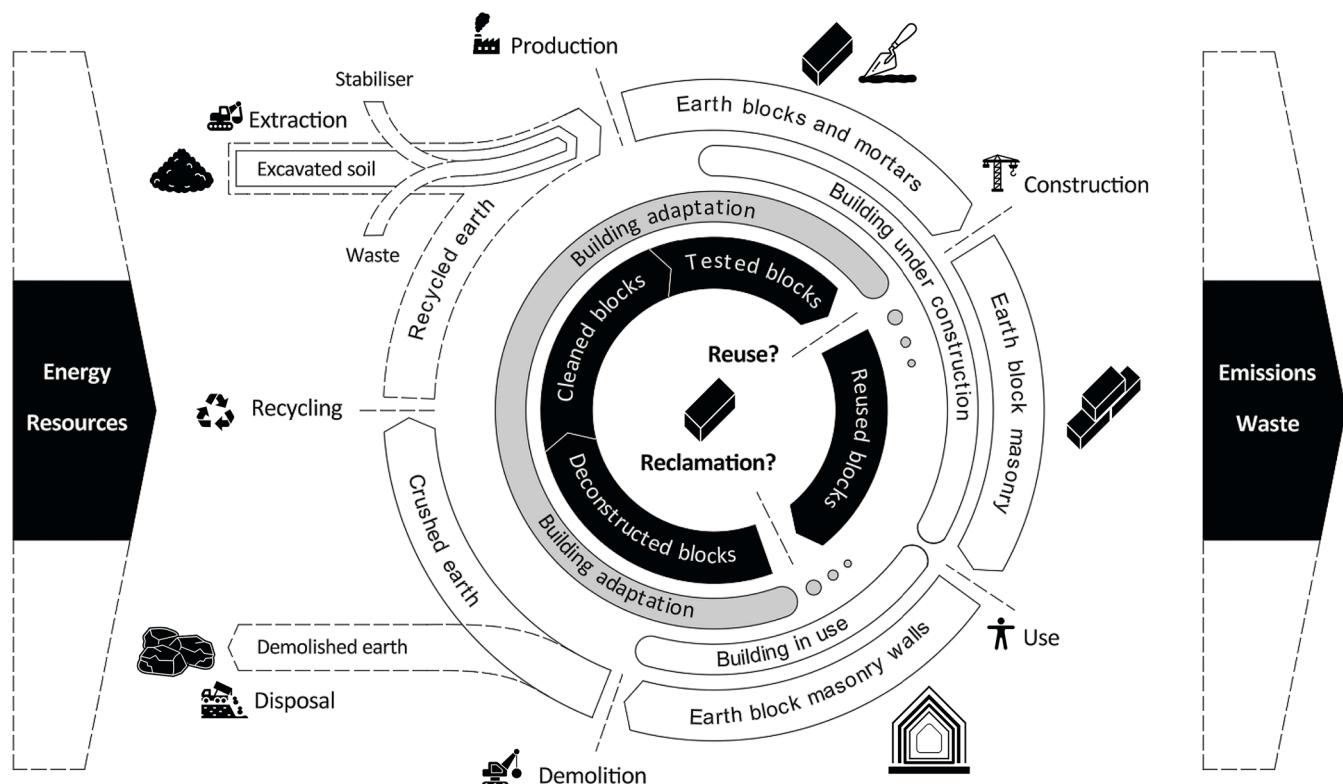


Fig. 1. Positioning the research rationale in the life cycle of earth blocks (adapted from [1]). Reuse extends the lifetime of earth blocks, thereby reducing the input of energy and resources, as well as the output of emissions and waste.

and discusses the implications for reuse and circular design, as well as the factors that may explain the observed changes, and provides directions for future research to study the underlying mechanisms. Finally, Section 5 summarises the key findings and their implications.

2. Experimental programme

Table 1 provides an overview of the experimental programme. The left column lists the materials investigated (new earth blocks, earth mortars, masonry columns, and reclaimed earth blocks) with their respective designations, while the subsequent columns outline the properties that were characterised. The corresponding standard followed is noted for each test, along with the sample sizes.

2.1. Materials

This study utilised two types of earth blocks and mortars (Fig. 2). Their properties are presented in Tables 2 and 3, respectively. Properties of earth block masonry columns are given in Table 4.

2.1.1. Earth blocks

This study used a non-stabilised moulded earth block (MEB) and a compressed earth block (CEB) stabilised with 5.67% cement (6% cement by mass added to the earth mix). Both blocks incorporate revalorised loess loam from Brussels excavation projects. MEBs contain additional Scheldt clay and fired brick waste, and CEBs contain additional Rhine sand and crushed concrete. Secondary, non-virgin resources, i.e. revalorised loam from excavation works and crushed brick waste, comprise 85% of MEBs, while the same loam and crushed concrete waste comprise 80% of CEBs. The MEBs, produced by a Belgian earth materials company using fired brick manufacturing equipment, are dried over three days in ventilated chambers at 30°C to 80°C, utilising residual factory heat. Similarly, CEBs are produced using vibro-compacting technology from a concrete block producer and cured for ten days in unventilated chambers at 23°C with a relative humidity of 50% to 78%. CEBs are compacted in the vertical orientation, i.e. with the block's bed faces facing sideways. After curing, both types of blocks were transported and stored indoors. The dimensions are (220 × 103 × 62) mm for MEBs and (290 × 130 × 90) mm for CEBs.

Table 1
Summary of the experimental programme.

Materials	Characterisation	Methods	Sample size
Earth blocks: Moulded Earth Block (MEB) Compressed Earth Block (CEB)	a) Bulk density b) Moisture content c) Compressive strength ^a : MEB CEBH CEBV	a) DIN 18,945 b) EN 772-10 c) EN 772-1	$n_{total} = 162$ $n = 72$ $n = 54$ $n = 36$
Earth mortars: Earth Mortar (EM) Earth-Adhesive Mortar (EAM)	d) Initial flow e) Compressive strength f) Flexural strength	d) EN 1015-3 e) EN 1015-11 f) EN 1015-11	$n = 3$ $n = 6$ $n = 3$
Masonry columns: MEB-EM MEB-EAM CEBH-EM CEBH-EAM CEBV-EM	g) Compressive strength (three block layers) h) Sustained loading (nine block layers ^b), followed by reclamation	g) EN 1052-1 h) 90-day compressive loading under constant stress (0.8 MPa)	$n = 3$ $n = 2$
Reclaimed earth blocks: R-MEB-EM R-MEB-EAM R-CEBH-EM R-CEBH-EAM R-CEBV-EM	i) Bulk density j) Compressive strength	i) DIN 18,945 j) EN 772-1	$n_{total} = 122$ $n = 14$ $n = 19$ $n = 32$ $n = 36$ $n = 21$

^a Tested in two orientations for CEBs: CEBH (horizontal = bed face down) and CEBV (vertical = stretcher face down).

^b Six block layers for CEBV-EM.

2.1.2. Mortars

Two commonly used mortars, an earth mortar (EM) and a thin-layer earth-adhesive mortar (EAM), were sourced from the same supplier as the earth blocks and were made with loess loam from urban excavations in Brussels. Secondary resources comprise 50% of the EM and 99% of the EAM. Each mortar also includes Brusselian sand from these excavations; additionally, the EM contains Rhine sand and Dordogne clay, while the EAM includes 1% methylcellulose. Particle sizes differ slightly, with 96% of EM particles under 2 mm and EAM comprising 99.5% of particles under 1 mm and 2 mm.

2.2. Test methods

Fig. 3 provides an overview of the main experimental setups employed in this study, which include: (i) compressive strength testing of both new and reclaimed earth blocks, (ii) characterisation of the compressive strength of small masonry columns, and (iii) sustained loading on larger masonry columns from which the earth blocks were reclaimed for testing their compressive strength afterwards.

2.2.1. Characterisation of earth blocks

2.2.1.1. Tests and testing conditions. The bulk density of the blocks was measured following DIN 18,945 [58]. The moisture content was determined using the NBN EN 772-10 standard [59]. The compressive strength was tested according to NBN EN 772-1 [60]. CEBs were tested no earlier than 450 days after production to ensure that early-age effects, such as cement hydration, did not confound the observed changes in compressive strength. For transparency, MEBs were tested 250 days after production, although they contain no binders capable of time-dependent chemical reactions. To ensure consistent testing conditions, new and reclaimed MEBs and CEBs were stored in the same stable environment for at least 90 days prior to testing. Testing of blocks of the same type was conducted within 7 days for MEBs and within 14 days for CEBs.

2.2.1.2. Compressive strength testing. The compressive strength was tested without the use of capping material, despite the relatively irregular surface texture of the MEBs. Exploratory tests on MEBs with a thin



Fig. 2. A non-stabilised moulded earth block (MEB) and a cement-stabilised compressed earth block (CEB) were combined with an earth mortar (EM) and a thin-layer earth adhesive mortar (EAM) (© photos by BC Materials).

Table 2

Properties of the studied earth blocks (for $n = 6$).

Name	Dimensions (mm)			Material composition		Bulk density			Moisture content			Compressive strength ^{b,c}		
	Length	Width	Height	Primary resources	Secondary resources ^a	Mean (g/cm ³)	SD (g/cm ³)	CoV (%)	Mean (%)	SD (%)	CoV (%)	Mean (MPa)	SD (MPa)	CoV (%)
MEB	238 ± 2	78 ± 2	57 ± 3	Scheldt clay	Loess loam Brick waste	1.82	0.03	1.4	2.70	0.09	12.7	3.28	0.16	5.0
CEB	290 ± 1	130 ± 1	90 ± 1	Rhine sand Cement CEM III 42.5 (5.67%)	Loess loam Crushed concrete	2.03	0.03	1.7	2.84	0.36	3.5	26.23	2.92	11.2

^a The MEBs and CEBs contain 85% and 80% secondary (non-virgin) resources, respectively.

^b Apparent compressive strength (ACS) for MEBs, measured at the slope change of the stress-strain diagram in a displacement-controlled setup.

^c Unconfined compressive strength (UCS) for CEBs, measured at the top of the stress-strain diagram in a force-controlled setup (bed face down).

Table 3

Properties of the studied fresh and hardened earth mortars ($n = 3$).

