Studies on Assemblies

Laboratory EAST

Mass Made Units

Studies on Assemblies: Mass Made Units

Laboratory EAST

ENAC Institute of Architecture
École Polytechnique Fédérale de Lausanne

Triest

Anja Fröhlich, Martin Fröhlich

Studies on Assemblies
An Investigation into Material, Construction and Tectonics

Every building is in essence a constellation of space-bounding elements. Different constructions have evolved for each of these over the course of history. For solid walls, for example, we can find, alongside rammed earth and reinforced concrete walls, numerous variants of dry and mortar-bedded masonry walls as well as hybrid forms such as post and beam structures with diverse solid infill materials. Our particular fascination is with wall constructions in which each distinct element of a wall assembly is discernible as a singular object.

Thinking in terms of building elements has existed since the beginnings of architecture as a means of creating structures that are quick and efficient to erect, take down or modify. The demountable architecture of the nomads or the stone block temples of the ancient Sumerians, for example, are as compelling today as innovative and appropriate solutions to sustainable building as they were thousands of years ago. Today, however, the space-bounding elements of a building have evolved in response to changing demands and increasingly complex technical, material and energy-efficiency requirements into multi-layered systems.

In *Studies on Assemblies*, we critically examine how materials are put together from an architectonic viewpoint. As part of ongoing research at Laboratory EAST into understanding the interdependencies and conditions of different construction methods and assemblies, we seek out and explore adaptable construction solutions. Of interest to us is not only how architectonic elements are joined but also how construction, thermal mass, zoning and materiality are interrelated. Each element is examined in terms of its specific function and contribution to the system of the wall. This approach aims to provide us with a curatorial means of appraising traditional and contemporary construction and fabrication techniques with a view to fostering responsible approaches to the use of materials and modular-elemental systems for the future.

Mass Made Units documents a study of solid, three-dimensional masonry structures created by stacking blocks or other prefabricated modular units. Each example reveals the specific rules of its construction in the context of the respective state of technological development and prevailing standards. The current state of the art prescribes a multi-leaf wall construction in which functions previously combined within a single wall – load-bearing, sheltering, insulating – are separated and fulfilled by individual layers, with steel anchors and wall ties acting as hidden connectors beneath the surface to ensure the integrity of the wall.

The first section of this booklet brings together theoretical reflections on the relationships between material, construction and tectonics. The ideas and insights presented here are the result of a conference and interdisciplinary discourse held at the EPF Lausanne. The contributions range from explorations into traditional and re-emerging uses of building materials such as unfired earth bricks to the central role of innovative material optimisations seen in the ongoing development of LC^3 at the EPFL. Further articles critically examine the suitability and application of different stone formats as well as the significant role of solid building envelopes. Corresponding examples of brick buildings from the region of Ghent and Leuven as well as of the use of massive stone blocks in a housing project in Geneva illustrate these diverse perspectives and insights and broaden our understanding of the many facets of unit-based masonry construction.

The second part of this booklet presents selected architectural works analysed by the Design Studio EAST students under the title “Mass Made Units”. This graphical study of exemplary projects offers an instructive overview of both our object of study and the constructive and climatic relationships. It provides a means of analysis that allows us to compare similar systems and reveal how they have developed.

Part I

Theories

Stone as Protagonist

A

Marlène Leroux, Francis Jacquier

When James C. Scott introduced the notion of métis to anthropologist Jean-Pierre Vernant, he sought to define a theoretical framework for "domesticating the state" that was still inclined towards simplifications and the levelling of local mores. Indeed, it is necessary to organise in order to modernise. That is undoubtedly why scientific and technological knowledge replace practical wisdom. Yet nowadays we must question the relevance of systematically distancing ourselves from this form of wisdom rooted in praxis and experience. *Métis* here evokes the idea of cunning, in the sense of all the ways in which an individual can act astutely in a particular context. Instead of following established dogma, this form of intelligence is fluid, elusive, and sometimes disconcerting.

The approach we develop at Atelier Archiplein emerges from this position: one that is committed yet ready for constant adjustment, drawing on the concept of *métis*. Avoiding both militancy and blame-seeking, the aim is to explore alternative strategies that take into account historical, geographical and cultural aspects, as well as energy and environmental considerations – in other words, a low-tech, culturalist approach. This undertaking could not be developed without reflecting on the economic, legal and political framework that extensively influences the values behind building production today, while redefining the background conditions necessary for quality production.

The use of massive structural stone and wood emerges as one of the most convincing answers to the question of the durability of buildings, as the abundant historical heritage of our towns and cities can testify. The use of these natural materials is an invitation to formal modesty, sobriety in constructive thought and integration of the various technical devices in the service of a coherent architecture that is open to easy transformation. In short, the aim is to identify the conditions necessary for fair and far-sighted architectural practice, through a skilful combination of the valuable contributions of history and the performance of today's techniques.

"The monuments of the past withstand time, endure for centuries, even after their function has been lost and their raison d'être has been altered, transformed, or even forgotten [...] In this vast and deep repository of presences, so typical and recurrent in European and Mediterranean towns, stone is the protagonist. It is so present and widespread that it almost becomes a synonym of architecture."[1] We can but agree with the words of Luca Ortelli: stone is still synonymous with architecture, starting with the fact that we continue to talk about "laying the foundation stone" of a building. Yet it is almost fifty years since massive stone has been used in ordinary production, such as stone farmhouse buildings or residential buildings. The last such operations on any scale ended in the 1960s with, at least as far as is documented, the massive stone apartment blocks designed by Fernand Pouillon, of which those in Paris, Aix-en-Provence and Algiers offer the best examples.

Fig. 1. Stone quarry sourcing for the housing project in Plan-les-Ouates.

However, for a number of years now, massive stone construction has seen a veritable renaissance. Exhibitions, publications and training courses focusing on this material continue to multiply, making stone a hot topic among professionals and the general public alike. At the same time, a growing number of architects are demonstrating the economic and technical feasibility of using this material to its full structural potential. No longer confined to the restoration of historic monuments or purely decorative uses, stone has (once again) become a contemporary material, accessible to all.

Ecological Consciousness

The revival of stone construction today is based on ecological awareness, a commitment to reducing energy consumption and ecological footprints. The renewed interest in stone goes beyond its timeless mechanical and aesthetic qualities. It goes hand in hand with a widespread awareness of the environmental challenges to which we must all respond as a matter of urgency: increasing scarcity of raw materials, energy crises, and unchecked damage to our living environments. Like wood, earth and plant fibres, stone represents a virtuous alternative to synthetic materials. Geo-sourced, very little energy is needed to extract and transform the stone before it is used. Carefully treated, a block of stone can be used indefinitely, within the same building or recycled. The construction sector, which is currently responsible for 43% of annual energy consumption and generates 23% of France's greenhouse gas emissions, needs to radically rethink its production methods.

Stone has a clear role to play in this collective effort, as a precious and essential component of an environmentally friendly building culture. While there are multiple, interdependent pathways to reducing carbon emissions, the design and production of housing, whether new or renovations, plays a major role. A better appreciation of the various sectors helps to raise public awareness of the carbon footprint of our production and consumption choices, and engages us with architectural production and lifestyles that take resources and, more generally, ecosystem requirements into account. The great diversity of current approaches reflects a constant need for adaptation and micro-innovation in the face of normative hindrances and constraints, deaf to the specific characteristics of non-industrial materials, whether stone, wood or earth.

