REFORMING GROUNDS:

BUILDING WITH THE EARTH'S FORGOTTEN RESOURCES

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ABSTRACT

The global construction industry's reliance on finite, carbon-intensive materials has exacerbated ecological crises, including climate change, habitat destruction, and resource depletion. To aid the architecture and construction industry to move towards a post-carbon economy, this research investigates how surplus materials and agricultural by-products from quarrying and farming could be repurposed into building components for a new regional vernacular architecture. It hones in on methods and techniques for repurposing limestone surplus as a context, to ultimately advocate for transforming post-extractive stone and clay sites into material hubs for learning and making. These hubs aim to foster material sensibility, promote circular building practices, and support participatory self-build residential projects that empower communities towards self-resilience. The findings demonstrate what types of surplus there are, possible repurposing methods, and what sorts of regional architecture could be born out of such productive landscapes.

Keywords: *Repurposing waste, natural materials, bio- geo- construction, limestone, regional housing*

I. INTRODUCTION

1.1. Context

The global construction industry remains a major contributor to climate change and environmental degradation, responsible for approximately 39% of global energy-related carbon dioxide emissions, of which 11% arises from embodied carbon in manufacturing building materials such as steel, cement and glass (Global Alliance for Buildings and Construction, 2021). With annual material extraction surpassing 100 billion tonnes, the linear material flows dominating this sector perpetuate waste and inefficiency, resulting in only 8.6% of materials being reused globally (United Nations Environment Programme, 2024; Circle Economy, 2023). Additionally, global supply chains obscure the ecological and social impacts of material sourcing, transportation, and disposal, reinforcing systems that are disconnected from local ecosystems and communities (Moe, 2020). By integrating regional supply chains, repurposing waste, and fostering local resilience, the construction industry has the potential to redefine its role as a driver of ecological regeneration and sustainable development (European Commission, 2020).

Waste streams within the quarrying and agriculture industries provide huge quantities of material which could be redirected towards building material manufacturing, instead of mining for virgin resources. Stone quarries often produce an abundance of surplus materials as a result of the extraction, production, and manufacturing processes such as off-cuts, aggregates, powders and sludge. For instance, in the UK, limestone quarrying generates approximately 8.5 million tonnes of quarry waste annually, which represents about 11% of the total limestone production of 76.3 million tonnes (Ministry of Agriculture, Nature and Food Quality, 2007). In addition, the majority of land use in the Netherlands is dedicated to agriculture (Statistics Netherlands [CBS] and Cadastre, 2020), with an estimated generation of between 12 to 14 million tonnes of agricultural by-products annually (Green Chemistry, 2022) such as straw, hemp and flax. The surplus from agricultural and stone industries is often under-utilised, repurposed for unsustainable industries, burned or discarded. This raises the question: what if construction materials could be sourced locally and combined with industrial surplus or by-products to create a circular, rather than linear, material economy?

South Limburg, the southernmost region of the Netherlands, exemplifies the challenges and opportunities inherent in transforming post-industrial landscapes into regenerative systems. Historically characterised by extensive geological extraction and agricultural productivity, the region is home to extensive farmland and ex-mining sites such as the ENCI quarry in Maastricht. Once part of a an extensive limestone mining network and quarry and then a central hub for cement production, the ENCI quarry ceased operations in 2018, leaving behind vast reserves of limestone by-products and a scarred landscape in need of ecological restoration (Natuurmonumenten, 2023). This location also benefits from its proximity to significant agricultural activity, surrounding the sites periphery. These also take part in the EU initiative 'Contracts 2.0' which help to develop policy and incentives around farming and ecosystem conservation for farmers which could play a collaborative role in the transformation of the post-quarry into a regenerative material hub (Project Contracts2.0, 2024). The confluence of geological surplus and biological waste streams makes South Limburg a compelling case study for exploring new approaches to circular construction. The site's post-industrial context offers a unique opportunity to integrate permaculture-inspired design principles with the reuse of local resources, transforming it into a productive landscape that contributes to both environmental and social sustainability.

The project aims to demonstrate how circular material flows through repurposing materials can reduce embodied carbon, reconnect communities with their landscapes, and foster a culture of care and repair. This integration highlights the critical need to link global imperatives with local solutions: while the challenges of climate change and resource depletion require systemic transformations on a global scale, these solutions must be tailored to the unique ecological, cultural, and economic contexts of specific regions. In South Limburg, the proximity of surplus resources to a population grappling with housing shortages underscores the potential for architecture to catalyse regenerative, community-driven development. The ENCI quarry, envisioned as a hub for regenerative materials, will serve as a prototype for how post-industrial landscapes worldwide can be revitalised to address both local and global challenges.

1.2. Research Questions

The overall research question for this paper is:

How can we make and assemble regional housing from collected and grown materials from quarry surplus and agricultural by-products repurposed into building components?

The sub-questions which will be discussed in order to address this question are:

1. What surplus/by-product materials can be found in stone quarries?

2. What methods and techniques can be used to turn stone surplus materials into building components for wall construction?
3. What are the architectural tectonics of such building systems?

II. Methods & Methodology

2.1. Case Studies, Tectonics and Techniques

The research comes in two parts, a case study booklet and a research paper, somewhat separate but connected in some ways by both informing one another. The case study booklet is the first research output offering a collection of exemplary contemporary residential architecture from natural building materials to demonstrate applications of surplus bio/geo materials. Throughout, the terms 'surplus' and 'by-products' are sometimes used interchangeably and they coincide with 'natural building materials' since I focus on repurposing materials of stone, earth, straw, and hemp, although it should be acknowledges that there are some specific differences, I will not be delving into those in this paper but focus on these categories instead. Each section starts with these general categorisations and some illustrations showcasing the processing and lifecycle involved for such materials. The housing examples chosen for each technique are from a predominantly temperate climate (with a few mediterranean examples) and collates information on the construction assembly steps through finding photos. The tectonics are next explored through drawings of nodes or fragments of each case, which dissect the assembly further into an easily understandable assemblage of tectonic categories, or language, such as compressing and screwing. This results in a sort of recipe for each component.

For the purpose of a more in-depth analysis, the research paper focuses on the context of the ENCI quarry in South-Limburg by discussing specifically repurposing with limestone surplus/by-products which include off-cuts, aggregates, lime powder, and sludge. Since repurposing such waste streams is not common practice, case study and methods/techniques sometimes take from non-repurposed limestone or other types of stone will also need to be used. These might remain unprocessed, in the raw found state of the material or repurposed by being reused ion further processing (such as low-grade found limestone power repurposed into lime). Since the overall agenda is to encourage the development of low-carbon building components and due to their favourable thermal properties, biological surplus (straw, hemp, flax, seagrass, etc.) which are biogenic (which offset any energy involved in the stone processing to carbon negative) will also be mentioned in showing how the combination of geological and biological materials (as unprocessed as possible) can help to generate a regional vernacular architecture with favourable aesthetic and technical properties. The motive is to push natural building materials back into the construction industry while moving towards a post-carbon future through demonstrating their effectiveness and to encourage architects and non-architects to adopt low-tech methods and techniques more, in understanding that, especially when it comes to housing, self-building with low-tech means is much more socially, ecologically and economically viable than high-tech means.

The techniques that I have chosen to focus on are aiming for a balance or the ability to be adapted for both industrial and non-industrial means, so that they are applicable to both small and large scale production of building components. This is key to ensure that the program is adaptable, in that the building component techniques can be self-built but also meets current trends in the industry, such as in being able to speed up laborious processes through the ability to build components off site or through the use of mechanised equipment.

A key component of the research methodology is the application of a tectonic framework to analyse the case studies. The focus on tectonics was deliberate, as it provides a means of evaluating the ease of construction and accessibility of these systems. The chosen case studies were examined for their ability to communicate construction processes and material use through clear, easily legible language and imagery. This approach ensures the findings are accessible to a broad audience, including professionals, community stakeholders, and the general public. By prioritising clarity and visual comprehensibility, the research aims to make the benefits of surplus materials and their repurposing methods more widely understood and adopted.