Name	Particle sizes (%)		Material composition		Water content (%)	Initial flow (mm)	Flexural strength			Compressive strength ($n = 6$)		
	Main	Oversize	Primary resources	Secondary resources ^a			Mean (MPa)	SD (MPa)	CoV (%)	Mean (MPa)	SD (MPa)	CoV (%)
EM	96 (< 2 mm)	3.5 (2–4 mm)	Rhine sand	Loess loam	15.3	150 ± 5	1.21	0.13	10.7	3.09	0.56	18.1
		0.5 (4–6 mm)	Dordogne clay	Brusselian sand								
EAM	99.5 (< 1 mm)	0.5 (1–2 mm)	Methylcellulose (1%)	Loess loam	24.2	140 ± 5	1.78	0.21	11.8	3.37	0.14	4.2
				Brusselian sand								

^a The EM and EAM contain 50% and 99% secondary (non-virgin) resources, respectively.

Table 4

Properties of earth block masonry columns (three block layers) in different configurations ($n = 3$).

Name	Laying orientation	Blocks per layer	Mortar layer thickness (mm)	Aspect ratio ^a	Compressive strength		
					Mean (MPa)	SD (MPa)	CoV (%)
MEB-EM	Horizontal	2	10 ± 2	0.94 (2.90)	2.55	0.16	6.2
MEB-EAM	Horizontal	2	1–3	0.86 (2.61)	2.63	0.18	6.9
CEBH-EM	Horizontal	2	10 ± 2	1.07 (3.30)	4.83	0.59	12.2
CEBH-EAM	Horizontal	2	2	1.05 (3.15)	11.79	2.33	19.8
CEBV-EM	Vertical	3	10 ± 2	1.41 (2.86)	5.41	0.74	13.6

^a The aspect ratios of columns subjected to sustained loading are given between parentheses.

wood fibre cap showed no meaningful differences in failure mode or compressive strength compared with uncapped specimens, so capping was not applied to maintain consistency between tests on new and reclaimed blocks. Moreover, the softer outer surface of MEBs was observed to crush and flatten during initial loading, effectively creating a uniform contact surface that functionally mimics the effect of capping.

CEBs were tested in a force-controlled setup using a Toni Technik compression testing machine with Zwick-Roell TestXpert III control software at a loading rate of 0.15 MPa/s, allowing determination of unconfined compressive strength (UCS). The same method was unsuitable for MEBs because the testing machine did not register a distinct force drop and continued loading past the point of failure, a behaviour



Fig. 3. Experimental setups with CEBs (top) and MEBs (bottom) to determine (a) the compressive strength of new and reclaimed earth blocks, (b) the compressive strength of earth block masonry columns, and (c) the sustained loading of the earth block masonry columns.

previously noted in the literature and attributable to strong platen restraint effects in specimens with a low aspect ratio [52,61]. Instead, the apparent compressive strength (ACS) of MEBs was determined. Unlike the UCS, which is characteristic of the material that is independent of the means and methods to test it, the ACS is the measured compressive strength of a material under specific conditions, which can be influenced by factors like specimen size and testing setup [52]. In this study, the ACS of MEBs is determined at their yield point, i.e., when the slope of the stress-strain curve changes, yielding an elastic compressive stress estimated from the initial, near-linear portion of the stress-strain curve, before irreversible plastic deformation dominates. To detect this

transition more reliably, MEBs were tested in a displacement-controlled setup at a displacement rate of 10 mm/min.

CEBs were tested in two orientations: horizontally (with bed faces between the plates) and vertically (with stretcher faces between the plates), reflecting the two possible applications in the masonry (stretcher and shiner bond). To verify the true effect of block orientation on compressive strength in CEBs, the normalised compressive strength of CEBs was determined by multiplying it by a shape factor, as per NBN EN 772-1 [60] using linear extrapolation of tabular values.

Stress-strain diagrams illustrating the different compressive strength measurements for MEBs and CEBs are shown in Fig. 4. Although the two

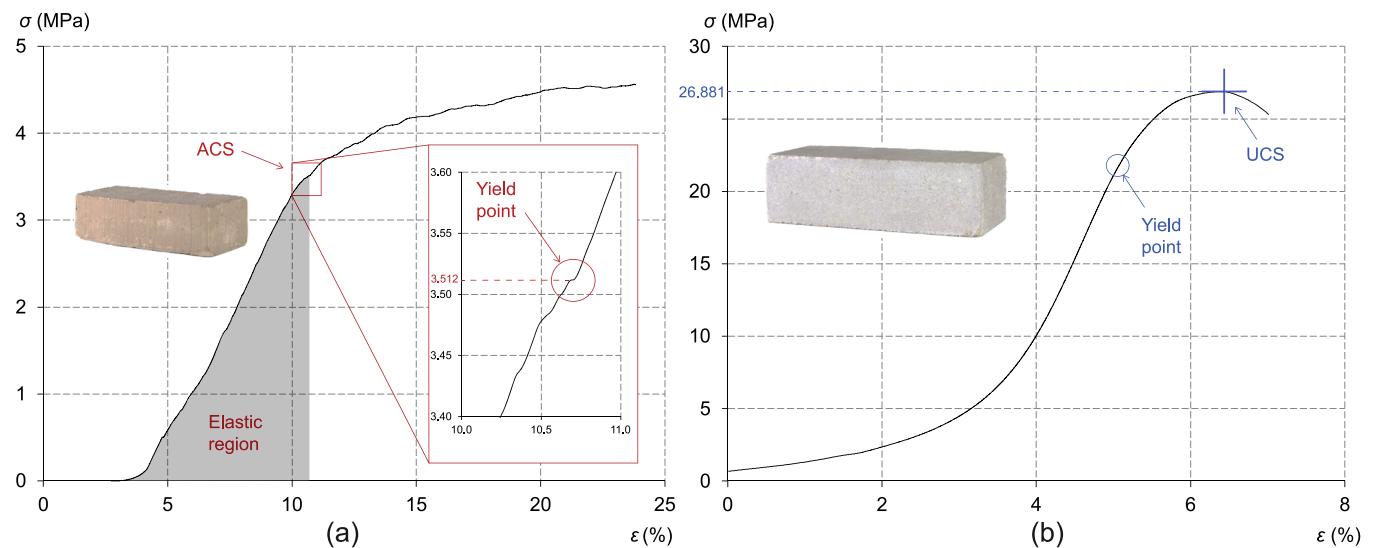


Fig. 4. Typical stress-strain curve observed for (a) MEBs, indicating its apparent compressive strength (ACS) at the yield point, and for (b) CEBs, indicating its unconfined compressive strength (UCS) at the ultimate strength point.

protocols yield different absolute strength characteristics for MEBs and CEBs, each comparison in this study concerns new and reclaimed blocks of the same type tested under identical conditions. Any protocol-related bias is therefore systematic within each material type and does not influence the observed differences between new and reclaimed blocks.

Finally, the sample size for reclaimed blocks depended on the number of successfully retrieved blocks, and the sample size of new blocks was at least as large, with the sample size expanded for increased confidence in cases where few blocks were retrieved.

2.2.2. Characterisation of mortars

The earth mortars were mixed following the NBN EN 1015-2 [62] standard using a planetary mixer. Once the fresh mortar was qualitatively assessed as workable, its consistency was assessed by an initial flow measurement, according to NBN EN 1015-3 [63], using the manual

table specified in NBN EN 459-2 [64]. Mortar prisms were cast and dried for 28 days at room temperature and relative humidity, following DIN 18,946 [65]. The EAM remained in the mould for three weeks, with a damp cloth on top to absorb excess moisture, while the EM prisms were covered with a paper sheet to prevent cracking due to uneven drying. They were unmoulded after one week. Compressive and flexural strengths of the hardened mortars were tested per NBN EN 1015-11 [66] on a DARTEC universal testing machine with Zwick-Roell TestXpert III control software and a 250 kN capacity. Flexural strength tests were conducted at a loading rate of 10 N/s, and compressive strength tests at 50 N/s.

2.2.3. Characterisation of earth block masonry columns

For every block-mortar combination, three cross-layered masonry columns, each three block layers high, were constructed and tested to

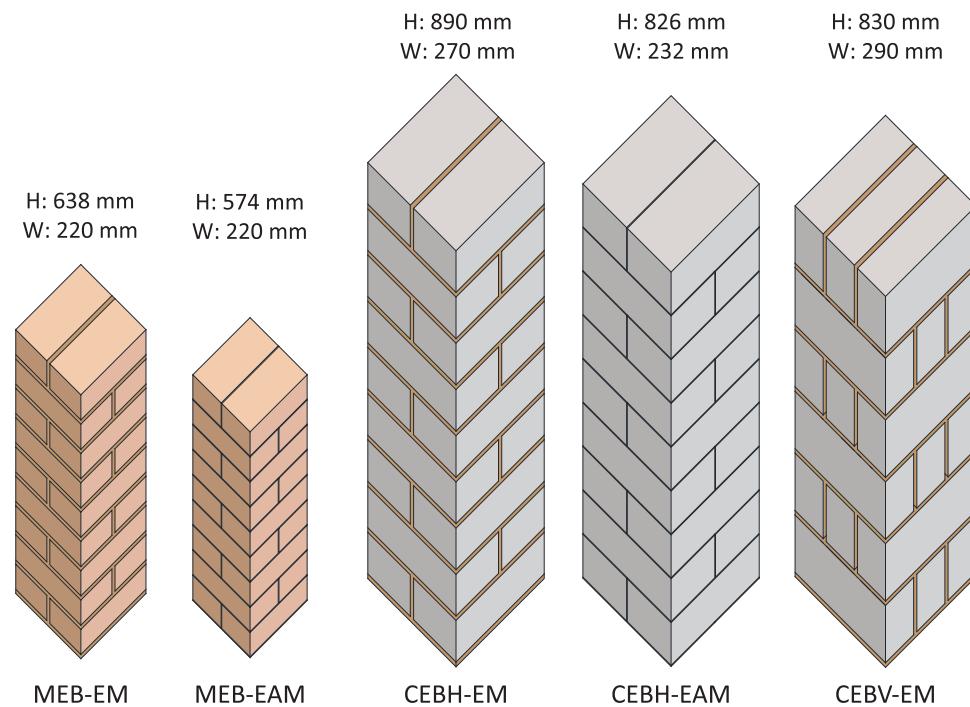


Fig. 5. Design and designation of earth block masonry columns subjected to sustained compressive loads.

determine their compressive strength. Since the CEBs are sometimes also laid in the vertical orientation in practice (bed face sideways), this configuration was additionally tested with the EM (CEBV-EM). The columns were constructed using a mortar layer of 10 ± 2 mm for the EM. The EAM was applied as a thin-layer mortar using an adhesive spreader, resulting in a thickness of 1–2 mm. CEBs were sawn using a stone-cutting table saw with a universal diamond blade to ensure the symmetry of the columns. Following the manufacturer's recommendation, the MEBs were pre-wetted before laying using a wet brush to improve bonding by removing residual sand from the block's unmoulding process. The bed faces of the CEBs were prewetted for one second in a water tray. After masonry, MEB columns dried at $T = 16 \pm 1^\circ\text{C}$ and $RH = 59 \pm 5\%$, and CEB-columns at $T = 15 \pm 1^\circ\text{C}$ and $RH = 43 \pm 5\%$ for 28 days. Afterwards, the three-layer columns were tested in compression following EN 772-1 [60]. MEB columns were tested at 0.05 MPa/s and CEB columns at 0.15 MPa/s in the Toni Technik compression test plant.