Fig. 2. Assessing a massive stone block at the quarry.

Stone is resistant to prescriptive frameworks and systems of evaluation, as shown by the article "The Hidden Value of Stone".[2] We could also pause to consider the issue of reducing embodied energy, as shown in Guillaume Habert's study. This confirms that, compared to buildings employing industrialised construction processes, a massive stone building presents an extremely low carbon footprint over 60 years of use and maintenance. This study is based on an analysis of the Résidence du Parc, a vast residential building constructed in massive stone by Fernand Pouillon. It should be noted that the authors underline the difficulty of assessing, over the long term, the scope of life cycle assessment, particularly in the case of a massive stone building: "The end of life of the different building elements is not taken into account, even though its inclusion in this case study would be a positive factor, since the blocks of stone used in the construction have the potential to be reused.” Indeed, although the question of the potential for re-use is not directly raised in this study, the authors naturally and poetically highlight one of the first “hidden values” of stone. The study then looks at the notion of stone’s invisibility from the point of view of its embodied energy compared with other materials. This long-term life cycle study also highlights the importance of energy performance and the ecological cost of maintenance. The authors conclude: “If the social aspect of stone is also taken into account through its reduced need for maintenance, then it is evident that the value of stone in the specific building is multifold.”

Fig. 3. The cutting of a stone block.

Bringing Periods and Knowledge into Dialogue

The relevance of building in massive stone today is not limited to ecological questions. The Covid-19 pandemic brought to the fore the fragility of certain sectors of the economy due to their dependence on heavily processed products. The construction sector was severely impacted as a result of its long and complex supply chains. Choosing stone as a structural material makes it possible to evade such risks. The product of geological processes, stone is already available in the ground, in abundance and close to the surface. There is no need for chemical alterations to improve its intrinsic properties. After extraction, a few simple cutting operations are all that is needed to make a rough block ready for use. The massive stone buildings left behind by different epochs of human history stand testimony to a long legacy of know-how relating to the extraction, transformation, assembly and maintenance of this material. Far from adopting a nostalgic stance, we want our work today to be part of the continuity of these experiences, while maintaining a reflective approach to them. By comparing technical resources with current requirements, and with the support of skilled craftsmen, we are contributing to the development of solid stone architecture that expresses the spirit of the times and is economically realistic.

While many types of industrial materials are condemned to remain either inert or to degrade over time, stone by contrast acquires a patina that further enhances its beauty. Attractive to the gaze, it also invites touch, and is a material that bears an identity. In reality, the ability of an object to withstand time arises from its capacity to arouse emotion, and the feeling evoked by a stone building, whether it is a fieldstone bond or ashlar courses, is instantaneous. The act of building entails responding today to a building that will stand for a long time into the future and be viewed through the prism of as yet unknown social contexts. It’s clear that the timeframe of architecture can never be a single use: one lasts, the other changes, and that’s all for the good. How, then, can we construct buildings that sufficiently arouse the senses, generate ample emotions and call on a shared culture to last the test of time?

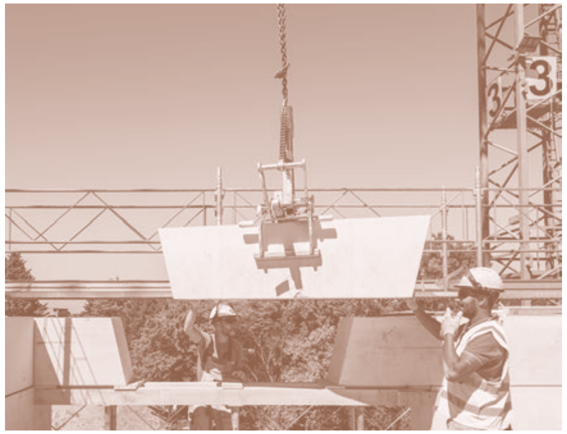


Fig. 4. Stone lintel assembly at the construction site.

Today, the durability of a building becomes all the more desirable with the common consensus around the need to save resources including raw materials, the soil, and energy. Even the most high-performance industrial materials are dependent on fossil fuels, while natural materials arise from a timespan that, however much we try, lie beyond our comprehension – whether it is the time taken for a forest to grow to maturity, or the geological time of a quarry. Reflecting this fact, a building ought to be built for all time, almost independently of its primary function. It should be able to withstand time and undergo whatever alterations are needed, or indeed be taken apart and reused in new constructions. We might think of the long history of the Cluny Abbey in Paris, for almost 400 years the largest building in Europe, until the French Revolution turned it into a vast quarry of ready-cut stones and it was dismantled to build the homes and farms of the region in accordance with the principle of spolia.[3]

Indeed, there was once a time when certain architectural elements such as columns, capitals and architraves were seen by the public authorities as a kind of moveable heritage. The need to preserve them extended beyond the lifetime of the building. As Lionel Devlieger of Rotor suggests in the context of Reverse Architecture: "This constant throws a completely different light on the inclusion, in paleo-Christian buildings, of fragments of ancient temples. Rather than a rupture with the past, the re-use established a continuity with it."[4]

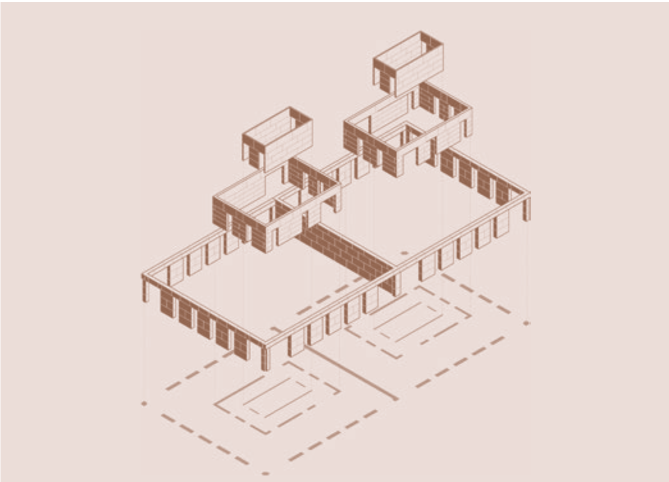


Fig. 5. Rings of load-bearing stone structural elements.

Four Residential Buildings in Massive Stone in Geneva

We turn to a project comprising 68 housing units in all categories (social housing, uncapped rental, and full ownership) for the municipality of Plan-les-Ouates (GE), in the Sciers District. The result of an SIA 142 competition, the four buildings had to occupy large footprints (21 m), with two buildings adjoining each other. Made entirely of solid stone blocks, the buildings have no vertical load-bearing concrete elements. In both the communal areas and the flats, the load-bearing stone structural elements are left in their raw state. The blocks used for the walls, measuring 190 × 80 cm, are left rough-sawn, imposing their format, invoking the actions involved in their installation, revealing the traces of the saw and, above all, revealing the various ancient forces that first formed them.

Beyond the choice of construction systems and materials employed, the question of how light reaches the interior of the buildings is key. Slightly offset, the internal structural elements converge at the centre, maximising the surfaces beside the window voids. Rigorous in appearance, this structural composition frees the interior layout of the apartments from load-bearing structures. The 'serving spaces' unfold around the inner structural element, accommodating the entrance halls to each apartment and the wet rooms. Along the periphery, the 'served spaces' form a strip around 5 m in breadth, containing the living rooms and bedrooms, except where it is interrupted by corner loggias, which function as living spaces in summer. The bedrooms are directly connected to the living rooms, permitting a certain diversity of uses. These rooms can be transformed into a study or become an extension of the living room.