To summarise, the methods employed were case study analysis, tectonic analysis, node drawings, field research (though not mentioned much), literature study and desktop study. The point of departure was Material Cultures' research project in collaboration with ETH, 'Planting Buildings' (2023) which inspired the node drawings as a method for analysis and the Circular Construction Materials Architecture Tectonics research booklet by CINARK for KADK (2019) which inspired the tectonic alphabet developed. The main sources which I consulted in full to find built case studies were the Natural Building Materials S M L (2024) book edited by Sandra Hofmeister, the manual of Biogenic House Sections (Lewis et al., 2022) and the online database of DETAIL inspiration.

III. Findings

3.1. Materials

What surplus/by-product materials can be found in stone quarries?

Quarries are usually open-pit mines where natural materials like stone, sand, gravel, clay, or minerals are extracted for construction, manufacturing or other industries. They are classified based on the material they produce, such as stone quarries (e.g., limestone, granite, marble, slate), aggregate quarries (sand, gravel, crushed stone), industrial mineral quarries for such as for quartz and salt, etc. (Hill Street Quarries, n.d.). Rock is the most abundant resource on Earth in its liquid, vicious and solid states, which is also extracted in quarries, the method depends on the type of rock, its location and what it will be used for (Schulz and Schulz, 2020, p. 15).

Stone quarrying generates substantial by-products and surplus materials which are quire often repurposed in use for polluting industries such as cement and asphalt production. These include fine particles such as stone dust and clay sediments, water-based residues like cutting sludge (Oates and Du, 2016), and larger offcuts or irregular fragments from shaping and processing operations. Statistics show that in stone quarrying waste can be as much as 50% of the extracted material due to irregular shapes and "due to legislation issues and waste definitions, large, defective blocks are crushed and down-cycled despite the fact that their physical–chemical and mechanical properties are often defined as equal to raw material" (Foote, Kozminska, and Gjorgjievski, 2024; Carredu, 2019). A minimum amount of 9-10% of wet sludge is generated in dimension limestone quarries (Adão et al., 2024). Surplus materials, including rejected aggregates, overburden, and stockpiles of unused inventory, often accumulate "most commonly produced during screening and crushing processes and then stock-piled as excess product" (Blevins and Santmier, 2023). However, they can also be leftover once a quarry site is shut down once it has finished extracting its primary resource.

3.2. Techniques & Methods

What methods and techniques can be used to turn stone surplus materials into building components for wall construction?

> RAW STONE / DIRECT REUSE (direct reuse of large off-cuts and aggregates) ~stacking

One method for repurposing stone from quarries is to directly reuse off-cuts in their raw state, either by cutting them to size or leaving them as irregular, and build walls up through the process of stacking. The stacking of irregular pieces is not common anymore but was once a common vernacular construction technique for building walls that is referred to as rubble masonry, which can be either dry-wall or mortared. Alternatively, off-cuts can be dressed (worked) by being pre-cut (with a machine) to size to create regular more standardised blocks for easier stacking or split/shaped using a chisel and hammer (by hand) to create much more custom block but requiring much more skill, usually involving a stonemason. The most common machines used to dimension stone after extraction from the quarry are diamond wire saws, block cutters, and bridge saws. The manual method is used for making split or 'squared stones'* so that the shape allows for a better fit when stacking the stone. While the methods of rubble masonry and processing the stone by hand and stacking takes more time and skill, it is much less expensive than using a machine and creates a much more characterful or rustic aesthetic when finished. However, since it may be tricky to find enough off-cuts of a similar size for dimension stone and/or rubble masonry, perhaps the easiest way to repurpose raw stone is to collect stone aggregates form the ex-quarry (or other locality) and create gabion walls, which simply involves boxing stones into metal cages, before stacking and clipping them in the formation of a wall.

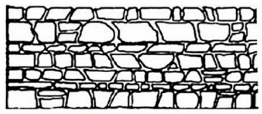
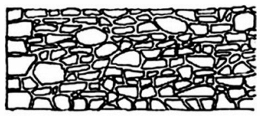
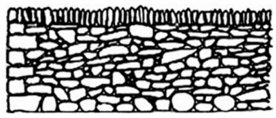
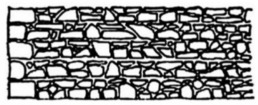
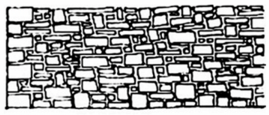
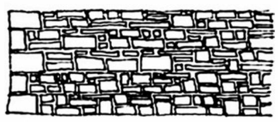
*please note that I am not talking about ashlar (meticulously chiseling each face) as this is overly laborious and expensive.

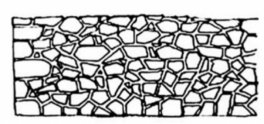
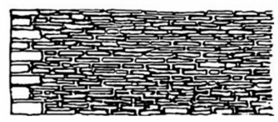
Rubble masonry *~stacking*

"The simplest forms of natural stone used as a building material are fieldstone and rubblestone….Like the larger boulders, it is found lying about in nature. In earlier times people would collect the easily transportable sizes and carry or cart them to the building site. Rubblestone results from the weathering of rock or from cutting work in quarries with no further processing. In contrast to fieldstone, it is distinguishable by its sharp fracture edges and irregular shapes." (Schulz and Schulz, 2020, p.14)

Stone can be shaped into regular, squared blocks or assembled using irregularly shaped pieces. Nowadays, it is most commonly used as a thin cladding panel or 'veneer' as decorative facing but traditionally stone was used as structural masonry or rubble masonry. Since stone walls exert significant pressure on the ground, the first crucial step in making a rubble wall is ensuring that the foundation and footings are sufficiently robust to distribute the load evenly is (Gunn, 2012, p.101). For house construction, laying the stones as found or quarried is common, with minimal shaping required to fit the stones in place (Gunn, 2012, p.107). It is best to trim around the face of the stone so that it is more rectangular in shape, with a flat top and bottom, or if not possible then when laying the stones the weight should be leaning inwards, towards the centre of the wall and not outwards (Gunn, 2012, p.107). When laying each course, the vertical joint should be centred to the centre of the stone below so that the weight is distributed evenly. A solid load-bearing or foundation wall can be built with or without mortar, but requires the most precise fit between the stones; along with flat faces, having a consistent height also makes this much more possible (Kennedy, Smith, and Wanek, 2015, p.164). When laying the stone, mortar can help to bind stones together and create a level base for each stone, eliminating the necessity for an exact fit between them whilst also sealing gaps, preventing airflow, and occupies space, reducing the number of stones required compared to a dry-stone wall (Gunn, 2012, p.107). A “traditional mortar mix is made of lime putty and sand. Modern masons often use a mortar of Portland cement and sand. Lime is a good addition to this mixture, as it slows down setting, making the mix workable over a longer time period; it also reduces the mortar’s brittleness.” (Kennedy, Smith, and Wanek, 2015, p.168). The exact proportions for the mortar mix vary vastly depending on the type of stone used for the construction but for limestone it is generally 1 part Portland cement, 3 parts lime, to 10 to 12 parts stone dust (see Gunn, 2012, p.214-217). In the case of using mortar, before placing a stone a bed of mortar should be plastered using a trowel before tapping the stone down into the mortar (Kennedy, Smith, and Wanek, 2015, p.168). This method, known as rubble stonework or rubble masonry, can be constructed using any type of stone, making it a versatile approach for building rough stone walls. For a further classification of the types of rubble walls, please see the table below (Table 1.).

Table 1. Types of Rubble Masonry.

Type	Description	Key Features	
Coursed Rubble	Stones are sorted by height and laid in horizontal courses, with each course having consistent	Neat and uniform appearance with courses differing above and below.	
Random Rubble	Irregular stones are fitted together without continuous courses. Through stones are used for strength, and bedding layers should	Highly variable shapes and sizes; susceptible to weathering if sedimentary stones are laid vertically.	
Dry Rubble	Random rubble laid without mortar, requiring high skill. Often used in barns or garden walls. Coping stones may be laid vertically for rain	Long-lasting if well-built; more suited to sheltered positions.	
Random Rubble Built to Courses	Irregular stones fitted so they form level beds at intervals of two to three stones high. Larger stones	Uses larger stones at corners for stability; creates a more structured look.	
Squared or Snecked Rubble	Stones of varying sizes are squared to provide vertical joints and level beds. Smaller stones fill	Equalises levels between adjoining stones; courses are not continuous.	
Squared Rubble in Courses	Irregular stones are squared and laid in horizontal beds periodically, similar to coursed random	Similar to coursed rubble but uses irregular sizes.	