2.2.4. Sustained loading of masonry columns

2.2.4.1. Column design and test setup. Two masonry columns per block-mortar combination, each nine block layers high, were prepared similarly to the three-block-layer columns. To maintain the same number of blocks per column (18), vertically laid CEBs with EM (CEBV-EM) were built in columns with only six block layers, as each layer consists of three blocks instead of two (Fig. 5). The columns were covered by square steel plates and tightened with steel rods between two steel beams. The hydraulic pressure was applied in parallel using cylindrical pistons placed on the columns. Since, for some columns, the CEBs had to be sawn to ensure column symmetry while respecting mortar thickness, the centralised load results in moderately different compressive stresses across column types due to cross-sectional variations (6%, 15% and 23%).

Load stability during the 90-day sustained loading phase was ensured using a pneumatically controlled hydraulic pump (Enerpac PAMG1405N, Turbo II). The system continuously regulates the hydraulic pressure and automatically compensates for any short-term pressure drops via the pneumatic side of the pump. An overpressure valve prevents excessive loading. In the event of a power failure, the air compressor is supported by a 300-litre pressure vessel that allows the target pressure to be maintained for a considerable duration, depending on the deformation response of the specimen. Any deformation in the test piece or minor relaxation in the steel elements is accommodated by extension of the hydraulic pistons, while the pressure control system maintains a constant applied stress.

2.2.4.2. Loading conditions. The masonry columns were subjected to sustained loading for 90 days. This loading period was selected to capture the short-term effects of sustained loading under controlled laboratory conditions, replicating a common time window in the literature on masonry creep behaviour [67]. Although the experiment does not simulate a specific service-life duration, the resulting data provide a basis for calibrating theoretical models of long-term behaviour, analogous to those used in creep modelling, which may later allow extrapolation of strength evolution beyond the experimental timeframe [68,69]. Columns with CEBs were loaded in the first campaign (January–April 2024) at $T = 15 \pm 1^\circ\text{C}$ and $RH = 42 \pm 5\%$, and columns with MEBs were loaded in the second campaign (September–December 2024) at $T = 15 \pm 1^\circ\text{C}$ and $RH = 58 \pm 6\%$.

Based on previous studies investigating creep deformation [55], the nine-layer columns were loaded in compression for 90 days at a stress of 0.8 MPa. This applied load corresponds roughly to the stress level (not considering load eccentricities) at the bottom of a ground-floor wall

supporting three storeys with load-bearing floors, which can be considered a relatively heavy load on an internal wall. It was calculated using Eurocode 1 and Eurocode 6, assuming the floor slabs spanning approximately 9 m across the wall extremities, a floor load of 7 kN/m^2 including self-weight, and a wall self-weight of 5 kN/m , all distributed over standard masonry units of 140 mm width.

Although MEBs and CEBs differ substantially in compressive strength, the same absolute sustained load was applied to both types. This choice was intentional: the aim was to reproduce a realistic service-level stress representative of this application context, rather than to apply a percentage of each material's strength. Using a single load level avoids introducing an additional variable and allows the study to focus on how sustained service loading influences the compressive strength of reclaimed blocks within each block type, with the aim of evaluating their fitness for reuse under equal load-bearing conditions.

The applied load was also independent of the joint thickness between EM and EAM. Any potential non-uniformities in load transfer would be more strongly influenced by local surface roughness or internal thickness variations of the earth blocks than by the nominal joint thickness. Furthermore, the applied load was also independent of column height, which varied slightly across columns of the same block type due to differences in joint thickness (EM vs. EAM) or block orientation (CEBH vs. CEBV). Creep deformation, assessed in a separate study, was measured between fixed gauge points set at identical distances for all specimens. This ensured that deformation was evaluated over the same height and number of joints, and no indications were found that the reduced column height affected the measurements.

2.2.5. Reclamation of earth blocks

After loading the ten masonry columns for 90 days, the pistons and steel plates were removed before starting the reclamation process. All columns were deconstructed using a Bosch Professional impact hammer drill with a tile chisel, working on a 720-Watt motor in percussion-only mode. The columns were consistently hit as straight as possible at the mortar-bed T-junctions, using a 50 mm wide chisel to separate the blocks while limiting damage (Fig. 6). After each column was deconstructed, the recovered blocks were cleaned using a 100 mm wide joint knife.

During the reclamation process, block damage was evaluated based on the dimensional tolerances outlined in the French standard AFNOR XP P13-901 [70] for earth blocks (Fig. 7). According to this standard, corner damage is permitted only if it fits within a trirectangular tetrahedron formed by an equilateral triangle with sides up to 20 mm. Edge damage is acceptable if it does not exceed 30 mm in length and 5 mm in width. The compressive strength was measured only for reclaimed earth blocks with tolerable damage, in the same manner as for new blocks.

Deconstruction was highly effective and efficient for all column types except CEB-EAM. In this configuration, the combination of a very strong bond and a flat block surface with a thin-layer mortar hindered chisel insertion during hammer-drill deconstruction, leading to increased damage. This issue did not arise with MEB-EAM, as the more irregular surface texture of MEBs enabled easier and more targeted chisel placement, improving block–mortar separation. For CEBH-EM, CEBV-EM and MEB-EM, the relatively low strength of EM facilitated separation, and only minimal drilling was required.

Block cleaning was highly efficient for CEBH-EM and CEBV-EM, but more challenging for MEB-EM, MEB-EAM and CEB-EAM. For MEBs, the higher adhesion of both EM and EAM, combined with their rougher surface texture, made the removal of residual mortar with the joint knife more demanding. For CEBs, the very low adhesion of EM enabled rapid cleaning, whereas the high adhesion of EAM presented more difficulty, although it generally caused less damage than that observed during

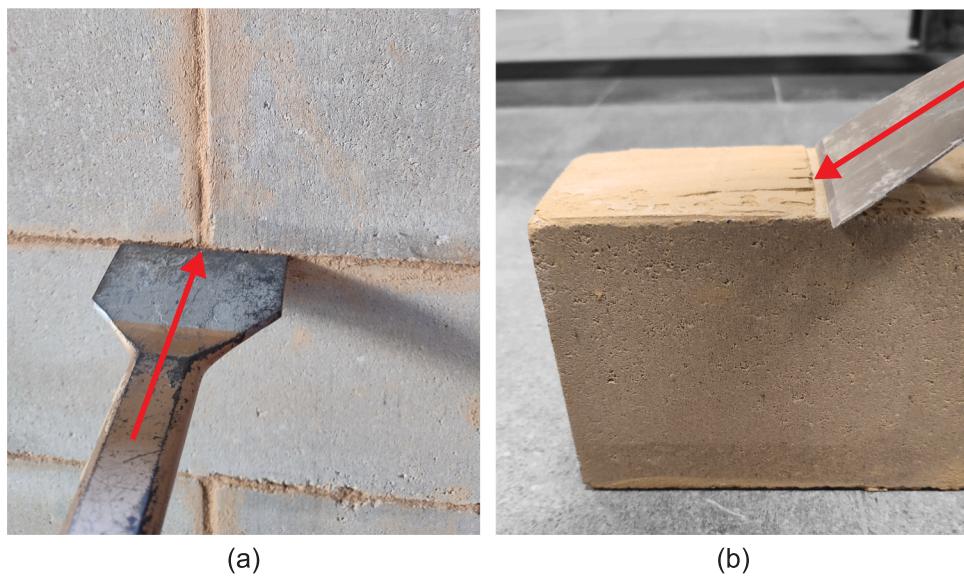


Fig. 6. Reclamation process consisting of (a) deconstruction of the masonry and (b) cleaning of recovered blocks (example shown for CEB-EAM columns).

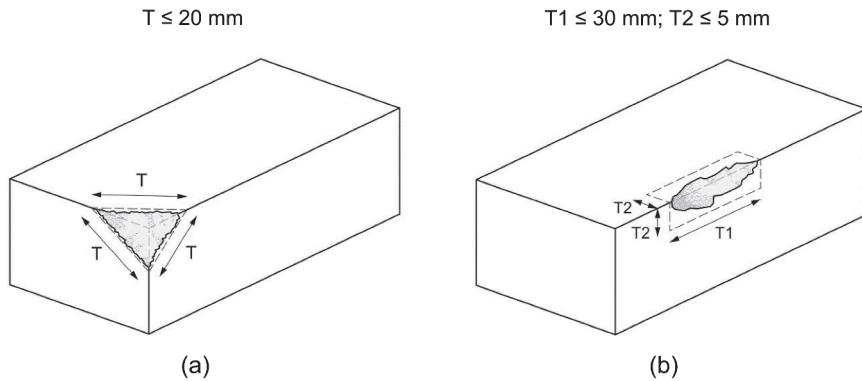


Fig. 7. Damage tolerances as per AFNOR XP P13–901 for (a) corners, and (b) edges.

deconstruction.

2.3. Evaluating fitness for reuse of reclaimed blocks

After successfully reclaiming the blocks from the loaded masonry columns, their compressive strength was tested using the same methods described for earth block characterisation in Section 2.2.3. The results were compared to a sample size of new blocks that was at least as large as that of the reclaimed blocks, ensuring a robust baseline for analysis.

To assess whether changes in compressive strength might hinder or benefit reuse, we went beyond descriptive statistics based on mean

values and standard deviations. Descriptive statistics alone may be misleading, particularly when error bars overlap, potentially obscuring meaningful differences in compressive strength or suggesting false ones. Therefore, we applied two complementary inferential statistical methods to evaluate the significance of any observed changes.