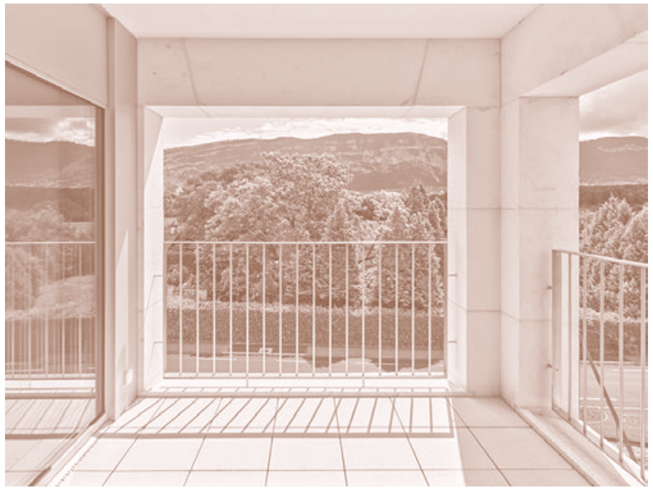


Fig. 6. A glimpse of the loggia, showcasing lintel and keystone.

The use of massive stone invariably calls for formal modesty, rational construction solutions and the use of a range of technical devices to achieve a coherent architecture. We focused on passive solutions, such as compactness and consistency in openings to ensure a good balance between visual openness and the risk of overheating in summer, and comfort in winter. The sobriety of the façades incorporates moulded elements that reflect technical requirements, such as the cornice that both directs water runoff away from the wall and casts a shadow that emphasises the different floors, or the handling of the building corners with a reflex angle. We could go into further detail about the technical aspects of the work, looking at the processes used to extract the stone, the rate at which it is laid, or the strategies explored to overcome seismic constraints, and further consider the issues of life cycles and insulation types.

But the challenge of using natural materials in contemporary construction goes far beyond technical, economic and even environmental issues.

Fig. 7. Massive stone construction: residential block in Plan-les-Ouates municipality.

A building's ability to endure over time, and to withstand changes in usage, stems above all from its capacity to appeal without being solely adapted to a specific purpose. It draws the user into a dimension that is more cultural and reflective than utilitarian and practical. Persuaded of its intrinsic value, the user will find ways to adapt and reassess the rules of generic use in favour of the well-being offered by a particular place. Or perhaps the user will make alterations to the building to find a point of convergence between contemporary uses and built substance. You can feel the roughness by touch, the irregularities revealed by raking light, the coolness or warmth that radiates from the solid mass of the material. During visits to the massive stone buildings in Plan-les-Ouates, it's not unusual to catch a visitor brushing their fingertips against one of the 10,000 blocks of stone, or marvelling at how cool the façades are despite the high outside temperatures. It is through the prism of this emotional experience that we should consider the potential of massive stone construction as one of the most credible ways to ensure a building's longevity.

1 Bruno Marchand et al., *Matières 14 – L'oeuvre et le temps*, Lausanne: EPFL Press 2018.
2 Guillaume Habert, "The hidden value of stone: Life cycle assessment of the construction and refurbishment of a 60-year-old residential stone building", in: Ruben Paul Borg/Paul Gauci/Cyril Spiteri Staines (eds.), *SBE 16 Malta: Europe and the Mediterranean Towards a Sustainable Built Environment*, conference lecture on March 17, ETH Zurich 2016, pp. 115–122.
3 Joseph Alchermes, "Spolia in Roman Cities of the Late Empire: Legislative Rationales and Architectural Reuse." in: *Dumbarton Oaks Papers*, vol. 48, 1994, pp. 167–178.
4 Lionel Devlieger, "L'architecture à L'envers", in: *Criticat*, 18/2016 autumn, 2016, pp. 90–101.

On Mass Made Units

B

Lieven Nijs

BLAF's architectural practice operates between two poles: engagement and building. For BLAF, both are imperatives, the necessary conditions for architectural practice: engagement is the origin of every architectural work, building the finality. Between the two is the battleground – the *dirty kitchen* – of design and realisation. Our research into the practice of building at BLAF [5] is an epistemic history of paradoxes,[6] positions, concepts, interdependencies and explorations – a state of confusion, if one so will, that has allowed us to constantly make new design decisions. Our research into wall constructions using brick masonry is a journey that developed out of the dozens of variations and optimisations of building facades that we tested in practice over the past 20 years.[7] Those variations can be broadly divided into four categories:

- Structures with lightweight internal structures and lightweight cladding
- Structures with solid internal structures and masonry facades
- Structures with solid internal structures and lightweight cladding
- Structures with lightweight internal structures and masonry facades

The evolution of our "Big Brick Hybrids" is rooted in the integration of three fundamental construction principles: timber (frame) construction, the implementation of cavity wall systems, and the principles of passive house design. In this article, we focus specifically on the cavity wall approach and its direct relevance to the "Big Brick Hybrids" development.

The Cavity Wall

Flanders prides itself on being a "brick region", and owes this moniker in part to the iconic historical buildings that have contributed to brick's reputation as a sustainable and local building material since the 13th century. Yet the "traditional" cavity wall, as we know it today in many European regions, is a relatively young concept. Although all indications suggest that the principles were already identified around 1850,[8] the cavity wall as a *building system* did not achieve more widespread adoption in our region until the 1950s, thanks to the rise of clinker based cement mortar. Between 1850 and 1970, the evolution of the cavity wall constituted mainly optimisations of the elements and their industrial production processes: the development of building foils, wall ties, anchors, mortars, forming and baking methods, formats, etc. All this time, however, the underlying building system remained unchanged. A major change only came about at the beginning of the 1970s. It is generally believed that the 1973 oil crisis prompted the widespread introduction of cavity wall thermal insulation, although it was resisted by the construction industry for a long time. Research from 1998 showed that even after the introduction of obligatory thermal insulation regulations in 1992, only a minority of new houses met the insulation standard.[9] Resistance to the increased complexity of implementation is often cited as a reason for the slow initial uptake of cavity insulation. Construction sequences and logistics needed to be changed, and generations of masons had to be retrained.

The invisibility of the cavity played an important role in the development of the cavity wall. For a long while, the precise functioning of the cavity remained a mystery to building physicists. Theoretical simulation methods were developed to visualise hygrothermal behaviour within the cavity, but despite considerable advances in the field, disclaimers are still often made about the results even today. The invisibility of the cavity also meant that it was typically hard to enforce or monitor the installation of cavity insulation. This only changed in 2001, with the obligation (in Belgium) to provide a post-intervention file detailing the materials and elements employed within a building for the health and safety of those undertaking future work on the building. Despite the problems attached to it, one might say that the invisibility of the cavity was also fundamental to its success. Despite the successive widening of the cavity to accommodate more insulation, and the accompanying growing complexity of the construction, the outward appearance of a cavity wall and the structural role of the facade masonry was left unchanged.

The structural role of the facing brick cavity leaf, adequately addressed as “the brick dress” by Jan Peter Wingender, lies somewhere between load-bearing and cladding. It is built by stacking bricks, and in this sense differs little from load-bearing structures. However, the slender width of the facing leaf means it cannot serve a true load-bearing function, and can even barely ensure its own structural integrity: it bears its own weight within the limits of what is possible, and is aided by fittings, such as wall ties, which transfer horizontal and vertical forces to the inner leaf of the structure.