Type	Description	Key Features	
Polygonal or Rag Walling	Irregularly shaped stones fitted together without straight courses, often used to fit a variety of shapes.	Flexible arrangement; avoids straight, horizontal courses.	
Bookleaf Walling	Small stones (approximately 75mm) laid in regular courses, often chosen for contrasting	Stones are of small size; regular and aesthetic finish with contrasting colours.	

Note: Table is based on the descriptions and uses the illustrations by Sarah Gunn in her book Stone House Construction (2012).

While constructing a rubble stone masonry wall is simple in that the material for it requires little to no processing, selecting and sorting the stone might be tedious and careful attention to technique is needed to create a well-built durable rubble wall. One way to ensure the stability and durability of a wall lies in the type of wall being constructed. Depending on the depth of the stone, it can be single leaf (one horizontal course for each layer) seen in 'Class A' in Figure 1, two facing leaves (two separate sources of stone on the inner and outer side) with or without a core of rubble and/or mortar to bind the layers and with varying levels of connection, but often being connected by mortar, ties, or through-stones, see 'Class B'. There are also three leaf or multi-leaf walls which are similar to the two leaf system but the third leaf is more distinct, see 'Class C' (Szabó, Funari, and Lourenço, 2023). Whilst strength of these walls depends greatly on the stone, connection and construction, generally one leaf walls are the most robust when constructed properly, as they have a single unified structure. If the found stone is closer to a boulder (rounded stone) it might be more suitable to employ casting techniques (discussed in the next section).

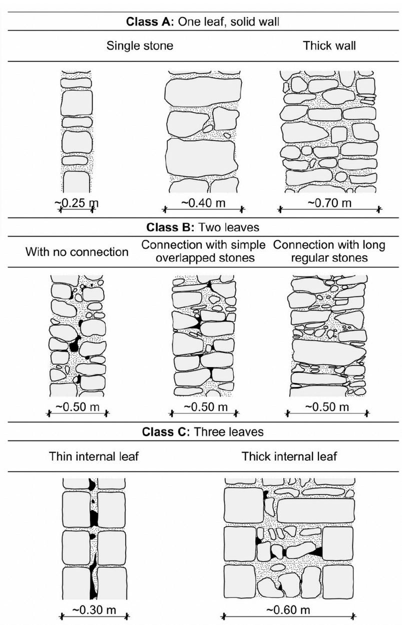


Figure 1. Types of of masonry wall sections, leaf classifications

Various houses in rubble masonry exist, though it is mostly historic examples so it is seen as an outdated way of constructing, it is still popular in rural areas (or places with strong cultural preservation) where well-constructed walls stand the test of time and are commonly renovated. In figure 3, the process of a group of friends constructing a single leaf masonry wall is shown, for the Jacobs House II which was designed by Frank Lloyd Wright and constructed between 1946 and 1948. Figure 4 left side shows a house in Chamoson, Switzerland with limestone rubble masonry standing strong since 1814, which was renovated in 2005 by Savioz Fabrizzi Architectes to include additional thermal mass of reinforced concrete behind, contemporary windows and a new façade formerly of timber weatherboarding. Another renovated example of local random rubble, also in Switzerland, is the Stone House in Ticino by Wespi de Meuron Romeo who removed the roof, restored the façades and a new prefabricated structure of timber and glulam was put in to divide and modernise the space inside (see figure 4 - right side). A new build by BC Architects (2019-2024) is Woodstock, a private house in the Ardennes which is built from local stone, timber and earth, according to the vernacular techniques native of the area of Wallonie. It is a collaborative process with masons, masons, craftsmen, artisans, and technicians (BC Architects, n.d.). Figure 5 shows some steps from the process of construction including the stone being collected from a local quarry, then sawed, and then in the process of constructing the two-leaf walls from it.

Figure 2. The Jacobs House 2 by Frank Lloyd Wright, under construction

Figure 3. The Roduit House Transformation, Savioz Fabrizzi Architectes (right) and the Stone House in Ticino by Wespi de Meuron Romeo (left)

Figure 4. Collecting, sawing and stacking stone for Woodstock by BC Architects

Dimension / dressed stone (by machine) *~cutting and stacking*

Processing of stone by mechanised means allows for further precision when dimensioning and is generally the process stone goes through for most projects today. Once the quarried stone is transported to the factory to be industrially processed, various methods can be used such as steel-shot abrasion or diamond saws (for 20-80mm thick slabs); taglia blocci saws (for stone tiles or long strips with a thickness of about 15mm); or gangsaws with circular blades or steel wires (for course slabs > 80 mm thick) (Hegger et al*.,* 2006, p.42).

A recent example from 2017 of dimension stone (using mechanised methods) is the Social Housing Project (17 social collective housing units) in Paris designed by Barrault Pressacco. The building uses a hybrid system combining different materials to optimise both thermal and structural performance. Massive load-bearing limestone facades of varying in thickness from 350mm at the base to 300mm above, supported by a steel frame and concrete porticos to the ground floor (Barrault Pressacco, 2019). To reduce load transfers to the façades, CLT is used for the floors. Hemplime insulates the building, a mixture of hemp shiv, lime and water, which has been sprayed from the inside onto the stone walls, before being troweled and coated (Pavillon de l'Arsenal, 2018, p.34). The Brétignac stone used is a type of limestone which originates from a local quarry called Sireuil Quarry in France. Photographs by Giaime Meloni taken for the *Pierre* exhibition, 'Révéler la ressource' (2018), capture some of the process for manufacturing, processing and assembling the limestone. First the stones would have been rough-cut to be extracted from the quarry (see fig.6.a.) and moved with a truck to be cut with a large circular diamond saw (fig. 6.b.) to become standardised components. The smooth, finished surface, suggest polishing or refinement, likely for aesthetic purposes in addition to improved fit within the façade. When transported to site the blocks are lifted into place with a crane (fig. 6.c.) and each stone is stacked within a layer of lime mortar (15mm) with temporary wooden spacers to align and level the stones so that gaps are consistent and to prevent uneven pressure (fig. 6.d.).

Figure 5. Key steps in construction of the Social Housing Project by Barrault Pressacco.

Whilst the project by Barrault Pressacco is an interesting case study, in the context of repurposing large off-cuts from disused quarries nearby, it might be tricky to source enough stone especially of such a large size, so a scaled-down approach might be needed. Alternatively, if only small aggregates are available, then it would be much more relevant to use gabions for repurposing the stone for constructing walls.

Gabions *~boxing and stacking*

Gabion technologies are retaining structures and the most practiced type of reuse of stone waste from quarries. Gabions are (generally steel) cages filled with an assortment of stones stacked one by one to form a unified structure, such as a wall, with each cage securely linked to the next using wire or small steel connectors (Souza, 2019). They are typically classified into three types, box, mattress, and bag, distinguished by its unique shape and dimensions, tailored to suit specific construction needs (Souza, 2019). The illustration (fig.1) shows the process for making the individual components. "[Gabions] have been used for centuries in civil engineering and landscaping works, but their first use in a building was in 1994 when Ian Richie used them on his arts centre in Terrasson, France" (Hegger *et al.,* 2006, p.110). Historical records reveal that mats and woven vegetal baskets were employed by ancient Sumerian, Babylonian, and Egyptian civilisations to transport and stabilise piles of stones and soil. In modern history, this technique evolved for use in military and water infrastructure, incorporating wire containers (Bischof, Gebert, & Hutter, 2020, p.7-8). Gabions can be made in situ/prefabricated and can contribute to quarry reconversion since they are excellent at retaining large masses of loose rock.