First, the independent *t*-test was used to calculate confidence intervals, indicating the estimated range of true mean differences and effect sizes, which reflect the magnitude of those differences. Second, the General Linear Model (GLM), a linear regression-based method, was employed to provide a more robust assessment by predicting the dependent variable (compressive strength) as a function of independent

Table 5

Compressive strengths (f_c) and normalised compressive strength (f_b) of new and reclaimed earth blocks.

Block ID	Condition	n ^a	f_c (MPa)	SD (MPa)	CoV (%)	f_b (MPa)	SD (MPa)	CoV (%)	Change (%)
MEB	New	72	3.6	0.3	8.2	-	-	-	-
R-MEB-EM	Reclaimed	14 (39%) ^b	4.0	0.4	10.5	-	-	-	+ 11
R-MEB-EAM	Reclaimed	19 (53%) ^b	3.8	0.4	10.4	-	-	-	+ 6
CEBH	New	54	23.5	3.3	14.0	20.9	2.9	14.0	-
CEBV	New	36	18.3	3.9	21.4	20.9	4.5	21.4	-
R-CEBH-EM	Reclaimed	32 (89%)	19.9	4.4	21.9	17.7	3.9	21.9	- 15
R-CEBV-EAM	Reclaimed	21 (58%)	24.4	2.4	10.0	21.7	2.2	10.0	+ 4
R-CEBV-EM	Reclaimed	36 (100%)	16.7	4.0	24.0	19.1	4.6	24.0	- 9

^a Percentage of successfully reclaimed blocks (per two columns of 18 blocks each) is given between parentheses.

^b Some blocks were discarded as they were unsuitable for testing due to accidental transportation, rather than due to reclamation. Reclamation rates were higher in a previous study on test walls (Pelicaen et al., 2024).

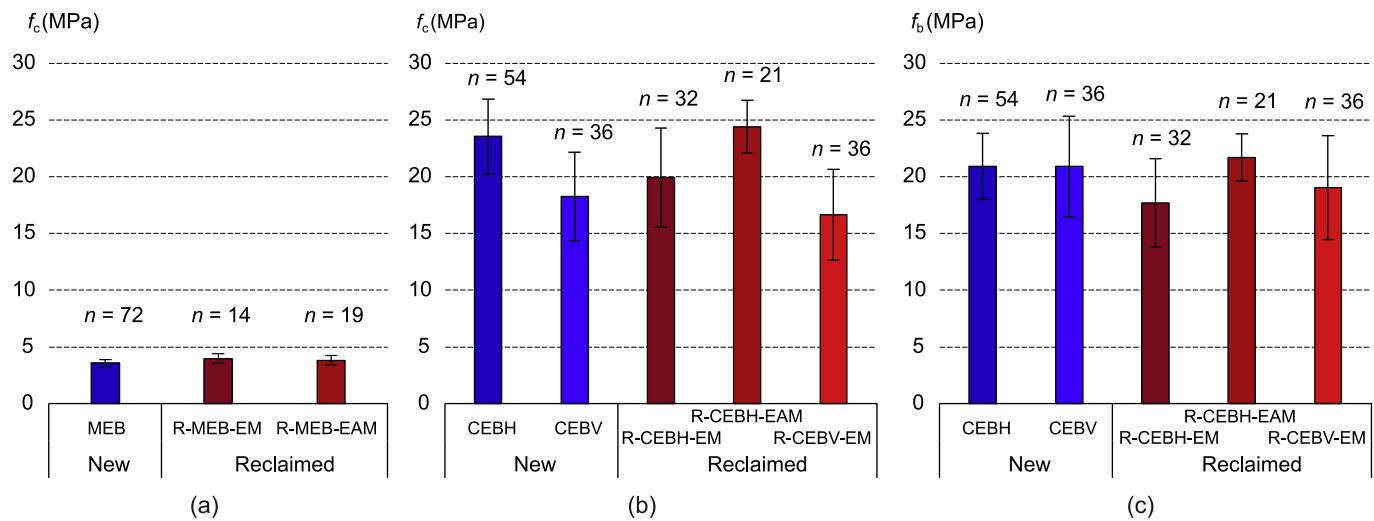


Fig. 8. Mean compressive strength (f_c) of new and reclaimed (a) MEBs and (b) CEBs, and (c) normalised mean compressive strength (f_b) of new and reclaimed CEBs. These results are descriptive; statistical significance of the observed changes is verified through the inferential analyses presented in Section 3.2.

variables (e.g., block condition, mortar type), while controlling for covariates such as block density. The respective results sections provide detailed descriptions of these statistical methods and their application.

3. Results

3.1. Descriptive results

This section summarises the descriptive results by comparing the mean values and variability of compressive strength for new and reclaimed MEBs and CEBs, as reported in Table 5 and illustrated in Fig. 8. Although these results provide useful initial insights, the conclusions of this study are based primarily on the more rigorous inferential statistical analysis presented in Section 3.2.

For CEBs, the compressive strength strongly depends on the testing orientation. Indeed, the mean compressive strength of new CEBs tested in the horizontal orientation (CEBH) is 5.2 MPa higher than that tested in the vertical orientation (CEBV). However, when corrected for the shape factor according to EN 772-1 [60], the normalised compressive strength is equal to that of CEBV, with a complete overlap of error bars. This verification indicates that the vertical compaction direction of the CEB production does not affect the direction in which the compressive strength is tested when the shape is accounted for.

Based on the mean values, the compressive strength of reclaimed MEBs from MEB-EM columns (R-MEB-EM) is 11% higher than that of new MEBs, while MEBs from MEB-EAM columns (R-MEB-EAM) show a 6% increase, both with partially overlapping error bars. The normalised compressive strength of reclaimed CEBs from columns laid horizontally with EM (R-CEBH-EM) is 15% than that of new CEBs tested horizontally (CEBH). In contrast, CEBs reclaimed from horizontal EAM-laid columns (R-CEBH-EAM) exhibit a 4% increase, and vertically laid CEBs with EM (R-CEBV-EM) show a 9% reduction compared to new CEBV.

The descriptive results reveal changes in the compressive strength of reclaimed earth blocks after sustained loading. However, the high variability in results, particularly for CEBs, leads to (partially) overlapping error bars, which may obscure the true significance of observed differences. To address this uncertainty, a more detailed statistical analysis was conducted to assess the significance of variations in compressive strength.

3.2. Inferential statistical analysis

Building on the descriptive findings, this section employs inferential

statistical methods, including independent *t*-tests and General Linear Models (GLMs), to assess the statistical significance of observed differences and further isolate the effect of sustained loading by accounting for confounding variables, such as density.

3.3. Implementing the independent *t*-tests

The *t*-test is a statistical method to compare the means of two dependent or independent groups or samples to determine whether the observed difference is statistically significant [56]. To ensure the validity of the independent *t*-tests, the underlying assumptions were systematically verified. Independence was guaranteed by the destructive nature of compressive testing, which prevents repeated measurements on the same specimen. Normality within each group was assessed through Q-Q plots and confirmed, where necessary, using the Kolmogorov-Smirnov test. Homogeneity of variances was evaluated using Fisher's *F*-test, and Welch's *t*-test was applied when this assumption was not met. Compressive strength is a continuous variable, while block condition (new or reclaimed) is a categorical variable with two levels; residual plots indicated no significant outliers. The diagnostic figures supporting these checks are provided in the Supplementary Material.

Two hypotheses are formulated to evaluate whether the mean compressive strengths of two groups of earth blocks differ significantly. The null hypothesis (H_0) assumes that there is no significant difference between the group means. In contrast, the alternative hypothesis (H_1) suggests a significant difference exists. Since both positive and negative changes in compressive strength were observed, a two-tailed *t*-test was employed to account for the possibility of differences in either direction, ensuring an unbiased assessment of statistical significance. Since the normality assumption was met using the Kolmogorov-Smirnov test, Fisher's *F*-test was applied for checking variance homogeneity. When the assumption of equal variances is justified, the following formula for the *t*-statistic can be applied:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1+n_2-2}} \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \quad (1)$$

where \bar{X}_1 and \bar{X}_2 represent the mean values of the two groups, S_1^2 and S_2^2 are their respective variances and n_1 and n_2 denote their sample sizes. This formula pools the variances of the two groups, providing a more precise estimate of the standard error when variance homogeneity can be assumed. For cases where the variances of the two groups are unequal, the *t*-statistic is calculated using Welch's *t*-test as follows:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} \quad (2)$$

In both cases, the *t*-statistic quantifies the magnitude of the difference between group means relative to the standard error, reflecting the sampling variability of this difference. It follows a *t*-distribution, which resembles the normal distribution but varies depending on the degrees of freedom. The *p*-value associated with the *t*-test quantifies the probability of observing a difference as extreme as, or more extreme than, the one measured, assuming the null hypothesis is true. A smaller *p*-value (typically below a threshold of 0.05) indicates stronger evidence against the null hypothesis, suggesting that the observed difference is statistically significant and, therefore, the alternative hypothesis is true. The *p*-value is derived from the cumulative probability distribution of the *t*-statistic, comparing the observed *t*-value with the expected distribution under the null hypothesis.

In addition to the *p*-value, a 95% confidence interval *CI* can be calculated to estimate the range within which the true mean difference is likely to lie:

$$CI = (\bar{X}_1 - \bar{X}_2) \pm t \sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}} \quad (3)$$

where *t* is the critical value from the *t*-distribution corresponding to the 95% confidence level. A narrow confidence interval suggests a more precise estimate, while a wide interval indicates greater uncertainty.

To complement statistical significance, the effect size is determined using Cohen's *d*, which measures the magnitude of the difference between group means in standard deviation units. It is calculated as the mean difference relative to the pooled standard deviation:

$$d = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1+n_2-2}}} \quad (4)$$

Cohen's *d* provides a standardised measure of the effect, allowing comparisons across studies and contexts. Common thresholds interpret effect sizes as small (*d* ≈ 0.2), medium (*d* ≈ 0.5), and large (*d* ≈ 0.8) [71]. The *p*-value, confidence interval, and effect size offer a comprehensive assessment of the statistical significance and practical relevance of the difference in compressive strength between the groups.