Big Brick Hybrids
The Cavity Wall Is Dead

In 2014, BLAF observed that for the construction of highly energy-efficient structures, brick masonry was rapidly losing ground as the outer skin of a facade. We attribute this evolution to what takes place in the cavity. Ever thicker layers of non-compressible thermal insulation make structurally connecting the inner and outer leaves of cavity walls increasingly complex, expensive, error-prone, and thus pernicious for the longevity of the structure. The use of cavity ties, for example, creates hundreds of miniature thermal bridges, and is thus in some European energy standards no longer an option. The hybrid role of the brick outer leaf, between supporting and cladding, is no longer tenable. The alternative of using lightweight cladding materials for the outer skin is, however, in our opinion, disappointing in terms of durability and visual quality. The limited life expectancy of lightweight cladding materials leads to an erosion of the architect’s sense of responsibility for facade design.[10] At the same time, it has become apparent that the cavity wall has reached the limits of its practicability and performance.[11] The cavity wall is dead.

Dematerialisation

As brick contains significant amounts of embodied energy and CO_2, brick producers have come under increasing pressure in recent years to find ways of optimising production processes and facilitating the use of the material in carbon neutral approaches to building. The brick industry has mainly responded by “dematerialising” or “going on a diet”:

- Thinner facing bricks make it possible to recover 2 cm for additional insulation within the same building system and structural thickness, and also reduce ceramic material by around 20%. However, an even more slender facing leaf is less stable, requiring an increased density of supporting mechanisms (wall ties and facade supports), which impact on construction cost, energy management and the service life of the masonry.

- The most radical form of dematerialisation is the reduction of the brick from a building block to a facing tile. So-called brick slips deliver material savings of up to 75%. That is if they are produced as such, because most brick slips on the market are cut from regular bricks and thereby result in the overproduction of 50% of ceramic material which is subsequently downcycled as waste. Moreover, slips are typically bonded to other materials. As a result, they are degraded to mixed waste at the end of their life cycle. In response, ceramic producers are currently developing dry mounting systems for brick slips. From this we can conclude that the future challenge for dematerialisation still lies within the applied construction systems.

The strategy of material reduction is nothing new. In 19th century masonry constructions, “facing bricks” and stone slips were commonly used. Material savings were also an important consideration back then, for example as a means of reducing transport weight.[12] And material savings was likewise cited as an important driver of the development of twin wall constructions with an intermediary cavity.[13]

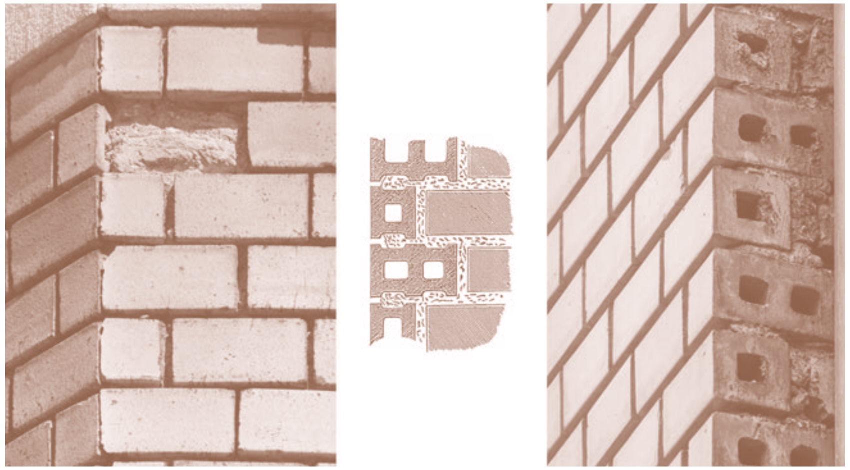


Fig. 8. Investigation of “facing bricks” and stone strips.

However, the strategy of material reduction in the case of brick remains counter-intuitive. The structural principle of stacking seems inseparable for the expression of masonry. Indeed, most cladding systems continue to emulate the expression of stacked masonry, a paradox that has spawned fierce debates on tectonics and the honesty of construction.[14]

Reuse

In the 2015 U.N. Paris Agreement, the transition to a circular economy was identified as a key condition for meeting global climate goals. With it, a new paradox was born: where sustainability takes a primarily long-term perspective, discourse on circularity appears to bring the notion of temporality to the fore. Consequently, the emphasis on the reusability of elements in the building materials industry takes precedence over the sustainability and performance of the systems themselves. One example of this is the development of dry-stacking systems, in which bricks are no longer laid on top of one another but stacked on dimensionally stable profiles. Such systems claim to provide an answer to the shortage of skilled bricklayers and promote speed of execution. They are “designed for deconstruction”: when disassembled the bricks remain in circulation and retain their value. The main disadvantage of dry-stacking systems is that they are often

applied in cavity wall constructions. The limited stability of the facing leaf in the absence of mortar is compensated for by a multitude of wall ties and auxiliary structures, resulting in a shorter service life of the masonry. The developers of demountable brick facades promote short-term construction under the guise of circularity. With “brick as a service” being one of the possible new approaches, the circular economy raises the question of wether we have thought properly about the purpose of a material that can last for hundreds of years in the first place.

Fig. 9. dnA House, Asse. Photo: Stijn Bollaert.

For the dnA house and other BLAF projects, we chose to reuse reclaimed bricks for the following reasons:

- Quality
  The first machine-produced bricks in our region (early 20th century) are of a much better quality than most contemporary facing bricks. That high quality was the result of higher energy consumption and higher CO_2 emissions during the production process.

- Environment
  By reusing bricks, no new bricks need to be produced, lessening the impact on raw materials, water, air, CO_2, energy, and so on.

- Aesthetics
  Reclaimed bricks have a timeless aesthetic quality that is at once generic and banal. With this, BLAF wishes to counter fashion trends and take up a position against linear economy reflexes among brick manufacturers.

The dnA house has since been picked up and studied worldwide as an exemplary model of circular construction, often focusing on the reused bricks, their aesthetic and physical properties. For us at BLAF, however, our main concern was the lock-in of the construction principle of the cavity wall.

The Wood-and-Brick Hybrid

The dnA house (2010–2013) was the first time BLAF employed the construction principle of a wooden inner structure with a thermally and structurally independent outer masonry wall. An earlier project, the dhL house (2007–2009), which likewise featured a wooden inner structure but was surrounded by a half-brick thick outer wall shell of brick bond masonry using the cavity wall principle (the so called "brick veneer" method), exposed a number of challenges of hybrid wood and brick structures. While the thicker outer leaf in the dnA house may at first seem paradoxical, it made it possible to address the problems with the cavity wall approach.

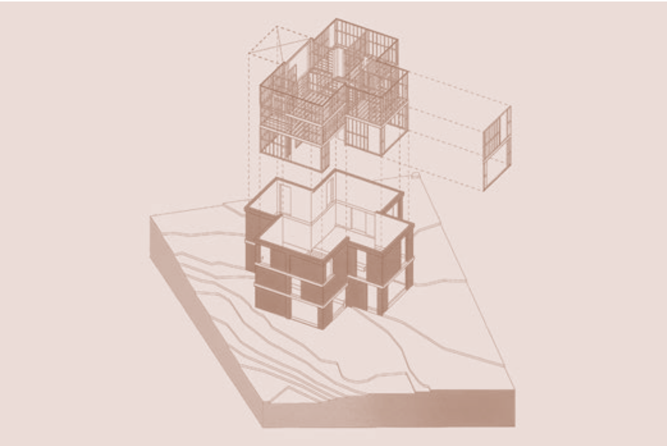


Fig. 10. The wood-and-stone hybrid. dnA House, Asse.