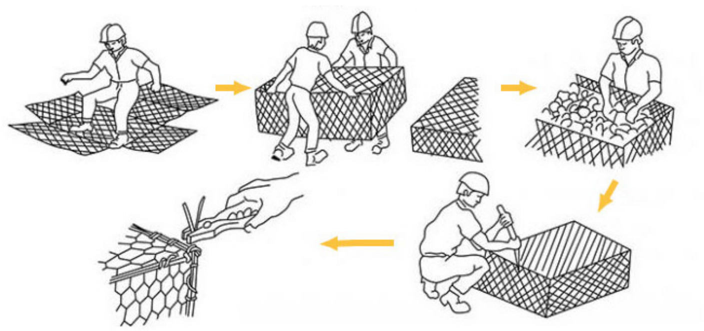


Figure 6. How to make a gabion cage

Within architecture and design, they are mostly used for landscaping, and although they are less common in wall systems for architecture there are some interesting examples in housing design. When used they are typically used as an outer skin attached to a concrete structure behind. For example, for the House in Stadtbergen, Germany (also called 9x9 House) by Titus Bernhard and House in the Landscape by Kropka Studio in Zawiercie, Poland which uses gabion baskets filled with local limestone. There are also some examples such as the Stone House and Base Valley House in Japan, both by Hiroshi Sambuichi, and Base Camp retreat in Washington, U.S. by Johnston Architects which integrate them into a wood-frame structure, but again not as the main load-bearing structure. Another example is the ZEB Pilot House in Norway, by Snøhetta and others such as Scandinavia's largest research body SINTEF, who incorporated gabion stone cages mainly with the function of providing good thermal mass to this zero emission building.

> *CAST STONE WALLS (new mix using powder/sludge poured in formwork filled with stone/aggregates) ~casting*

A more processed method for repurposing the limestone dust/powder and small aggregates leftover post-extraction, could be to process what is left into lime or to incorporate it into a new mixture for binding. Despite the inferred irony of this, (repurposing suggesting seeking a close to zero-carbon manufacturing process) combining it with, i.e. repurposed rubblestones or hemp and ensuring small-scale, local production mean that the manufacture process is low carbon, especially when compared with other much more processed materials such as concrete or steel. Also, in the case of biogenic materials such as hemp which sequesters co2 from the air as it grows, the co2 in generating the lime becomes offset, so much so that the combination means that the material composite's co2 becomes carbon negative. Or to avoid processing limestone into lime altogether, lime can be reused from buildings which are demolished; old lime mortar can be easily crushed and recycled for use as aggregate in new lime mortars (EcoRight, 2023) which highlights the closed-loop system of the material, reducing the need for virgin resources in new construction.

Formed masonry is a broad term referring to masonry techniques that use formwork to shape and support walls during construction. This method allows for the combination of stones, concrete/lime, or mortar within temporary moulds (forms). Various types of formwork can be employed, including timber planks fixed to a framework such as in the mosaic rubble method or formwork made in smaller sections which moves vertically along the wall, such as with the slipform method. The process can be summarised in 3 parts; (1) Stones or aggregates are placed within the formwork; (2) Mortar or concrete/lime is poured to fill gaps between the stones or layers; and (3) Once firm, the framework can be moved up to do the next section (planks/entire sections depending on formwork). Forms must be removed before the mortar is too hard, with excess being scraped off the stones promptly in the process using a wire brush, scrub brush and/or sponges (Gunn, 2012, p.120). The setting time can be anywhere from an hour (if quick-setting additives are used) to two days (Kennedy, Smith, and Wanek, 2015, p.170). Modular formwork systems are generally only a few courses high (around 600mm) and are designed to be demountable. By limiting wall lengths to modular constraints, the number of forms needed is minimised, streamlining construction and reducing material waste. The key advantage of this method over traditional stone walling is the efficiency and suitability for repetitive components, along with the reduced reliance on stone placement and quality, making it much more accessible and less labour-intensive.

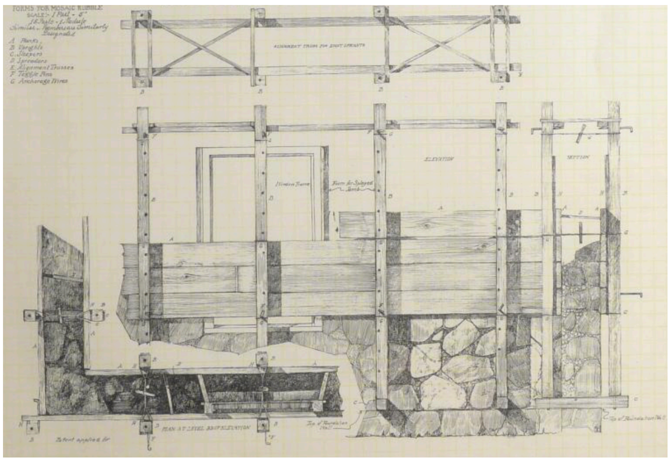


Figure 7. Illustration by Ernest Flagg of the mosaic rubble form in elevation, section and plan, featured in his book 'Small Houses: Their Economic Design and Construction' (1922. p.21).

Mosaic Rubble *~casting*
Architect Ernest Flagg (1857-1947) developed the 'mosaic rubble' technique in the 1920s, described by Sarah Gunn (2012) in her book Stone House Construction, explaining this type of formwork method as a simple and efficient approach to stone masonry since it is suitable for unskilled labour, requiring no nailing, and no waste (Gunn, 2012, p.120-121). After placing levelled footings and damp-proofing, greased timber sleepers are embedded in the masonry, which securely anchor 100mm x 100mm timber uprights with steel pins. These uprights are carefully braced both horizontally and vertically to ensure precise alignment and create a stable framework (see figure 7). Wooden planks, typically 150mm high, are layered to guide the placement of stones, which are set flush against the outer edge, before concrete is shovelled in. As construction progresses, the planks are gradually moved upwards and an uncovered face can be cleaned and joints can be pointed (filled with lime-mortar), or as Flagg suggests gaps filled with fine stone chips for a more refined finish. Openings for doors and windows are added using full-width (of the wall) forms and splayed so they can be taken out after. Door and window frames are then set in place and supported by wall ties.

Figure 8. Photo/illustration of slipform (Nearing, H. and Nearing, S., 1990, p.326)

Slipform *~casting*
Helen Nearing (1904-1995) and Scott Nearing (1883-1983) were pioneers of the slipform stone masonry movement, building on the work of Ernest Flagg. They developed a stronger concrete mix of 6 parts gravel, 3 parts sand, and 1 part cement, which, although weaker than modern standards, has stood the test of time (Elpel, n.d.). Additionally, the Nearing's replaced Flagg's lightweight plank formwork with more robust forms measuring approximately 1,825 mm long and 410 mm high, constructed from lightweight spruce or pine for easier handling (Gunn, 2012, p.121).The Nearing's' method involves laying a two-inch bed of mortar, placing stones with flat faces against the forms, and pouring concrete around the stones while ensuring the mix does not stain their exposed faces. Reinforcement, such as rebar, scrap iron, or barbed wire, is added incrementally to strengthen the structure (Elpel, n.d.). After 48 hours, the forms can be removed and 'leapfrogged' upwards (see figure 8), allowing continuous wall construction without the need for extensive more fixed formwork as with Ernest's technique. The slipform technique was further developed by Karl and Sue Schwenke for use in their own stone house which they documented each step of the process in detail in their book 'Build Your Own Stone House: Using the Easy Slipform Method' (1991). They felt that a maximum size of 2.4 m x 475 mm was most comfortable for handling, framed with 100 mm x 50 mm top studs at 600 mm centres

and faced with 25 mm thick boards with a 12 mm gap between them (see figure 9, left). When put together the formwork is kept apart using twisted, pulled and taught steel wire anchored to bent nails that act as an anchor in the forms, with added bracing using timber spacers (see figure 9, right).