3.3.1. Results of the independent *t*-tests

The independent *t*-test was conducted for all relevant comparisons outlined in Section 3, and the results are summarised in Table 6, together with the *F*-test results. For MEBs, the difference in compressive strength is statistically significant (*p* < 0.05). Negative values for the *t*-

statistic, Cohen's *d*, and the confidence interval *CI* indicate that the mean compressive strength of Group 1 is lower than that of Group 2, suggesting higher compressive strength for reclaimed MEBs after sustained loading. Blocks reclaimed from columns laid with EM (R-MEB-EM) exhibit a large effect size (*d* > 0.8), while those from columns laid with EAM (R-MEB-EAM) show a medium to large effect size (0.5 < *d* < 0.8). The confidence interval for the true mean difference ranges from 0.2 to 0.6 MPa for reclaimed blocks laid with EM and from 0.03 to 0.5 MPa for those laid with EAM. These findings provide quantitative support to the visual comparison of mean compressive strengths and standard deviations, offering a more precise interpretation of the observed differences.

For CEBs, a control test was performed by comparing new blocks tested in horizontal orientation (CEBH) with those in vertical orientation (CEBV). The compressive strength of CEBV is lower than CEBH, and the difference is significant (*p* < 0.0001), with a very large effect size (*d* = 1.4) and a confidence interval ranging from 3.5 to 7.1 MPa. On the other hand, the normalised compressive strength is equal for both groups (*p* = 0.97), suggesting that the difference in compressive strength can be predominantly attributed to the shape factor, as per EN 772-1 [60].

When comparing new CEBs to reclaimed CEBs laid horizontally with EM (R-CEBH-EM), the latter shows lower compressive strength, and the difference is highly significant (*p* = 0.0002) with a large effect size (*d* > 0.8). When applying the *t*-test to the normalised compressive strength, the only difference from the compressive strength lies in the confidence interval, which ranges from 1.5 to 5.0 MPa, compared to 1.7 to 5.6 MPa, respectively. In the case of reclaimed CEBs from columns laid horizontally with EAM (R-CEBH-EAM), the compressive strength difference with horizontally tested new CEBs is insignificant (*p* = 0.2). To a lesser extent, the same accounts for reclaimed CEBs from columns laid vertically with EM (R-CEBV-EM; *p* = 0.09).

The results from the independent *t*-tests quantitatively reinforce the trends observed in the visual comparison of mean compressive strengths and standard deviations, offering a more precise interpretation of the observed differences. These findings align with the descriptive analysis presented in Section 3, underscoring the statistical significance of the observed trends. However, incorporating covariates into the analysis can enhance the robustness and deepen the understanding of these trends. To address this, a General Linear Model (GLM) was applied to account for additional factors, such as density, and to explore potential interactions that may influence compressive strength.

3.3.2. Implementing the general linear models (GLMs)

The compressive strength of earth blocks is influenced by a variety of factors, including material properties (e.g. soil composition, particle size distribution, stabiliser type and content), manufacturing process (e.g.

Table 6

Results from the independent *t*-test for equality of means between groups of the compressive strengths (*f_c*) and normalised compressive strength (*f_b*) of new and reclaimed earth blocks, and Fisher's *F*-test for equality of variances between groups.

Property	Group 1	<i>n</i>	Mean (MPa)	Group 2	<i>n</i>	Mean (MPa)	Fisher's <i>F</i> -test ^a			Independent <i>t</i> -test ^b				
							<i>F</i>	<i>p</i>	Variance	<i>t</i>	<i>p</i>	Mean	<i>d</i> ^c	<i>CI</i> ^d (MPa)
<i>f_c</i>	R-MEB-EM	14	3.99	MEB	72	3.59	0.47	0.02	Unequal	3.33	0.005	Unequal	0.97	(0.19, 0.62)
<i>f_c</i>	R-MEB-EAM	19	3.83			3.59	0.53	0.03	Unequal	2.45	0.02	Unequal	0.63	(0.03, 0.46)
<i>f_c</i>	CEBH	54	18.26	CEBV	36	23.54	0.70	0.12	Equal	6.84	< 0.0001	Unequal	1.44	(3.51, 7.06)
			20.89			20.92	0.42	0.002	Unequal	0.04	0.97	Equal	-	-
<i>f_c</i>	R-CEBH-EM	32	19.92	CEBH	54	23.54	0.56	0.03	Unequal	-4.00	0.0002	Unequal	-0.90	(-5.56, -1.69)
<i>f_b</i>			17.70			20.92	0.56	0.03	Unequal	-4.00	0.0002	Unequal	-0.90	(-4.95, -1.50)
<i>f_c</i>	R-CEBH-EAM	21	24.41	CEBH	54	23.54	1.96	0.046	Unequal	1.29	0.20	Equal	-	-
<i>f_b</i>			21.69			20.92	1.96	0.046	Unequal	1.29	0.20	Equal	-	-
<i>f_c</i>	R-CEBV-EM	36	16.65	CEBV	36	18.26	0.02	0.89	Equal	-1.71	0.09	Equal	-	-
<i>f_b</i>			19.05			20.89	0.02	0.89	Equal	-1.71	0.09	Equal	-	-

^a Levene's test was used for groups with non-normality (only R-CEBV-EM).

^b Welch's *t*-test was used for samples with unequal variance.

^c Effect size (*d* ≥ 0.8 is considered large).

^d 95% confidence interval on mean differences.

compaction type and pressure, water content, curing conditions), testing procedures (capping, platen restraint), and geometric properties (block size, aspect ratio) [52,72–75]. Multiple studies have demonstrated that higher compaction effort increases the compressive strength of earth blocks, primarily due to a corresponding increase in density [25,72,74, 76–79]. Slight variations in density within a production batch can affect the compressive strength of individual blocks, and sustained loading may also influence block density over time. In this study, which focuses on industrially produced earth blocks, density emerges as the primary variable across the tested specimens. By including density as a covariate, its influence can be statistically accounted for, allowing us to isolate a more intrinsic measure of compressive strength. This approach enables a clear comparison between the compressive strength of new and reclaimed earth blocks and, thus, the effect of sustained loading, minimising the confounding effects of density variation.

The data was modelled in Statistical Analysis System (SAS) software to control for density as a covariate and analysed using the General Linear Model (GLM). The GLM represents the dependent variable (compressive strength) as a linear combination of multiple independent variables, each scaled by a weight factor that indicates the contribution of each independent variable to the model's prediction. The GLM enables us to describe the relationship between variables, assess their statistical significance, and predict the dependent variable based on new independent variable values [56]. The basic principle of the GLM is known as linear regression, which in its simplest form (two variables) refers to:

$$Y = \beta_0 + \beta_1 X + \epsilon \quad (5)$$

The β_1 coefficient indicates the expected change in Y with a one-unit increase in X , while the intercept β_0 serves as an offset, representing the expected value of Y when $X = 0$. The error term ϵ captures the remaining variability in the data after fitting the model, commonly referred to as residuals. The error term can be dropped after calculating the fitted or expected value based on the model. The equation for observation i becomes:

$$\hat{Y}_i = \beta_0 + \beta_1 x_i \quad (6)$$

The data met the following model assumptions: (1) linearity between predictors and outcomes, verified by the absence of patterns in residual plots; (2) homoscedasticity of errors, confirmed through consistent variance in residual plots; (3) normality of errors, checked by alignment of the QQ-plot with a 45° reference line; and (4) independence, ensured by the destructive nature of compressive strength testing. Residual Q-Q plots to verify these assumptions are provided in the Supplementary Material.

The tested blocks can be grouped according to three categorical variables (Table 7): (1) the condition in which blocks were tested (new or reclaimed), (2) the mortar that was used to construct the columns (none for new blocks and earth or earth-adhesive for reclaimed blocks), and (3) the orientation in which the blocks were tested (horizontal or vertical). For reclaimed blocks, the testing orientation also corresponds to their original placement in the columns. In the case of MEBs, this

Table 7
Grouping of blocks by three categorical variables.

Block type	<i>n</i>	Condition	Mortar ^a	Orientation ^b
MEB	72	New	-	-
R-MEB-EM	14	Reclaimed	Earth	-
R-MEB-EAM	19	Reclaimed	Earth-adhesive	-
CEBH	54	New	-	Horizontal
CEBV	36	New	-	Vertical
R-CEBH-EM	32	Reclaimed	Earth	Horizontal
R-CEBH-EAM	21	Reclaimed	Earth-adhesive	Horizontal
R-CEBV-EM	36	Reclaimed	Earth	Vertical

^a New blocks were not laid with mortar.

^b MEBs were not laid or tested vertically.

orientation was consistently horizontal.

The GLM can combine continuous and categorical variables to predict the dependent variable. In this study, density (X_1) is the continuous variable (predictor), and block type (X_2) is a composite categorical variable defined by condition, mortar, and orientation. When assessing the effect of sustained loading on the compressive strength, i.e. comparing reclaimed block types to new block types, the GLM can be expressed as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \epsilon \quad (7)$$

If new blocks are taken as the reference (0) and reclaimed blocks as the comparator (1), the term $\beta_2 \times 2$ becomes zero for new blocks and β_2 for reclaimed blocks. When there is an effect of sustained loading on compressive strength after controlling for density, the data may be described by two parallel regression lines with the same slope (β_1) but different intercepts (β_0 for new blocks, $\beta_0 + \beta_2$ for reclaimed blocks). However, when there is an interaction between density and block type, i.e. when density is affected by sustained loading, the relationship between density and compressive strength changes for reclaimed blocks. This interaction is captured by the term $\beta_3 X_1 X_2$, which represents the difference in slope between new and reclaimed blocks. The GLM then becomes:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_1 X_2 + \epsilon \quad (8)$$

In this interaction model, the regression lines for reclaimed blocks differ not only in intercept ($\beta_0 + \beta_2$) but also in slope ($\beta_1 + \beta_3$). This suggests that changes in compressive strength may be partly attributed to variations in density resulting from sustained loading. An additional *F*-test was conducted to verify differences in mean densities across block groups by comparing the variance between group means with the variance within groups. Due to their distinct properties and behaviour compared to CEBs, MEBs were analysed separately to ensure accurate modelling and interpretation of results.

The best-fit models were identified using a stepwise selection procedure. This approach iteratively evaluates candidate models by adding predictor variables (forward selection) or removing them (backward elimination) based on predefined statistical criteria. At each step, model performance is typically assessed using the Akaike Information Criterion (AIC), which is best suited for achieving predictive performance, or the Bayesian Information Criterion (BIC), which is best suited for finding the simplest model [80,81]. In this study, given the relatively small datasets per group and the presence of only one predictor variable (density), forward selection was combined with AIC to avoid underfitting by not penalising for model complexity.