The construction of the dnA house was convincing and successful on many levels. However, the main disadvantage of this construction method is its cost. Brick masonry is labour-intensive, and therefore expensive. In 2017, the Dutch Association for Building Ceramics KNB launched a publication promoting cavity walls with a self-supporting brick facing leaf, including interesting examples from projects by Tony Fretton, DOK architects and Office Winhov, among others. Until now, this so-called Brick BENG (brick carbon neutral house) construction principle has not seen broad adoption, leading us to conclude that the higher cost price of the materials and manual labour for bricklaying are currently still decisive obstacles.

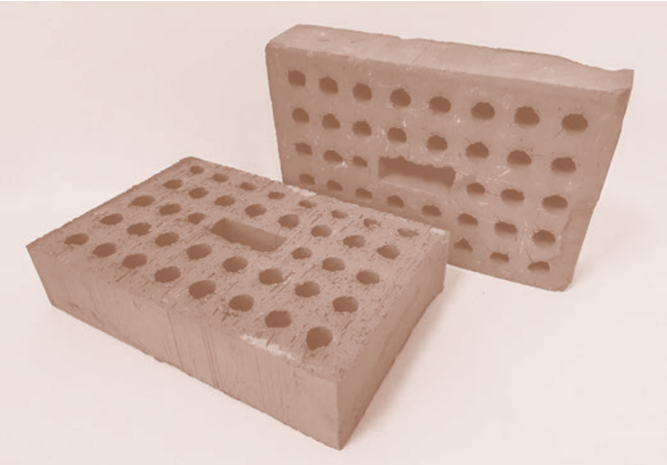


Fig. 11. BLAF's Big Brick 1.0, manufactured by Wienerberger, 2016.

Big Brick

The aim of revisiting the construction method of the dnA house in an economical way led BLAF to develop a new facing brick. This module adopts the familiar proportions of brick masonry, essentially looking like a regular stretcher brick, but with a greater width. This makes it possible to erect an external wall with the same structural properties as a brick wall and at the same speed as a half-brick wide external cavity wall. In the past, thicker brick formats – known as the "mop" or "moef" – were used to erect solid masonry structures as early as the 13th century. BLAF has christened this new facing brick the "Big Brick".

The Big Brick 1.0 is based on an existing product from a manufacturer's range, in which only one dimension was modified. With the first batch, we realised three projects: our so-called "Big Brick Pilots". The construction entailed the use of two main materials in the most appropriate way. Brick for permanence, durability, low maintenance, "pathos" of representation, and wood for temporality, adaptability, interior and ecology. In addition it entailed the radical disconnection between the constructions of the shell and the infill, both in terms of stability and thermally. Each project explores a different strategy for post-insulation of the brick shell, investigating the role of each layer and material of the construction.

For the development of Big Brick 2.0, tailor made for the odG housing project, we also addressed the production process. Working together with the manufacturer, we developed an extruded facing brick made of only one type of local red-brick clay, without any additional minerals or toxic synthetic additives. To minimise energy consumption during production, any supplementary production processes that served only aesthetic reasons (such as surface flaming) and not the physical properties of the brick were omitted.

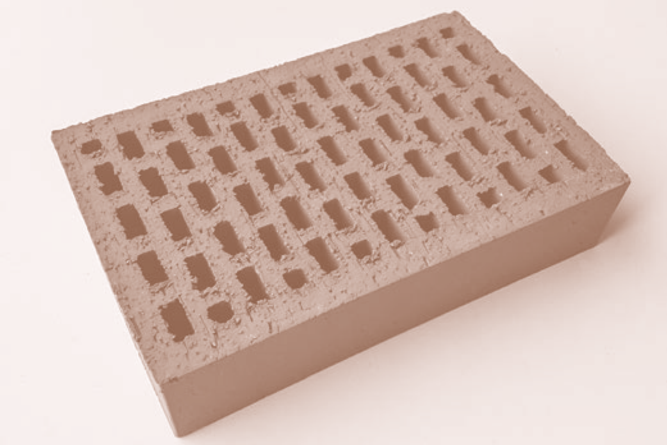


Fig. 12. BLAF's Big Brick 2.0, manufactured by Ploegsteert, 2018.

Re-Materialisation

As mentioned earlier, the construction approach of Big Brick Hybrids shifts the focus from the reusability of building bricks to the sustainability of the facade construction (the notion of the durable ruin). The strategy of re-materialising the façade, and the radical constructive disconnection between the brick shell and the timber frame infill, serves the clear distinction between the public and the private, the "wet" construction and the "dry" construction, the permanent and the temporary, the carbon based and the bio based, the "visible" and the "invisible". By doing so, we have tried to tackle the lock-in of the cavity wall system. The commitment to the longevity of masonry, through the design and construction principle, does not replace the need to consider the reusability of the building blocks. In the next phase, the research focus will therefore widen once again. The nature of the open-system construction principle allows us to test the application of other mortars, or alternatively investigate the development of Big Brick dry-stacking systems. Other types of building bricks, such as natural stone, unfired earth blocks, or carbon bricks, will also be candidates for future research.

Fig. 13. The construction (or "the ruin") of the jtB House, Blanden.

5 Arnaud Hendrickx, "The (under)searching practice" in: Isabelle Blancke et al. (eds.), *When attitudes take shape*, Antwerpen: Flemish Architecture Institute (Architectuurboek Vlaanderen) 2020.
6 Lieven Nijs, "Brick: Building Block Of Paradoxes", in: *A+*, Back to Brick, 294/2022, pp. 72–76.
7 Nathan Claeys, *30 Ways to build a wall*, master's thesis, Ghent University 2019.
8 D. Bernstein/J.P. Champetier/F. Pfeiffer, *La maçonnerie sans fard: Méthodes récentes de maçonnerie apparente* (Collection Architecture et technologie), Paris: Editions du Moniteur 1982.
9 Griet Verbeeck, *Optimization of extremely low energy residential buildings*, KU Leuven 2007.
10 Lieven Nijs/Bart Vanden Driessche, *BLAF architecten. First notes on the building system and product development for the construction of sustainable and energy-efficient, brick faced buildings*, September 2014.
11 Jan Peter Wingender, *Brick: an exacting material*, Architectura & Natura Press 2016.
12 Wilko Potgeter, *Die Erfindung des Verblendsteins: Bautechnik des Backstein-Rohbaus im Zeitalter der Industrialisierung*, Petersberg: Michael Imhof Verlag 2022.
13 Cf. D. Bernstein/J.P. Champetier/F. Pfeiffer, footnote 8.
14 Udo Garritzmann, *Modes of Tectonic Thinking: Proposal for a Non-Dualistic Understanding of Tectonic Expression in Architecture*, doctoral thesis, Aarhus School of Architecture 2021.

Limestone Calcined Clay Cement (LC³)

C

Beatrice Malchiodi, Hisham Hafez, Karen Scrivener

A Pioneering Contributor to Decarbonising the Construction Sector

It is universally acknowledged that construction, and in particular the widespread use of cement-based materials on an industrial scale, makes a substantial contribution to current carbon emissions.