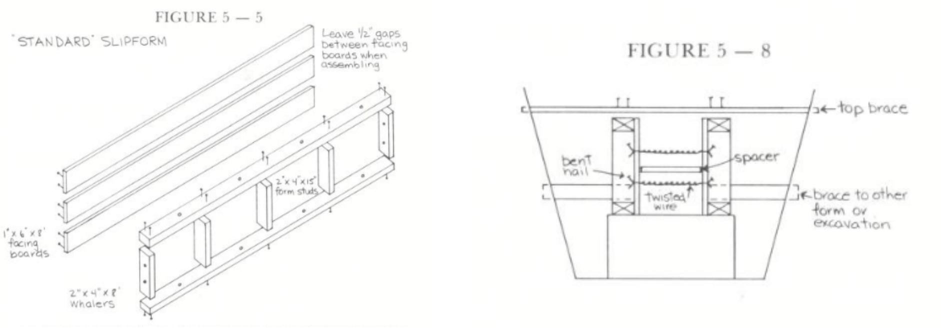


Figure 9. - Illustration of how to put slipform form together (left) and a section showing the spacers, wire and bracing (right)

Stone aggregates and lime *~casting*

The Casa 1413 House, in northern Catalonia Spain, designed by Harquitectes (2014) and constructed 2016-2017, is built using the technique of casting using slip-form masonry which they poetically describe as “a mixture between adobe and cyclopean” (H Arquitectes, n.d.). It is built using 1 metre thick entirely load-bearing walls that reuse stones from an old stone wall that demarcated the site previously which were cast in formwork using a mix of lime, cement and aggregate from the site (see fig. 10.a.). What is unconventional is their use of particles of recycled expanded glass added to the mortar mix to enhance insulation. In a temporary formwork, the stones were placed and the mixture poured (fig. 10.b.), before being tamped and smoothed (fig. 10.c.). As each layer dries the formwork is moved up, and once dried the formwork removed. The exterior surfaces facing the street were chipped away at with a bush-hammer to expose the rubblestone, providing a textured finish, while the interior surfaces retain the formwork's imprint. See the diagram below (figure 11) for a full step-by-step illustrated process of the wall construction method.

Figure 10. - Photos showing the process of making the Casa 1413 stone rubble cast walls

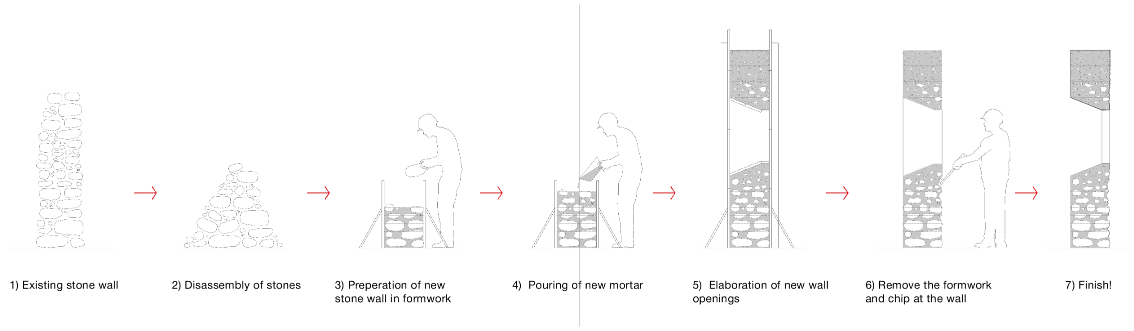


Figure 11. - Diagram showing the steps for making the Casa 1413 stone rubble cast walls

A variation on this technique was used for the ‘17 temporary housing units: Alacant 19’ project, designed by Taller11. It is a co-housing development, located in Sant Ferran, Formentera, Balearic Islands, with construction ongoing since 2022. This example is also made through cast in-situ formwork, but it features a combination of lime and stone walls as well as lime-cast walls that are reinforced with *posidonia* fibres (Neptune seagrass). Figure 12 shows the steps for the structural walls made with lime concrete, recycled aggregates from the excavation, and other excavation waste from landfill sites (Márquez Cecilia and Levene, 2023, p.307). The lime mortar and *posidonia* mix were subjected to workshops and testing to check performance, giving the conductivity and resistance required. Neptune grass offers a low thermal conductivity of approximately 0.043 W/mK, making it effective in reducing heat loss. Additionally, it possesses inherent flame-retardant properties, classifying it as a "poorly flammable" material (building material class B2) (Haute Innovation, 2010). Its resistance to decay, owing to minimal protein and salt content, further enhances its durability in construction applications.

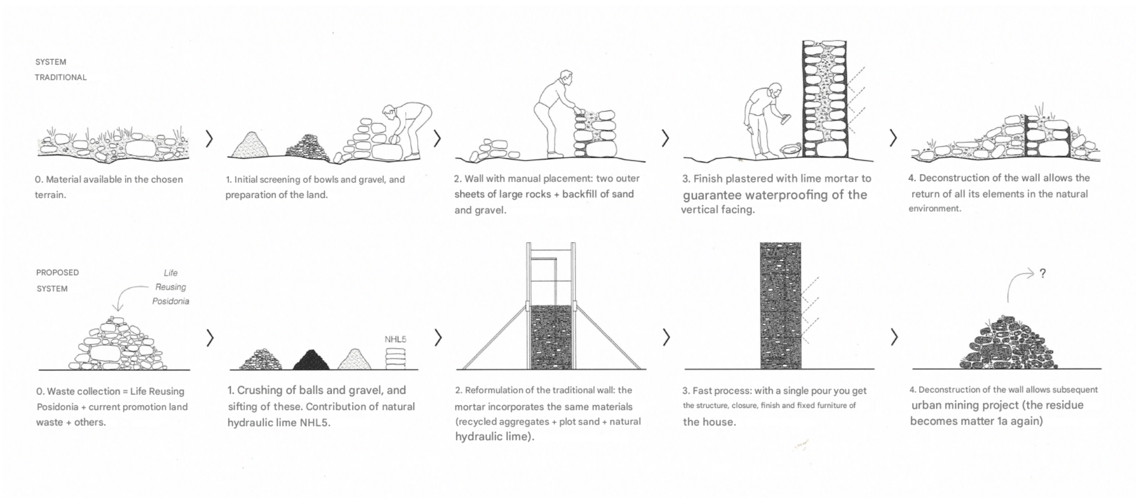


Figure 12. - Diagram showing the traditional stone masonry technique (above) and the proposed casting technique (below) for the ’17 temporary housing units’

It should be mentioned that both of the projects above were designed for The Balearic Social Housing institute (IBAVI) which is a public body established in 1986 for the government (housing ministry) to develop social housing. IBAVI regularly design regional, low-cost and low-carbon beautiful architecture incorporating vernacular methods in contemporary ways and with locally sourced materials such as seagrass, limestone and clay bricks or through using urban mining strategies to repurpose byproducts/surplus from industry. “They work to demonstrate the feasibility of using pre-industrial products such as Neptune grass (*Posidonia oceánica*) and lime concrete” whilst “making buildings that appeal to local people who identify with the architecture and materials at a culturally visceral level" (Bates, 2023, p.349; p.351). The "bedrock" of much of their project is Marès sandstone, native to the islands (Bates, 2023, p.353) which is similar to the marl sandstone abundant in the Limburg region. Even though the Mediterranean climate is quite different to the temperate climate in the Netherlands, where the ENCI quarry is located, the techniques can be adapted such as by increasing the amount of insulation that is used in the walls. In terms of protection from weathering, there might need to be more protection coated on the stone and larger coping or overhang, with footings that ensure protection from water.

The casting techniques mentioned so far are cast-in situ but there is also the possibility to pre-fabricate cast elements off-site first, in factory or other setting so that the manufacture process can be more controlled and construction on site is sped up through the process of stacking. Such an example of pre-cast repurposed stone and aggregate cast blocks can be seen in the Social Housing 2104, by Harquitectes. Approximately 140 m^3 of ceramic and concrete fragments were reused as fill for foundation pits and 160 m^3 of sandstone (whole Marès stone) was recycled into 1,700 large lime concrete blocks, each incorporating up to 40% recycled sandstone. These prefabricated blocks, measuring about 135 cm in length and 42 cm in height, have varying widths per floor (70, 60, 50 or 40 cm) and are stacked to form the load-bearing walls of the building (Harquitectes, 2021). Casting through formwork in combination with stacking offers a great solution for repurposing stone for walls in a reasonably quick and easy way. The next section, 'block forming' will delve deeper into the concept of making through smaller units, with a focus on the binder that stabilises the mixture.