Finally, if the best-fit model included density as a covariate, adjusted means and confidence intervals were calculated using the least squares method. This method entails estimating the marginal means of compressive strength after statistically controlling for density, which is achieved by evaluating the fitted GLM at the mean density of the dataset. The adjusted mean for each group, \bar{X}_{adj} , is calculated as:

$$\bar{X}_{adj} = \beta_0 + \beta_1 \bar{X}_1 + \beta_2 \bar{X}_2 + \beta_3 \bar{X}_1 \bar{X}_2 \quad (9)$$

Where \bar{X}_1 is the average density per group. The confidence intervals for the adjusted means are obtained using the standard error of the least-squares means:

$$CI = \bar{X}_{adj} \pm \frac{t_{\alpha/2, df}}{2} \cdot SE(\bar{X}_{adj}) \quad (10)$$

Where $t_{\alpha/2, df}$ is the critical value from the t-distribution and $SE(\bar{X}_{adj})$ is the standard error derived from the variance-covariance matrix of the model parameters. This approach provides a robust estimate of group differences while controlling for systematic variation in density. Least-squares means additionally adjust for unbalanced data, ensuring that groups with unequal sample sizes (e.g. CEBH, CEBH-EM, and CEBH-EAM) are treated statistically as if they contained an equal number of

Table 8

GLM results for the compressive strength of new earth blocks and reclaimed earth blocks after sustained loading.

Reference group (0)	n	Comparison group (1)	n	AIC	R ²	Adj. R ²	Parameter	Coeff.	Est.	SE	t	p	Adj. mean ^a (MPa)	CI ^b (MPa)
MEB	72	R-MEB-EM	14	53.7	0.19	0.17	Intercept	β_0	3.6	0.04	94.4	< 0.0001	-	-
							R-MEB-EM	β_1	0.4	0.09	4.3	< 0.0001	-	-
							MEB	-	0	-	-	-	-	-
MEB	72	R-MEB-EAM	19	58.8	0.09	0.08	Intercept	β_0	3.6	0.04	94.2	< 0.0001	-	-
							R-MEB-EAM	β_1	0.3	0.08	3.0	0.004	-	-
							MEB	-	0	-	-	-	-	-
CEBH	54	R-CEBH-EM	32	379.0	0.75	0.74	Intercept	β_0	-110.1	14.5	-7.6	< 0.0001	-	-
							ρ	β_1	66.5	7.2	9.2	< 0.0001	-	-
							R-CEBH-EM	β_2	-77.6	25.2	-3.1	0.003	21.50 (- 6.3%)	[20.69, 22.30] (-2.35, -0.58)
CEBH	54	R-CEBH-EAM	21	315.6	0.63	0.62	CEBH	-	0	-	-	-	22.95	[22.36, 23.53]
							$\rho * R-CEBH-EM$	β_3	38.1	12.6	3.0	0.003	-	-
							$\rho * CEBH$	-	0	-	-	-	-	-
CEBH	36	R-CEBV-EM	36	346.4	0.61	0.59	Intercept	β_0	-96.6	11.0	-8.8	< 0.0001	-	-
							ρ	β_1	59.7	5.5	11.0	< 0.0001	-	-
							R-CEBV-EM	β_2	-1.5	0.5	-2.7	0.008	22.73 (- 6.0%)	[21.84, 23.61] (-2.25, -0.64)
CEBV	36	R-CEBV-EAM	36	346.4	0.61	0.59	CEBV	-	0	-	-	-	24.19	[23.66, 23.61]
							ρ	β_1	77.7	7.8	10.0	< 0.0001	-	-
							R-CEBV-EM	β_2	-0.7	0.6	-1.1	0.3	-	-
CEBV	36	R-CEBV-EAM	36	346.4	0.61	0.59	CEBV	-	0	-	-	-	-	-

^a Least-squares mean value. For R-MEB-EM and R-MEB-EAM, these are equal to the descriptive mean values. For R-CEBV-EM, it is not significant.

^b 95% confidence interval on adjusted means with mean differences of reclaimed blocks between round brackets.

observations. As a result, the adjusted mean of the reference group (such as CEBH) may differ slightly across models. This variation is expected and reflects the appropriate weighting inherent to least-squares estimation in unbalanced designs.

3.3.3. Results of the GLMs

The GLM results for the compressive strength of new versus reclaimed earth blocks are summarised in Table 8, and the corresponding regression lines are shown in Fig. 9.

3.3.3.1. Analysis for MEBs. A first GLM was fitted to describe the data based on the measured compressive strengths and densities of all the MEBs. When comparing new with reclaimed MEBs using Eq. (5), excluding density, the effect of sustained loading on the compressive strength is statistically significant ($p < 0.0001$). The same result is obtained when controlling for density using Eq. (7). The compressive strength marginally increases with density, and the coefficient of determination ($R^2 = 0.16$) indicates that only 16% of the variance in compressive strength is explained by density and MEB type (new or reclaimed), suggesting limited predictive accuracy [82]. According to [83], an R^2 value between 0.10 and 0.50 is only acceptable when the explanatory variables are statistically significant. However, in this case, density does not significantly affect compressive strength ($p = 0.4$), making the best-fitting model one that excludes density as a predictor. Furthermore, no significant differences in density were observed between new and reclaimed MEBs, regardless of the type of mortar.

The lack of correlation between density and compressive strength of MEBs could be attributed to several factors: (1) inaccurate dimension measurements due to the block's irregular surfaces and edges; (2) limited accuracy in compressive strength measurements, which rely on visually detecting slope changes in the stress-strain curves; (3) density's weak predictive power for compressive strength in this type of earth block. While dynamic soil compaction has been shown to increase the compressive strength of adobes by 79% compared to static compaction methods [76] – such as those used in the production of MEBs – the low variability among blocks produced by static compaction may obscure the influence of density on compressive strength. Furthermore, the compaction of MEBs is inherently limited due to their high water and clay content during moulding, which may restrict the potential for density to act as a reliable predictor.

When comparing new MEBs individually with reclaimed R-MEB-EM and R-MEB-EAM, two regression models were derived using Eq. (5),

excluding density. The compressive strength in R-MEB-EM is significantly higher ($p < 0.0001$) than new MEBs, with a mean increase of approximately 0.4 MPa. Similarly, the compressive strength in R-MEB-EAM shows a significant increase ($p = 0.004$), with an average gain of about 0.3 MPa. However, both models exhibit relatively low R^2 values (18% for R-MEB-EM and 9% for R-MEB-EAM), indicating that only a small proportion of the variance in compressive strength is explained by the condition of the blocks. This suggests that other factors not captured by the model considerably contribute to the variance.

3.3.3.2. Analysis for CEBs. A second GLM was fitted to the measured compressive strengths and densities of all the CEBs. Using Eq. (5), the model confirms that density has a statistically significant effect on compressive strength ($p < 0.0001$; $R^2 = 0.48$) when no other explanatory variables are considered. Likewise, sustained loading also shows a significant effect on compressive strength ($p = 0.01$). However, $R^2 = 0.03$, suggesting substantial variability in compressive strength when density is not accounted for. The best model for all CEBs is obtained when accounting for density and sustained loading using Eq. (7). Under this model, the effect of sustained loading remains significant ($p = 0.001$), and R^2 increases to 0.51, indicating that density explains a substantial portion of the variation in compressive strength. When density is analysed as the dependent variable with block types as categorical variables, significantly lower density is observed for R-CEBH-EM ($p = 0.01$), while significantly higher density is observed for R-CEBH-EAM ($p < 0.0001$) compared to CEBH.

To further isolate the effects of sustained loading, pairwise comparisons were made between specific CEB types: (1) CEBH and R-CEBH-EM, (2) CEBH and R-CEBH-EAM, and (3) CEBV and R-CEBV-EM. Comparison (1) versus (2) isolates the additional effect of the mortar type in the horizontal orientation. Comparison (1) versus (3) isolates the effect of laying and testing orientation for EM. The GLM results of these comparisons are described below.

(1) CEBH versus CEBH-EM:

The best model to fit these data is described by Eq. (8), which includes an interaction between density and block type. When controlling for density, the compressive strength of CEBH-EM is significantly lower than CEBH ($p = 0.003$; $R^2 = 0.75$). The negative estimate for R-CEBH-EM ($\beta_2 = -77.6$) reflects a reduced intercept, indicating a decrease in compressive strength. However, the interaction term ($\rho * R-CEBH-EM$) is significant ($p = 0.003$), increasing the effect of density ($\beta_3 = 38.1$). As a