The need to tackle this issue is even more urgent given the rate of economic growth and accompanying degree of urbanisation in emerging countries such as India, Latin America and Africa. Today, the unrivalled versatility and properties of concrete make it the most widely used material in building construction – and thus also to meet the growing demand for buildings and structures in emerging countries.

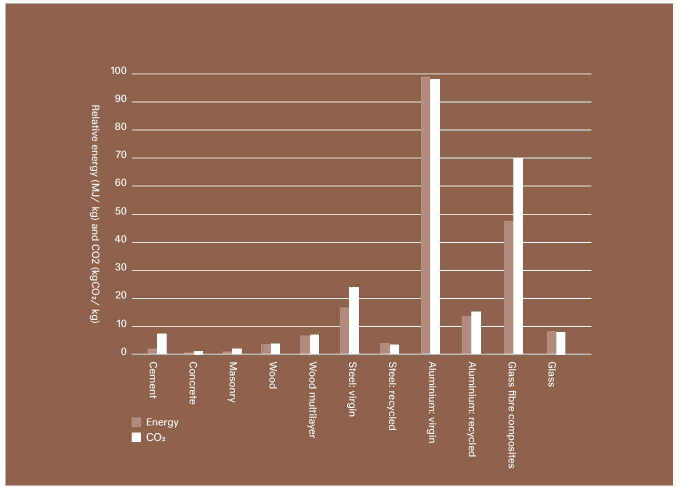


Fig. 14. Concrete is an environmentally-friendly material.

Concrete is a mix of graded aggregate particles (the primary ingredient of concrete providing compressive strength, shrinkage reduction, and cost benefits) and cement paste (composed of clinker, gypsum and water), which fills the spaces between the aggregate particles. Concrete is cheap, easily handled by low-skilled workers, is made with widely available raw materials and has good mechanical and durability properties. In addition, it is versatile and can be used to manufacture structural elements of various geometries both on-site and precast. The ability to produce modular load-bearing elements such as concrete bricks and blocks is particularly suited for simple and rapid construction methods, for example in contexts such as housing, where labour is a more convenient option than machinery.

Although concrete is intrinsically one of the most sustainable construction materials with a low proportion of embodied CO_2 per kg of material (Fig. 14), its scale of application makes it a large contributor to CO_2 emissions. 90% of emissions resulting from the production of concrete is due to just one of its constituents, i.e. clinker, which contributes to 6–8% of global CO_2 emissions but with a very uneven distribution among countries (Fig. 15). In some countries, cement-related emissions far exceed this percentage and these are therefore the primary target for remedial action to quickly achieve an effective reduction in carbon emissions.

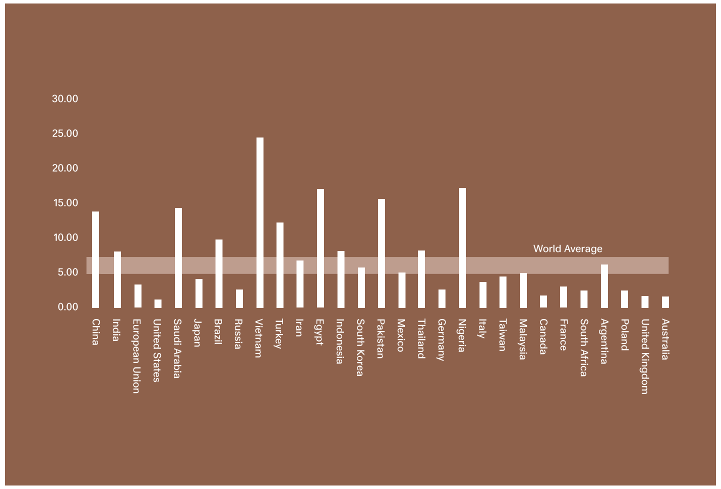


Fig. 15. Overall $\%CO_2$ emissions from cement production.

The solution to the problem requires a multi-level approach: reducing the clinker content in cement, the cement content in concrete, and the concrete content in structures. The LMC (Laboratory of Construction Materials) group at the École Polytechnique Fédérale de Lausanne has been pioneering this approach and since 2004, in collaboration with UCLV in Cuba, has developed the breakthrough LC^3 (limestone calcined clay cement) technology.

LC^3 is a sustainable cementitious binder that removes up to 50% clinker (LCC^4-50) from cement by introducing calcined clay and limestone, reducing CO_2 emissions by up to 40% compared to Ordinary Portland Cement (OPC) (Fig. 16). This represents the most promising and ready-to-use solution for improving the sustainability of cement without penalising the structural performance and durability of the final concrete.

Other binders aim to reduce the clinker content using waste materials such as slag, fly ash, etc., but these too are depleting finite resources and cannot provide a long-term solution. By contrast, a major plus of LC^3 is the widespread availability of clays and limestone worldwide. Indeed, they make up most of the earth's crust and are especially abundant in the Global South where economic growth is occurring at an increasing pace. Moreover, limestone and lower-purity clays, which are often wasted from ceramic and clinker production, can be used for LC^3.

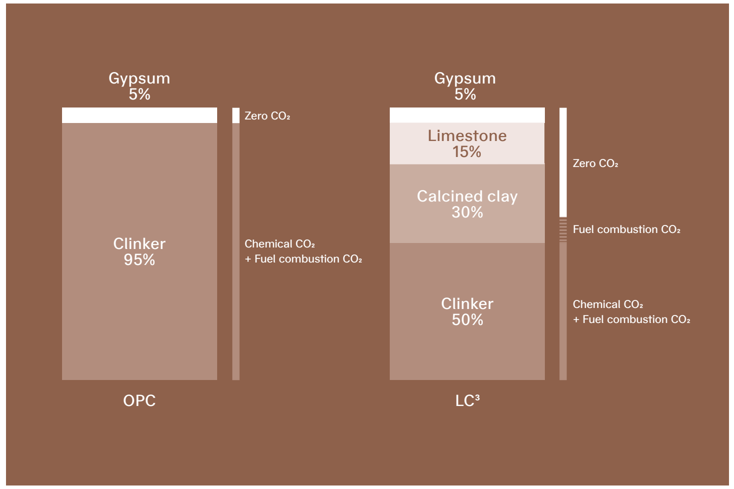


Fig. 16. Comparison of Ordinary Portland Cement (OPC) and LC^3-50 composition and related CO_2 emissions.

Given its low porosity, the use of LC^3 in concrete provides good resistance to weathering, such as permeability, sorptivity, chloride ion penetration, and sulphate attack. Thus, it is particularly suitable for exposed marine, groundwater, and damp-proof applications. It also has an extraordinary binding capacity and plasticity, making it ideal for indoor and outdoor plaster and mortar applications. Finally, LC^3 has a highly recognisable and distinctive colour, typically ranging from brick red to pale pink – a result of using iron-rich clays and of the clay calcination process under oxidation atmospheric conditions. Although this could be regarded as an added and desirable architectural aesthetic property, the standard grey colour of Ordinary Portland Cement (OPC) can be obtained by using clays with a low-iron content or conducting calcination in controlled atmospheric conditions.

Efforts are already underway to include the use of LC^3 in the cement standards. In 2018, Cuba approved the use of LC^3 as a ternary cement (NC 1208 standard) and since 2021, LC^3 has also been included in the European cement standard EN-197-5. Current initiatives are focusing on the inclusion of LC^3 use in concrete standards, which would legitimate its use in construction and encourage more widespread adoption. Updating standards normally takes a long time and involves a change in mindset, but with the commitment of all parties in the construction industry (i.e. researchers, industry, governments), new sustainability-oriented standards will hopefully be released in the next decade.