> BLOCK FORMING (lime, powder and sludge, combined with earth or plant fibres) ~stabilising in mould casts or mechanical press

Whilst there are many different ways to repurpose powder and sludge from quarries into stabilised blocks, a lot of the common methods used today are highly carbon intensive—cement-stabilised blocks, autoclaved aerated concrete (AAC), and calcium silicate bricks (CSBs)—there are also some key methods which do not involve such polluting processes which use lime as a stabiliser and are equally effective for use in wall constructions. These can stabilise earth or plant fibres, such as in the forming of hempcrete, hopcrete or earth blocks. The two methods I will focus on are lime stabilised compressed blocks or compressed stabilised earth blocks (CSEBs), unfired compressed earth blocks (CEBs) and the more traditional adobe moulded blocks.

Lime stabilisation is a widely used technique to help bind materials together through chemical reactions which enhance the physical characteristics of soil, and can be combined with plant fires for enhanced reinforcement or insulation (or to make blocks more lightweight). The Romans pioneered the use of pozzolanic reactions, would blend volcanic ash with lime to produce *opus caementicium*—an early form of concrete that incorporated natural and quarry-derived materials for monumental architecture like the Pantheon in Rome. Similarly, ancient civilisations in Egypt and Mesopotamia added organic fibres such as straw to clay bricks, enhancing their durability and thermal performance—practices still mirrored in compressed earth blocks (CEBs) today. It long been used for construction to improve strength, porosity, and weather resistance of adobe bricks and rammed earth (*pisé de terre*) which was a method of construction developed by the Portuguese in the 16th century (Holmes and Wingate, 1997, p. 152). When used with clay minerals, lime first replaces alkali ions like sodium and potassium, reducing plasticity, and later forms calcium silicates and silica gel, akin to Portland cement (Holmes and Wingate, 1997, p. 152). These newly formed compounds significantly increase the soil's strength, decrease its plasticity, and improve its ability to compact effectively, making it an ideal material for various construction applications (Thorpe, 2023). There are various methods that highlight the flexibility of lime as a stabilising agent.

In the chemicals process, lime interacts with clay minerals, reducing soil plasticity and liquid limits, which makes it easier to compact and more resistant to water. For soils with high clay content, lime works effectively as a stabiliser, often supplemented with small amounts of cement for immediate stability, while lime provides longer-term strength. Both quicklime and hydrated lime can be used, although care must be taken to ensure no unslaked lime remains (Holmes and Wingate, 1997, p. 157-158). The recommended lime content ranges between 3% and 10%, depending on soil type, with higher clay content requiring more lime. Proper moist curing, ideally for 14–28 days, is essential to achieve strength (Holmes and Wingate, 1997, p. 153).

The preparation and use of lime-stabilised earth blocks can involve traditional and/or modern methods, such as using wooden moulds or mechanical presses to compact soil for reduced shrinkage and increased strength. One widely practiced method is manual mixing and moulding, suitable for small-scale or community-level projects. Soil is mixed with lime and then water is added gradually until the desired consistency is achieved. The mixture is then compacted into moulds to form individual bricks. These are left to cure in a controlled, humid environment for several days, allowing the lime to react with the soil and form calcium silicate hydrates and aluminate hydrates that enhance the bricks' strength and durability (National Lime Association, 2004). For larger-scale production, mechanised methods such as block-making machines are used. These machines press the lime-soil mixture into uniform blocks under high pressure, improving their density and durability. Mechanical mixers are often employed to ensure consistent distribution of lime and water. Once pressed, the blocks undergo curing processes, such as air drying or moist curing, to solidify their structural integrity (Natural Building Blog, n.d.). Incorporating pozzolanic additives like fly ash or volcanic ash into the lime-soil mix further increases the bricks' strength and water resistance (Construction Wiki, 2023). A more modern adaptation combines lime stabilisation with compressed stabilised earth block (CSEB) technology. In this method, lime serves as a stabiliser in a hydraulic press that compacts the mixture into high-density blocks. These blocks are then air-cured to achieve strength levels comparable to traditional fired bricks, without the high energy costs of kilns (Building Limes Forum, n.d.).

Hand moulded blocks (adobe) ~ *moulding and stabilising*
Manual mixing and hand-moulding represent some of the oldest methods of block formation. This technique is explained in detail in Holmes and Wingate's book, 'Building with Lime' (1997, p.159-160). The process for making lime-stabilised bricks involves thoroughly mixing earth, water, and sometimes straw, ensuring the mixture is free of lumps and left to soak for at least 24 hours. "Topsoil (containing organic matter) should not be included, and grains larger than 10mm should be removed by sieving" (p.159). Once matured, the moisture content should be checked, and then lime is added before compacting the mixture into moulds by hand. Skilled brickmakers can produce up to 1,500 small bricks per day. Bricks should be kept moist and out of direct sunlight for a minimum of 14 days, ideally 28 days, to ensure proper curing. After 1–2 days, they can be removed from moulds and stood upright on the ground or pallets. Proper stacking allows air circulation to facilitate drying, which takes about three weeks in tropical climates and longer in colder, wetter conditions. Bricks must be fully dried before use, which can be confirmed by checking for moisture inside. Defective or broken bricks can be crushed and reused in the mix, maintaining the same lime proportions as the original batch (Holmes and Wingate, 1997, p.160).

In the Gooik house project, BC Architects, in collaboration with Bree-Eik Eco-Farm, developed an innovative insulating material called ‘hopcrete’. This material repurposes hop vine fibres, a by-product of beer production, combining them with binders such as lime, earth, and/or alginate. Hopcrete mirrors insulation properties similar to hempcrete or light earth (BC Materials, 2023). Laboratory tests conducted by Buildwise demonstrated its thermal performance, with lime-based panels achieving 0.0751 W/(m·K) and earth-alginate panels achieving a thermal conductivity value of 0.0773 W/(m·K). These were used for the The project highlights the potential of using local agricultural waste combined with lime-based or alienate binders to create moulded earth block building components for wall construction.

Compressed earth blocks (CEBs) and Lime-stabilised compressed earth blocks (CSEBs) *~pressing and stabilising*

In the 18th century, François Cointeraux, a Lyonnais architect who was impressed by the use of *pisé* and so in 1803, Cointeraux developed a mechanical press based on the traditional wine press which led to the start of CEB technology, “a building component that had the versatility of brick but the social, economic, and environmental potential of rammed earth” (Rael, 2009, p.157). In 1952, the Centro Interamericano de Vivienda (CINVA) was invented by Colombian engineer Raul Ramirez. Cinva-Ram has a steel box with a base that is filled with soil and a lever, once released, the lid can be removed and the lower plate can be raised further to extract the CEB, which can make up to five hundred blocks a day Rael, 2009, p. 157).

Lime-stabilised compressed blocks are an effective and durable alternative to traditional building materials, produced using either manually operated or motorised presses. These presses require a drier mix compared to hand-moulded bricks, enabling immediate removal of blocks for curing. The production rates vary significantly, with manual presses yielding 300–1000 blocks per day and motorised presses exceeding 2000. The optimal mix composition consists of 45–75% sand, 15–30% clay, 10–25% silt, and 3–10% lime (Holmes and Wingate, 1997, p. 160). When using dry hydrate as a stabiliser, it should be thoroughly mixed with the dry soil before water is gradually added to achieve a moisture content of 7–16%. A short waiting period of 1–3 days allows the lime to react with the soil prior to compaction (Holmes and Wingate, 1997, p.161).

Curing is a crucial for achieving block strength, requiring blocks to be kept shaded and moist for at least 14 days, ideally extending to 28 days, to allow pozzolanic reactions to occur. During the first week, blocks should be sprinkled daily to prevent them from completely drying up. Production efficiency is influenced by block size and workforce, with manual presses typically producing 350–500 blocks daily. Standard block dimensions are approximately 290 × 140mm, with interchangeable mould options for varied shapes (Holmes and Wingate, 1997, p.161). Once cured, lime-stabilised compressed blocks are robust and can be laid using lime:soil mortar (9:1:2) or lime:cement:soil mortar (8:1). Lime in the mortar enhances plasticity and minimises cracking, while tight mortar joints of less than 10mm ensure stability (Holmes and Wingate, 1997, p. 162). Stabilised walls are often coated with a thin lime-based render or finish for weather protection for added durability and aesthetic consistency.