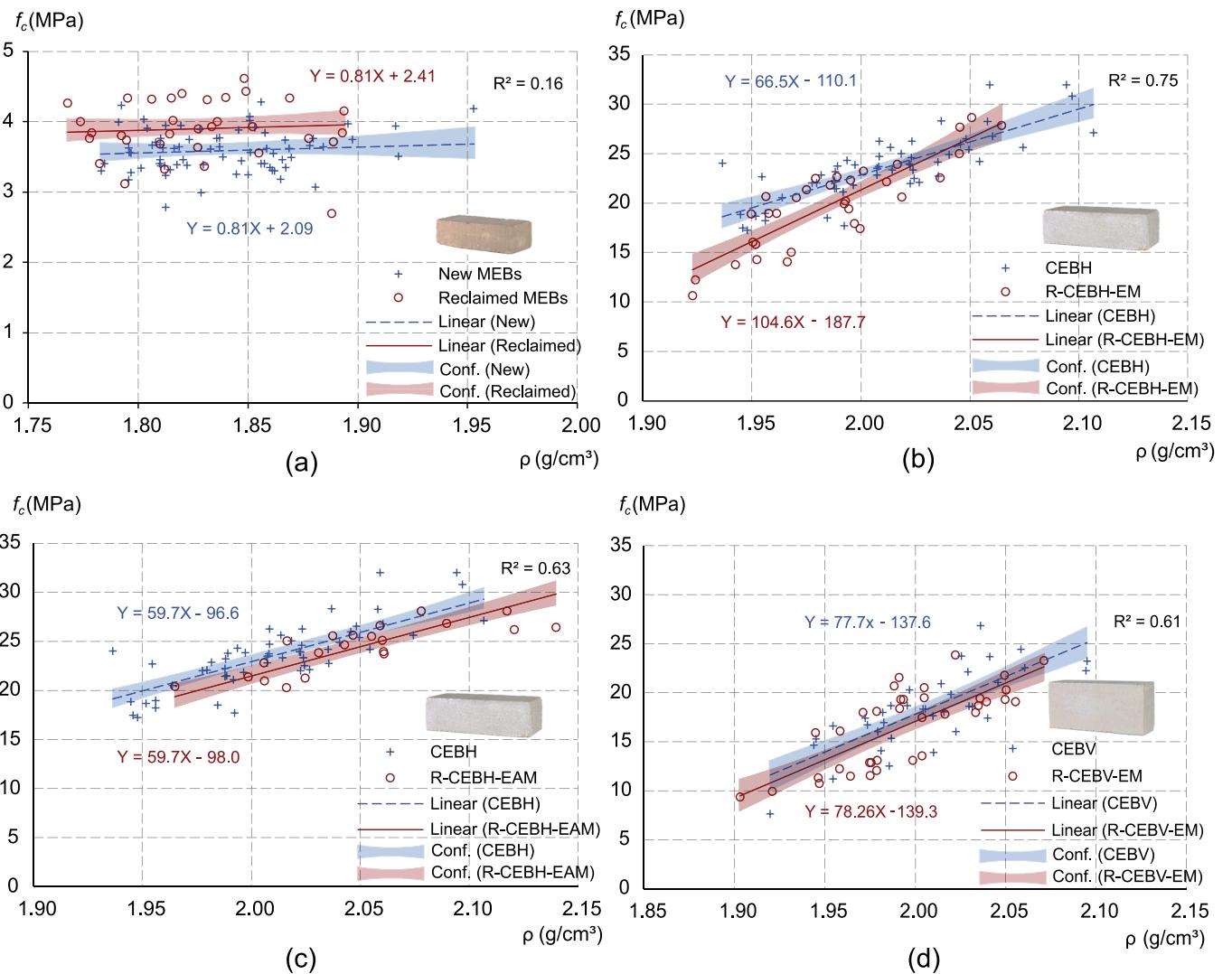


Fig. 9. Linear regressions of (a) the GLM for new MEBs ($n = 72$) and reclaimed MEBs ($n = 33$), (b) new CEBs ($n = 54$) and reclaimed CEBs from loaded columns laid horizontally with EM ($n = 32$), (c) new CEBs ($n = 54$) and reclaimed CEBs from loaded columns laid horizontally with EAM ($n = 21$), and (d) new CEBs ($n = 36$) and reclaimed CEBs from loaded columns laid vertically with EM ($n = 36$).

result, the regression lines for the two block groups have different slopes, indicating that the relationship between density and compressive strength differs between CEBH-EM and CEBH. This suggests that changes in density mediate the effect of sustained loading on compressive strength. Specifically, R-CEBH-EM blocks exhibit lower densities than new blocks, and the regression line reflects this shift, characterised by lower densities and compressive strengths. Finally, the adjusted means, corrected for density and the density-strength interaction, reveal a decrease in compressive strength of 6.3% with a confidence interval of -2.35 MPa to -0.58 MPa .

(2) CEBH versus CEBH-EAM:

The best model to describe these data is Eq. (7), excluding an interaction between density and block type. When controlling for density, the compressive strength of R-CEBH-EAM is significantly lower than that of CEBH ($p = 0.008; R^2 = 0.63$). This is reflected in the negative estimate for R-CEBH-EAM ($\beta_2 = -1.5$), which reduces the intercept and indicates a decrease in compressive strength. Notably, this finding strongly contrasts with the observed mean compressive strengths, where R-CEBH-EAM appears to outperform CEBH. Finally, the adjusted means correcting for density reveal a decrease in compressive strength of 6.0% with a confidence interval of -2.25 MPa to -0.64 MPa .

(3) CEBV versus CEBV-EM:

The best model to describe these data is also Eq. (7). When controlling for density, the compressive strength of R-CEBV-EM does not significantly differ from that of CEBV ($p = 0.3; R^2 = 0.61$). Indeed, the estimate for R-CEBV-EM is too small ($\beta_2 = -0.7$) to contribute to the prediction of compressive strength, or the effect may remain undetected due to the limited sample size. Visually, the parallel regression lines for CEBV and R-CEBV-EM are separated by a vertical distance too small to indicate significant changes in compressive strength within the given dataset. Therefore, the difference between the adjusted means, correcting for density, is also not significant. This suggests that, under current conditions, sustained loading has no measurable impact on the compressive strength of vertically oriented CEBs.

3.3.3.3. Verification of confounding factors for density changes. For CEBs, where density was found to be a significant predictor in the GLM, the potential influence of two confounding factors was examined: mass loss due to block damage during deconstruction and cleaning, and mass gain due to residual mortar retained in the block pores.

Because density is defined as block mass divided by block volume, a decrease in density implies either a loss in mass or an increase in volume, while an increase in density implies either a mass gain or a reduction in

volume. Potential mass losses (for density decreases) and mass gains (for density increases) were calculated with respect to the mean block volume of CEBH.

For R-CEBH-EM, the observed density decrease of 1.2% would require a mean mass loss of approximately 77 g. This scenario is unlikely, given the minimal block damage observed in this series and the fact that any retained hardened mortar would partially offset mass loss rather than contribute to it.

For R-CEBH-EAM, the observed density increase of 2.4% would require a mean mass gain of approximately 143 g of residual mortar. This scenario is also improbable, not only because such a large amount of mortar retention was not observed, but also because this scenario assumes no mass loss through block damage, despite damage occurring more frequently in R-CEBH-EAM than in R-CEBH-EM.

Taken together, these comparisons indicate that neither block damage nor residual mortar provides a realistic explanation for the observed density changes. This supports the interpretation that sustained loading is the most plausible factor driving the density variations identified in reclaimed CEBs.

3.4. Summary of compressive strength changes

In this section, we summarise the main findings on changes in compressive strength from each analytical method and clarify how the descriptive and inferential results relate to one another, including cases where they may initially appear contradictory. Because the GLM accounts for density as a predictor, it provides the most reliable estimate, and we therefore prioritise its outcomes. When the *t*-test is consistent with the GLM, it offers additional support for the observed differences in compressive strength. In instances where the two methods diverge, we rely solely on the GLMs' adjusted means and confidence intervals. Finally, when the GLM identifies a best-fit model that does not require density correction, the descriptive means and the confidence intervals from the *t*-test provide a sufficient basis for interpreting the observed changes.

Reclaimed MEBs laid with earth mortar (R-MEB-EM) and thin-layer earth-adhesive mortar (R-MEB-EAM) consistently demonstrated higher compressive strength than new blocks. Descriptive results revealed increases of 11% (R-MEB-EM) and 6% (R-MEB-EAM), with partial overlap of the error bars. The independent *t*-test confirmed statistically significant increases with confidence intervals of 0.2 to 0.6 MPa for R-MEB-EM and 0.03 to 0.5 MPa for R-MEB-EAM, with large and medium-to-large effect sizes, respectively. The GLM also identified significant increases in compressive strength for reclaimed MEBs, although no statistically significant relationship was found between density and compressive strength. Therefore, the changes in compressive strength are equal to the descriptive mean differences and confidence intervals from the *t*-test.

For reclaimed CEBs laid horizontally with earth mortar (R-CEBH-EM), the descriptive analysis revealed a 15% decrease in compressive strength compared to new blocks (CEBH), with partial overlap of the error bars. The *t*-test confirmed a statistically significant reduction in compressive strength with a confidence interval of 3.5 to 7.1 MPa and a large effect size. The GLM corroborated this finding, revealing an additional significant interaction between density and block type, which suggests that changes in density contribute to the observed effects of sustained loading. Therefore, the changes in compressive strength are equal to the adjusted means, showing a reduction of 6.3% with confidence intervals of -2.35 to -0.58 MPa.

For reclaimed CEBs laid horizontally with thin-layer earth adhesive mortar (R-CEBH-EAM), the descriptive analysis revealed a 4% increase in compressive strength, with partial overlap of the error bars. However, while the *t*-test detected no significant differences, the GLM identified a statistically significant reduction in compressive strength when controlling for density, not through changes in density. Therefore, the changes in compressive strength are equal to the adjusted means, showing a reduction of 6.0% with confidence intervals of -2.35 to

-0.64 MPa.

For reclaimed CEBs from columns laid vertically with EM (R-CEBV-EM), the descriptive analysis revealed a 9% reduction in compressive strength compared to new blocks (CEBV), with partial overlap of the error bars. However, neither the *t*-test nor the GLM detected significant differences, even when accounting for density. Therefore, the compressive strength remains unchanged after sustained loading.

Considering the results for both mortar types and the associated confidence intervals, reclaimed MEBs exhibit compressive strengths ranging from 3.6 to 4.2 MPa. Reclaimed CEBs in the horizontal orientation range between 20.7 and 23.6 MPa, while reclaimed CEBs in the vertical orientation show no reduction relative to new blocks, with strengths between 16.8 and 19.7 MPa.

4. Discussion

4.1. Implications for reuse

This study presents initial insights into the effects of sustained loading on the compressive strength of non-stabilised moulded earth blocks (MEBs) and cement-stabilised compressed earth blocks (CEBs), revealing that the two materials respond differently under such conditions. Notably, reclaimed MEBs exhibited increased compressive strength after sustained loading, which supports their potential for reuse. Conversely, reclaimed CEBs generally demonstrated either reduced or unchanged compressive strength, which could limit their suitability for reuse in load-bearing applications.

For reclaimed MEBs, the observed increases in compressive strength (11% and 6%) suggest viability for reuse in load-bearing applications. Hypothetically, under prolonged loading conditions, these increases could lead to a shift in the characteristic compressive strength of MEBs from Class 3 to Class 4 according to DIN 18,945 [58] and AFNOR XP P13-901 [70], thereby enhancing their structural performance and broadening their application in building typologies with varying live loads. However, if the relationship between the block's compressive strength and sustained loading duration mirrors trends observed in long-term masonry behaviour, such as creep deformation, the compressive strength of MEBs would reach a plateau over time or continue to increase until masonry failure [55]. Nonetheless, it is equally plausible that the gains in compressive strength may have plateaued within the timeframe of this study.