At present, more than 25 applications using LC³ are underway on different scales. In India, a house has been built in which 98% of traditional brick- and cement-based products was substituted with equivalent LC³-based products, saving 15.5 t of CO_2 emissions, or the equivalent of 10 passengers flying from Switzerland to South Africa.

Fig. 17. LC³ house in Jhansi, India.

Cement companies are already beginning to embrace this new sustainable cement. Not only does it allow the production of more sustainable and marketable products but can also reduce cement production costs by up to 25%. Furthermore, it can already be produced in a majority of the 3000-odd cement plants worldwide with minimal investment costs. The first clinker rotary kilns have already been converted to calciners in India and Cuba, and more and more cement companies are showing interest in the changed production method. Remarkably, the first permanent large-scale production of LC³ started in Colombia and the Ivory Coast in 2020 and chemical companies have already developed admixtures specifically for LC³.

Efforts are currently focusing on pushing down the clinker content to below 50% in LC³ and reducing CO_2 emissions in the final concrete structure by reducing the cement content in concrete and the amount of concrete in the structure. Large-scale tests and long-term durability tests on LC³-based structural concrete are also underway to demonstrate the feasibility of including it in international construction codes.

The benefits of using LC³ are being disseminated around the globe at all levels – academic, industrial and social – and given the widespread attention this material is receiving, we hope it will soon be applied on a large scale worldwide.

Building with Earth

D

Alia Bengana

Mass Utilisation Through Units

Revisiting the history of architecture through the lens of productive systems offers valuable insights into how resources are utilised. Prior to the Industrial Revolution, the scale of material usage was largely limited by the amount of human or animal labour one could invest and the distance over which materials could be reasonably transported. With increasing technological and scientific advancements, however, humans were able to exploit and transform the earth's resources for their own benefit on a vast scale, leading to an extractivist and productivist model that has prevailed for nearly two centuries. Since the advent of the age of the Anthropocene, however, we are being forced to confront the reality that material resources are finite. Here, the question of materials in architecture becomes crucial as we strive to cultivate a new culture of material usage, departing from the monolithic construction methods (i.e. concrete) so prevalent in the building sector in the past century. To work towards a sustainable future, it is essential to transition towards a resource-based approach to architectural design – one that encourages the utilisation of local materials that are renewable or reusable, requiring minimal or no processing, while also possessing the ability to sequester carbon and resulting in minimal emissions. This in turn fosters a circular economy of materials, promoting their longevity and reducing waste.

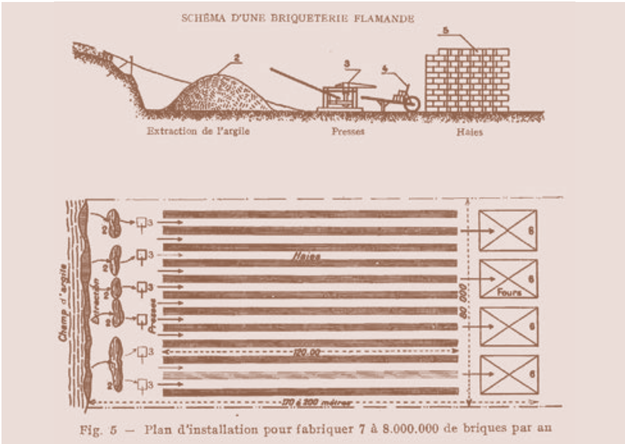


Fig. 18. Process chain schematic of a traditional Flemish brick factory.

To contribute to this necessary paradigm shift, it is worth investigating the potential of reintegrating ancestral, sustainable building materials into contemporary building practice. One such material is earth.

The State of Things

For over 11,000 years, earth has been a fundamental building material for constructing homes. Even today, a significant portion of the global population – around one third[15] – resides in earthen dwellings. In countries in the southern hemisphere, this proportion rises to more than half. Among the traditional construction techniques still used in practice, we find adobe, cob, rammed earth, and daub. Adobe, a blend of clay and straw, is pressed into moulds and sun-dried, while cob involves sculpting massive walls of earth and straw. Daub entails applying a mixture of earth and organic fibres to a wooden supporting framework. Rammed earth, a technique devoid of straw, employs movable, temporary wooden formwork to contain coarse moist earth that is compressed in successive layers. Among the more recent developments are Compressed Earth Blocks (CEB), which emerged in the 1950s in Colombia. Like rammed earth, this method employs compaction, but using fine damp earth in a simple metal machine with a manual lever arm.

Fig. 19. Manufacturing of large compressed earth blocks at the ERDEN Werkhalle.

Curiously, why did the practice of earth construction decline in Europe despite its widespread use up until the Second World War? Several factors contributed to this shift, with the most prominent being the unfavourable perception associated with this material. Earth is often deemed fragile and unsuitable for the European context, sometimes even linked to poverty in the global south. Concrete, on the other hand, represents modernity. Furthermore, expertise in earth construction has gradually waned, and architectural and engineering training devoted little attention to this material so that it became challenging to use. The absence of technical standards and norms also hindered its adoption. Lastly, cost poses a significant barrier: artisanal earth materials are more expensive than their industrial counterparts, despite requiring much lower energy for their production and processing. This is largely due to high labour costs in the northern hemisphere.

Advantages of Earth

Despite this, incorporating earth building materials into contemporary architectural practice has the potential to significantly reduce the embodied energy in constructions. Historically, efforts to decrease carbon emissions have primarily focused on reducing energy consumption, often overlooking the significance of materials. Earth has numerous advantages: it is an abundant raw material, its manufacturing processes emit minimal carbon emissions, it possesses hygroscopic, acoustic, and thermal properties, and it promotes a healthy indoor environment. Moreover, earth is a material that can be endlessly recycled. However, it does require protection from water, as it is sensitive to moisture. Techniques such as rammed earth, adobe, compressed earth blocks, and cob can all be used for load-bearing construction, although their load-bearing capacity is typically around a tenth of that of reinforced concrete.

Fig. 20. Construction site scenes with industrialised rammed earth modules on Groffeldstrasse in Buchs.

Industrialising Earth

Given the cost of traditional methods, how can existing building manufacturing and construction techniques facilitate the democratisation of this underutilised material? While the transition from small-scale to industrial-scale production is often seen as the primary route for achieving significant growth in the use of a material, in the case of earth building materials this implies a profound change in the practice of earth construction. Traditionally, an earth building is constructed by hand using local soil. Skills are developed in very specific ways: earth builders in a given region adjust and calibrate their working methods to the qualities of the locally available earth. Not all soils and earths can be used as they are, and often need to be adjusted in their composition by adding sand, gravel or a more clayey soil from another site. Adobe would seem unsuitable for industrial-scale production, as the production of blocks requires considerable manual work and large drying areas. It is, however, very well suited to small-scale self-build projects, as is the cob technique. Rammed earth is also produced on site, often using the same formwork systems normally used to form concrete. The work is long and laborious, requiring layers of around 12 cm to be compacted by hand and reduced to 8 cm using manual or pneumatic rammers. Martin Rauch, ceramist and earth builder, founder of the Lehm Ton Erde company in Austria, has, however, demonstrated that this technique can be outsourced and semi-industrialised. In a first demonstration project for the Ricola factory in Laufen, Switzerland, in 2014, large self-supporting wall sections were rammed in a purpose-built hall near the site, then transported by lorry and craned into place in huge blocks.[16] The joints between the large sections of wall were then painstakingly filled in by hand with a similar earth mass, so that they disappeared, leaving only the impression of an immense monolithic wall.