The compressed earth blocks (CEBs) used in the 43 Viviendas Sociales project, also called ‘Raw Rooms’ in Ibiza were produced using a mechanical process to compress the earth and were stabilised using lime. Manufactured by GLS Prefabricados and marketed by FETDETERRA in Catalonia, the blocks were composed of a specific mix of soil, non-expansive clay aggregate, and lime. This mixture was subjected to hydraulic compression using machinery similar to that employed in concrete block production (Anderson, 2023). The resulting blocks measured 10 cm by 12 cm by 20 cm and weighed less than 4 kilograms, facilitating manual handling during construction. After compression, the blocks underwent a curing period of three to four weeks to achieve the desired strength and durability. Once cured, they were transported to the construction site in Ibiza, where they were stacked to form 20 cm thick load-bearing walls without the need for heavy machinery. This method not only reduced the carbon footprint of the construction but also provided high thermal inertia and acoustic comfort for the social housing units.

CEBs offer several advantages over traditional mud bricks and rammed earth. One key benefit is their ability to be mass-produced at various scales, enabling their use as a commercially viable product (Rael, 2009, p. 157). The standardisation of CEBs allows for more accurate cost estimation. Unlike mud bricks, which can take weeks to cure, CEBs can be handled immediately after being pressed, significantly reducing construction time (Rael, 2009, p. 159). A single machine can produce a range of block sizes, offering flexibility, and advanced machines, such as those equipped with hydraulic presses, require minimal manual labor. Unlike rammed earth, which involves repeated compaction, CEBs are compressed only once, and the inclusion of stabilisers ensures higher compressive strength than mud bricks, making them both durable and efficient (Rael, 2009, p. 159). For all of these methods, perhaps the main advantage of using soil is that it can be sourced directly from almost any site saving carbon and cost for transport.

3.3. Tectonic Analysis

What are the architectural tectonics of such building systems?

To help to understand how these building components sit within the larger wall system, or 'skin' of the building, it is helpful to look to architectural tectonics through the lens of fragments. Tectonics can be defined as the relationship between form, structure and materiality and can help with further understanding how components are assembled through their meeting points or connections within the wider system. Based on this, I developed a tectonic language based on the methods I analysed to help to further break them down into simple terms that are the 'verbs' that catalyse their construction. I will focus on one technique for each of the three methods I discussed in the previous section; (1) dimension stone for raw stone / direct reuse *~stacking*; (2) formed masonry for cast stone walls *~casting*; and (3) compressed earth blocks (CEBs) for block forming *~stabilising*.

1. Dimensioned stone *~cutting and stacking*

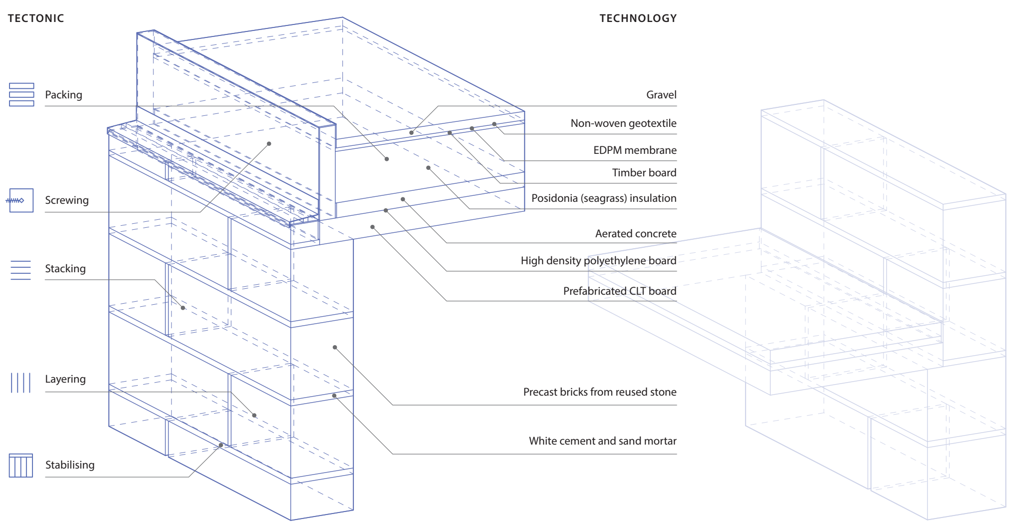


Figure 13. - Own drawing of node fragment for Social Housing 2104

Table 2. Tectonic Analysis Summary of Social Housing 2104

Social Housing 2104				
Category	**Criteria**	**Description**	**Score (1-5)**	**Comments**
Construction	Use of Natural Materials	Natural stone, CLT floors, seagrass insulation, concrete in lime mix and cement and sand for mortar, some synthetic materials in roof	3	Some materials are natural
	Use of Reused Materials	140m³ ceramic and concrete fragments for foundation, 160m³ of sandstone for blocks	3	Repurposed rubble from the preexisting building comprises 40% of each block
	Low Degree of Processing of Materials	The mix is processed but the stone is not. Processing is mostly in vibrating, levelling slab and then cutting to make the blocks	2	The combination of various techniques mean the processing is more than it is for casting in formwork in-situ
	Constructibility of Components	Forming slab moulds, placing stone and pouring mix, waiting 10 days then cutting	3	Relatively simple, requiring small team and some mid-scale machinery (concrete pump and circ. saw)
	Ease of Assembly	Stacking and laying mortar is fairly simple but the size of blocks means use of crane necessary for lifting	2	The assembly would have been much simpler if blocks were downsized
Performance	Durability of Materials	Cyclopean concrete incorporating Marès stone is durable	4	
	Thermic Properties	Stone provides good thermal mass	4	Cyclopean concrete and Marès stone are durable materials
	End-of-life-potential	All the main materials can be reused/recycled	3	Could be difficult to separate some parts
Aesthetics	Clear Tectonic Composition	The design clarity and structure of the construction components are visually clear.	4	
	Visibility of Joints/ Connections	Mortar is visible	5	
	Standard dimensions	Varying widths per floor (70/60/50/ 40cm) 135cm (length) x 42cm (height)	3	Somewhat standardised, varying widths customised to the specific structural needs of the project

2. Formed masonry ~*casting*

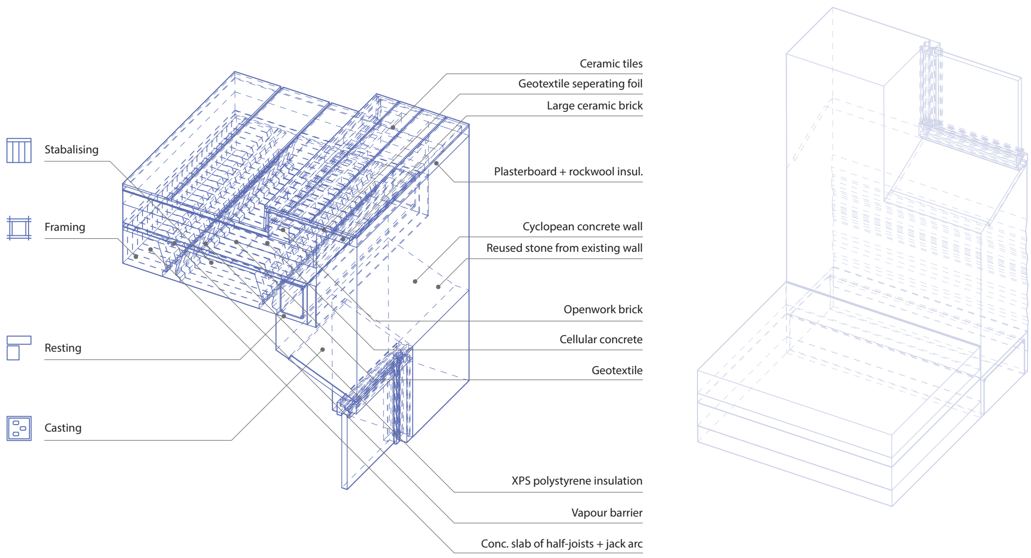


Figure 14. - Own drawing of node fragment for Casa 1413

Table 3. Tectonic Analysis Summary of Casa 1413

Casa 1413				
Category	**Criteria**	**Description**	**Score (1-5)**	**Comments**
Construction	Use of Natural Materials	Reused natural stone, the rest are quite manufactured (i.e. ceramic, brick, rock wool, etc.)	2	Some materials are natural but heavy use of concrete for roof structure, also some cement for the mortar mix for casting
	Use of Reused Materials	Reused stones from the old boundary wall, recycled glass particles and aggregates, sand .	4	Repurposed rubble from the preexisting wall plus found stone and recycled glass comprises over 50% (estimate) of the wall
	Low Degree of Processing of Materials	Roof materials are very processed, stone walls not so much but there is high portions of cement, concrete and other processed materials throughout construction still.	2	While there is prevalent percentage of reused and local material, theres more processed materials than not
	Constructibility of Components	Formwork is relatively simple to construct but requires a small team to construct, simple tools needed, no big machines except for walls	4	Relatively simple, requiring small team and little to no machinery