For reclaimed CEBs, their substantially higher initial compressive strength relative to MEBs means that the 6% reductions observed after 90 days of sustained loading do not compromise their suitability for reuse in load-bearing applications within the timeframe studied. It should be noted, however, that the service life of load-bearing masonry is considerably longer than 90 days, and no validated theoretical model currently exists to extrapolate these findings to longer periods. Further research is therefore required to determine whether the observed trends remain stable over typical service lifespans.

For CEBs reclaimed from load-bearing CEBH-EM or CEBH-EAM structures, a reduction in load-bearing capacity may occur in subsequent applications due to prolonged loading during the initial application. However, a substantial extension of the loading duration would be required to drop below strength class 6, the highest classification according to both German and French standards [58,70]. However, the magnitude of this drop in compressive strength (~ 10 MPa) is unlikely to occur, as it is possible that the decline rate would have begun to stabilise within the study's timeframe. An even more conservative scenario, in which compressive strength drops further to class 2, would confine reuse to non-load-bearing applications.

From a structural perspective, the observed changes in compressive strength could either mitigate or exacerbate the long-term structural integrity in load-bearing masonry subjected to phenomena such as creep deformation. This duality could translate into either a reduced structural lifespan or the possibility of extended use. From an environmental

standpoint, prolonging the use of the stabilised CEBs, given their higher embodied carbon, through reuse strategies such as leaving the structural masonry layer intact while modifying other building elements, aligns with design for longevity principles by delaying the need for new production and associated emissions.

4.2. Influencing factors and potential causes

For CEBs reclaimed from both CEBH-EM and CEBH-EAM columns, the GLM revealed statistically significant compressive strength reductions. The adjusted mean differences show that the magnitude of this reduction was similar for R-CEBH-EM and R-CEBH-EAM (both 6%). In contrast, reclaimed MEBs exhibited increases in compressive strength, although to differing extents: R-MEB-EM showed an 11% increase, compared to 6% for R-MEB-EAM. This may be linked to the thicker mortar layer of EM, given that EM and EAM exhibit comparable strength properties. One possible explanation relates to the thicker EM layer. Although EM and EAM have comparable strength properties, the greater thickness of EM may allow more uniform stress redistribution under sustained loading, particularly given the more irregular surface texture of MEBs. This could result in a more pronounced strengthening effect in R-MEB-EM. The smaller sample size of reclaimed MEBs ($n = 14$ and $n = 19$) may also contribute to the observed differences. However, this appears less likely because the compressive strength measurements for new MEBs were based on a very large sample ($n = 72$). These findings suggest that the mortar layer thickness may influence changes in compressive strength, highlighting the need for further investigation into how mortar properties affect the mechanical performance of reclaimed masonry units.

In addition, the observed density variations in CEBs reclaimed from CEBH-EM and CEBH-EAM columns warrant closer examination. In R-CEBH-EM, sustained loading appears to influence compressive strength via changes in density. However, in R-CEBH-EAM, density increases were recorded without a corresponding improvement in compressive strength, indicating that density alone cannot fully explain the compressive strength changes observed. This suggests that more complex interactions, potentially involving differential stress distributions influenced by mortar layer thickness and other characteristics, are at play.

Despite CEBs tested horizontally (CEBH) and those tested vertically (CEBV) exhibiting similar normalised compressive strengths after shape-factor correction, reclaimed blocks behaved differently: R-CEBV-EM showed no significant change in compressive strength, whereas R-CEBH-EM exhibited a marked reduction. This suggests that the orientation of blocks during service may impact the compressive strength of reclaimed CEBs. However, it remains possible that a real but small difference exists and was not detected by the GLM, given the available sample size.

Two other hypotheses may explain this behaviour. First, the difference may relate to the inherent anisotropy of CEBs stemming from their manufacturing process [77,84]. Vertical vibro-compaction can induce particle alignment and stronger bonding along the vertical axis, making blocks more susceptible to bond disruption or particle rearrangement when subjected to prolonged horizontal loading. Similar age- and loading-induced increases in anisotropy have also been observed in fired clay bricks [46].

Second, the contrasting outcomes may partly reflect differences in column geometry and resulting stress distribution. To maintain similar block counts per column, CEBV-EM columns consisted of six layers, each with three blocks, whereas CEBH-EM columns consisted of nine layers, each with two blocks. This produced differences in slenderness (aspect ratios of 2.86 vs. 3.30) and column strength (5.41 MPa vs. 4.83 MPa). The CEBV-EM configuration potentially promoted a more uniform stress field, reducing localised stress concentrations and thereby mitigating the strength reduction of the blocks under sustained loading.

These hypotheses underscore the need to conduct microscopic investigations on both new and reclaimed blocks to determine whether

microstructural alterations contribute to the observed changes in compressive strength and to elucidate the underlying mechanisms driving these changes. Such analyses could also test whether potential microstructural changes are induced by local states of biaxial tension or triaxial compression that could develop within the blocks during sustained loading due to differential strength and stiffness between the blocks and the mortar [85,86].

4.3. Limitations and directions for future research

This study provides a robust foundation for evaluating the fitness for reuse of reclaimed earth blocks after sustained loading based on their compressive strength. However, several limitations related to the scope of work and the full interpretation of the observed behaviour persist and should be addressed in future research. The following directions can be pursued:

- (1) While this study employed a sustained loading duration of 90 days, extending the loading period would be critical for determining whether compressive strength continues to evolve or stabilises, thus clarifying the long-term performance of reclaimed blocks. Moreover, the present dataset could be used to calibrate theoretical long-term loading models, enabling future extrapolation of strength development beyond the experimental timeframe.
- (2) Investigating different stress states akin to wall designs, including combined vertical and horizontal loading on single-leaf walls, could reveal insights distinct from those observed in vertically loaded columns comprising two or three block layers and thus better approximate real-world conditions.
- (3) While this study examined a single loading condition, investigating different loading levels for the same block-mortar combination could reveal thresholds in compressive strength and guide appropriate reuse in different building typologies and applications.
- (4) A more detailed microstructural investigation using SEM, XRD or CT would allow the detection of mechanisms such as crack propagation, particle rearrangement and interfacial degradation. This would provide clearer insight into how sustained loading affects the internal structure of earth blocks, help identify any microcracking induced during reclamation, and offer stronger evidence regarding the hypothesised effects of block orientation and stress distribution.
- (5) Although the potential influence of block damage and residual mortar in pores on density measurements was considered and deemed unlikely, future studies should directly compare block density before and after sustained loading (e.g. using a paired *t*-test) to verify these conclusions and further elucidate the relationship between density variations and compressive strength.
- (6) While laboratory simulations provide controlled and reproducible conditions, real-world factors, such as environmental exposure, will likely influence the mechanical performance of reclaimed earth blocks. Comparative studies involving blocks retrieved from actual structures would help validate laboratory findings and bridge the gap between experimental conditions and practical applications.
- (7) Future research should expand its focus beyond compressive strength to include other technical properties to verify the reclaimed block's fitness for reuse, such as stiffness, durability, and bond strength, particularly under combined loading and weathering conditions.
- (8) Integrating inferential statistics provided a rigorous framework for analysing compressive strength variations when descriptive trends were inconclusive. Incorporating additional GLM variables obtainable through non-destructive testing, such as block stiffness, could offer more accurate and nuanced interpretations.

Replicating this study across similar earth block–mortar configurations would also enable statistical meta-analyses and support broader, more generalisable conclusions.

(9) Drawing on parallels with timber design practice in Eurocode 5, future studies should explore whether sustained loading justifies the introduction of a modification factor for earth block masonry in future revisions of Eurocode 6. Such a factor could adjust strength parameters to account for long-term effects, enhancing the reliability of structural evaluations and promoting wider acceptance of earth blocks.

5. Conclusions

This pioneering study offers new insights into the mechanical performance of waste-based earth blocks reclaimed from load-bearing masonry, demonstrating their potential for reuse. Long-term compressive loads were applied to masonry columns built with non-stabilised moulded earth blocks (MEBs) and cement-stabilised compressed earth blocks (CEBs), paired with both an earth mortar (EM) and a thin-layer earth-adhesive mortar (EAM). After 90 days of sustained loading, the columns were deconstructed, and the compressive strength of reclaimed blocks was compared to that of new blocks using inferential statistics applied to large sample sizes. The main findings are as follows:

- 1) Sustained loading alters the compressive strength of earth blocks. MEBs consistently showed increases, whereas CEBs exhibited either reductions or no change.
- 2) Both reclaimed MEBs and CEBs, exhibiting compressive strengths of 3.6 to 4.2 MPa and 20.7 to 23.6 MPa, respectively, remain suitable for reuse in load-bearing applications within the 90-day loading period studied. For CEBs, however, further research is required to determine whether the observed 6% reduction stabilises or continues under longer loading durations.
- 3) Changes in compressive strength depend on mortar type and block orientation. MEBs showed increases of 11% in MEB-EM and 6% in MEB-EAM. For CEBs, horizontally laid CEBH-EM and CEBH-EAM both showed reductions of 6%, while vertically laid CEBV-EM showed no change.
- 4) Variations in compressive strength were sometimes accompanied by changes in density, particularly in horizontally laid CEBs with EM, where density reductions contributed to the observed strength loss.

Methodologically, this study advances the evaluation of fitness for reuse by isolating the effects of sustained loading, by developing a replicable testing sequence, and by integrating inferential statistical techniques that can detect changes in mechanical performance that descriptive statistics alone may overlook or misinterpret.

Although the observed reductions in reclaimed CEBs do not preclude reuse, they emphasise the importance of understanding long-term behaviour. Future research should investigate the effects of various loading conditions and durations, explore the microstructural mechanisms underlying the evolution of strength, and assess the interactions between sustained loading and environmental exposure. Further work should also examine other performance indicators relevant to reuse, including stiffness, durability, and bond strength. Ultimately, achieving a balance between high reclamation performance and reliable long-term mechanical performance will be essential to establishing earth block reuse as a viable circular alternative to demolition, thereby contributing to the closure of material loops in the construction sector.

CRedit authorship contribution statement

Erik Pelicaen: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rafael Novais Passarelli:** Writing – review & editing, Supervision. **Veerle**

Vandersmissen: Writing – review & editing, Formal analysis. **Erik Nuyts:** Formal analysis. **Rik Steensels:** Writing – review & editing, Investigation, Data curation. **Eline Vereecken:** Writing – review & editing. **Bram Vandoren:** Writing – review & editing. **Elke Knapen:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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Data availability

Experimental data from this research are made available by the corresponding author upon request.

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