Casa 1413				
Category	**Criteria**	**Description**	**Score (1-5)**	**Comments**
	Ease of Assembly	Making framework, placing stone and pouring mix, curing and chipping	3	Fast setting time and reasonably easy construction. Chipping away at walls is laborious
Performance	Durability of Materials	Cyclopean and adobe technique enhances durability	5	Based on traditional masonry techniques known for their longevity
	Thermic Properties	Small particles of recycled expanded glass are added to the traditional mortar base to enhance thermal properties	4	High thermal mass
	End-of-life-potential	All the main materials can be reused/recycled	2	Potential to be reused/ recycled but not easy to dismount or sort
Aesthetics	Clear Tectonic Composition	Rough, rustic aesthetic of cast walls contribute to an interesting textural finish, with some variety of shades depicting composition	5	Technique is clear, seen on the rough markings of the walls and lack of 'joints' one monolithic yet human-scale wall
	Visibility of Joints/ Connections	Joints of wall to roof are visible, nothing is concealed	5	Lack of connections in wall but the rest can be seen clearly
	Standard dimensions	Non-standard for cast wall (although perhaps also not applicable)	1	Design is non-modular, it is highly bespoke, with little control over output

3. Compressed earth blocks ~*compressing, stabilising and stacking*

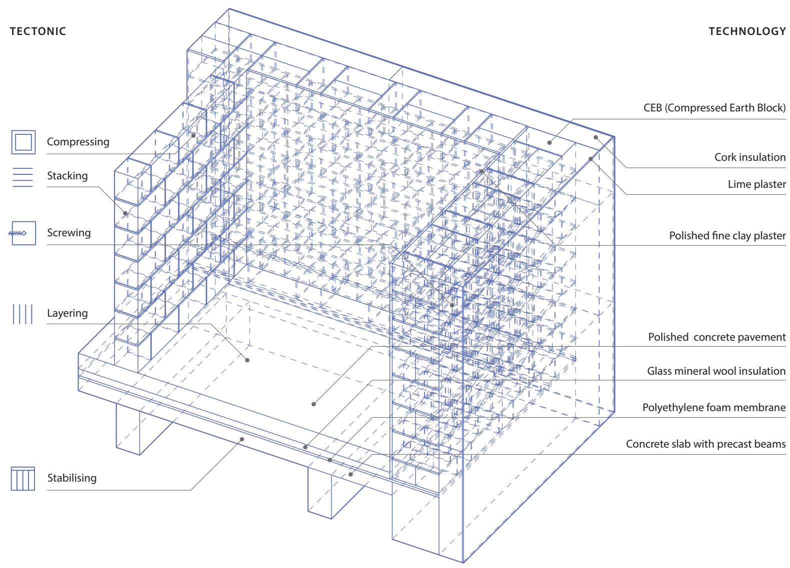


Figure 15. - Own drawing of node fragment for Raw Rooms

Table 4. Tectonic Analysis Summary of Raw Rooms

Raw Rooms				
Category	**Criteria**	**Description**	**Score (1-5)**	**Comments**
Construction	Use of Natural Materials	Mostly used local soil and lime is also locally sourced, cork for insulation, clay plaster finish	5	Earth is predominant construction material
	Use of Reused Materials	No mention of reused materials	1	Whether soil is considered a reuse of material is subjective
	Low Degree of Processing of Materials	Mostly unprocessed, except for the concrete floors and membranes	4	Unfired earth required almost no processing, I is pressed and stabilised
	Constructibility of Components	Manual steel dry press is very simple way to make CEBs. Block mixture was designed specifically for this project.	4	Manual press allows for easy fabrication while not being too high-tech
	Ease of Assembly	Manual steel dry press prefabrication of CEBs allows for easy and quick construction on site, the long length of time is more in that the bricks are small	5	Lightweight (under 4 kilograms), make for easy handling and and stacking without heavy machinery
Performance	Durability of Materials	They are protected from elements by having cork insulation to outer side and lime coating (weather resistant)	5	Stabilised with lime to ensure durability of CEBs, outer protection
	Thermic Properties	Earth blocks have moderate thermal mass. Cork is an excellent insulator and lime plaster coating is breathable	4	Cork thermal conductivity, typically around 0.037 to 0.040 W/mK (low) means it restricts heat transfer
	End-of-life-potential	Materials can be reused/ recycled with ease	5	Easy to sort as materials are kept separate
Aesthetics	Clear Tectonic Composition	From the inside the blocks are clear but the lime render on outer face hides cork insulation behind	4	CEB walls and concrete floors visibly supporting the building.
	Visibility of Joints/ Connections	Clear to see mortar between blocks, connection of cork insulation panels not visible, exposed soffit shows floor	4	Raw aesthetic allows the details to be seen. Fine clay plaster to inner side to make use of CEBs hygroscopic properties
	Standard dimensions	Standard sizes of 10 x 10 x 20 CEBs	5	manufactured by GLS Prefabricados and marketed by FETDETERRA

Table 5. Tectonic Analysis Summary - Comparison

Score Comparison				
Category	**Criteria**	**Social Housing 2104**	**Casa 1413**	**Raw Rooms**
Construction	Use of Natural Materials	3	2	5
	Use of Reused Materials	3	4	1
	Low Degree of Processing of Materials	2	2	4
	Constructibility of Components	3	4	4
	Ease of Assembly Process	2	3	5
Performance	Durability of Materials	4	5	5
	Thermic Properties	4	4	4
	End-of-life-potential	3	2	5
Aesthetics	Clear Tectonic Composition	4	5	4
	Visibility of Joints/ Connections	5	5	4
	Standardised Components	3	1	5

III. Conclusions

This study highlights the potential of repurposing surplus materials, offering practical solutions to the construction industry's pressing ecological challenges by drawing insights from material availability, techniques, and architectural applications. It begins by identifying the abundance of unused resources found in stone quarries—off-cuts, aggregates, and sludge—that are often discarded but could replace virgin materials (section 3.1.) before exploring practical methods for transforming these materials into building components. Section 3.2. includes techniques like raw stone stacking, gabions, cast stone walls, and compressed earth blocks. These approaches range from low-tech, labor-intensive methods to scalable, industrial processes, highlighting flexibility in their application. The integration of geological and biological materials, such as combining limestone waste with plant fibres, further enhances the performance and sustainability of construction components. The final section (3.3.) evaluates the architectural implications of these systems through tectonic analysis, comparing their construction, aesthetics, and performance. All in all, the study demonstrates that despite often being considered waste, by-product and surplus materials can yield durable, visually striking building systems with clear tectonic compositions. Together, these findings provide a holistic understanding of how surplus materials can be repurposed into functional building solutions.

The research offers a blueprint for transitioning the construction industry toward circular practices, emphasising that local resources and simple techniques can drive global change. By transforming waste into opportunity, the study bridges ecological, economic, and social goals, advocating for a regenerative future in architecture.

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Figure 3 (left) - Laurent Savioz Architecte (2007) *Umbau eines Wohnhauses in Chamoson*, DETAIL, Issue 5, pp. 500-504. Photos by Thomas Jantscher; Figure 3 (right) - Wespi de Meuron Romeo Architekten (2019) *Steinhaus im Tessin (Stone House in Ticino)*, DETAIL, Issue 11, pp. 52–59. Photos by Albrecht Immanuel Schnabel.

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Figure 13 - Own drawing of node fragment for Social Housing 2104

Figure 14 - Own drawing of node fragment for Casa 1413

Figure 15 - Own drawing of node fragment for Raw Rooms