Fig. 21. Construction site scenes with industrialised rammed earth modules on Groffeldstrasse in Buchs.

Martin Rauch has since refined this method in subsequent projects for Mlzd architekten ag's Birdwatching Museum in Sempach, and for the Alnatura headquarters in Darmstadt, Germany. These projects are, however, ambitious-scale projects with a corresponding cost for their production. It is hard to imagine this technique being extended to more modest sites or social housing projects, for example.

Fig. 22. Construction site scenes with industrialised rammed earth modules on Groffeldstrasse in Buchs.

Compressed Earth Blocks

Compressed earth blocks have emerged as a potentially transformative technique for making unfired earth elements more accessible and affordable, thus democratising their use. Originally developed by Colombian engineer Raul Ramirez during a research programme focused on rural housing, the success of the first Colombian compressed earth blocks (CEB) press, capable of producing up to 800 units per day, led to its rapid replication in other Latin American countries, various regions of Africa, and even as far as India. Subsequently, the technique was further refined through the introduction of hydraulic presses, mechanising the production process.

In Europe, the CRAterre laboratory in Grenoble holds the distinction of being the world's first centre of expertise in earth building. Established in 1979, it played a crucial role in managing a programme aimed at constructing 20,000 social housing units and public facilities using unfired bricks during the 1980s, spearheaded by the Société Immobilière of Mayotte.[17] The choice of compressed earth blocks was motivated by their ease and speed of installation. Inspired by the success of the project, an initiative was started to industrialise the earth-based construction industry on the island, leading to the creation of over twenty local brick-works. Alongside maximising the use of indigenous resources, it also generated employment opportunities for people in Mayotte, thanks to a comprehensive training programme organised by CRAterre. The resulting housing is closely aligned with the local way of life and the island's delicate ecosystem. However, despite the promising achievements of the Mayotte project, earth construction techniques have not been widely adopted in the decades that followed.

Fig. 23. On-site production of compressed earth blocks.

The Potential of Soil From Excavation Works

Although the use of earth in construction remains limited, a growing phenomenon in recent years holds the potential to contribute to its wider adoption: the soil produced during excavation works. Each year, the cantons of Vaud and Geneva alone generate approximately 4.8 million m³ of excavation soil, which is classified as type A waste.[18] By comparison, the colossal construction sites of projects in the Greater Paris region are expected to generate an estimated 400 million m³ of excavated soil by 2030.[19] At present, this soil is legally classified as waste and often ends up in landfills. The canton of Geneva already exports 45% of its excavation soil, with 25% going to France, while the canton of Vaud is expected to reach saturation point by 2023.[20]

The abundance of this material, and its potential for transformation into a valuable resource for the construction industry, is evident in Switzerland and throughout Europe. As long as there are no regulations limiting excavation works, or the construction of car parks and other underground structures, the quantity of excavated material is unlikely to decrease.

Consequently, interest in the potential of this material is growing. While rammed earth projects often occupy the spotlight in publications, those involved in establishing tangible sectors and wishing to promote affordable earth construction in Europe are turning their attention to the production of compressed earth units.

Sector Activators

There are three prominent protagonists of earth block production in Europe: Terrabloc in Switzerland, Cycle Terre in France, and BC architects in Belgium.

In 2011, Terrabloc initially adopted mobile semi-automatic presses that could be transported to construction sites. Using a small Belgian hydraulic press, they manufactured compressed earth blocks in the heart of Geneva for the load-bearing interior walls of the Geisendorf school canteen, designed by the architect David Reffo. Fortunately, the excavated soil on the site was suitable for the CEB technique. Terrabloc also had access to adequate storage and drying space, a highly valuable resource in the city. Moreover, they collaborated with a public client who agreed to bear the additional cost of this small-scale production.

Fig. 24. Load-bearing interior walls at the Geisendorf School, designed by architect David Reffo.

To maintain affordable prices, Terrabloc established a partnership with the Cornaz cement block company in Allaman, located in the Canton of Vaud. This provided the opportunity for "industrial co-working", i.e. sharing an existing facility suitable for producing compressed earth blocks rather than having to construct a dedicated one. This approach allowed them to initiate production based on specific projects and the availability of excavated soil from the Lake Geneva region, which they recycled. Their partners included earthworkers and managers of gravel pits and landfill sites for earth materials, who contacted them when they needed to dispose of excavated soil from a construction site. Terrabloc would assess the soil's qualities on site to determine whether to divert a portion of the excavated material to the Allaman plant instead of sending it to a landfill. This semi-industrialised approach has enabled Terrabloc to reduce costs compared with bricks compressed on site. They will also be able to supply a significant number of blocks for Roger Boltshauser's upcoming housing development in Zurich. Additionally, the transition to a semi-industrial scale has allowed them to develop other larger formats of compressed blocks and interior partition elements. Among these, the interior partition module (8×25×40 cm) is particularly noteworthy as it offers a low-carbon alternative to stud wall partitions: unlike traditional plasterboard on metallic studs, it has better acoustic properties, thermal inertia, and moisture regulation properties due to its greater mass. The even larger formats (30×80×15 cm) additionally resemble rammed earth in their aesthetics due to their more massive size but require a small crane for installation due to their weight, making them less manoeuvrable.

Fig. 25. Manufacturing of the interior partition modules at Terrabloc.

In 2021 in the Paris region, the Cycle Terre factory opened its doors with the help of European funding. This allowed the factory to establish a production facility for earth materials during a time of market uncertainty. Their flagship product is also compressed earth blocks. The founders of Cycle Terre see the factory's objectives as focusing on three main areas and leverage the combined expertise of 13 public and private partners involved in the initiative:

- Producing building materials exclusively from soil excavated from construction sites in the Greater Paris region.

- Creating a regulatory framework that facilitates the use of non-standard products.

Vocational training and reorientation, initially with a view to providing job security for the factory's own staff and later to benefit other construction companies. Additionally, raising awareness of earth-based construction materials among building professionals, architects, engineers, design offices, and public and private sector clients through training courses and visits.

Fig. 26. Educating craftsmen and promoting compressed earth brick (BTC) construction.

The recently implemented RE2020 environmental regulations in France, which require a carbon footprint assessment before granting planning permission and encourage the use of earth and bio-based materials, have helped the factory gradually increase production. Like Terrabloc, Cycle Terre has also diversified its product range and now offers 2 cm thick extruded fibre-reinforced clay building boards alongside its bricks and mortars. These portable panel products can be fastened to timber or metallic studs and used in place of plasterboard to create interior partition walls. The cavity between the facing panels can then be insulated.

BC materials was created in Brussels by the architects of Bruxelles Cooperation in 2018. The initiative arose after successfully completing various projects using compressed earth bricks and rammed earth in Africa and Belgium and stems from a desire to actively advance the construction industry's shift towards circular approaches, replacing highly processed materials with local resources, including those reclaimed through urban mining such as excavation material, which is also currently classified as building waste in Belgium. BC materials established its production unit close to their architectural office in the centre of Brussels, and use a fully dismantlable hall. They produce three unfired earth-based products for sale: compressed earth blocks, plasters, and ready-mixed bigbags of rammed earth. B2B sales to their network of architects, contractors, and builders are their primary focus. The company also regularly conducts training courses, open to all, including students, architects, and contractors, to promote knowledge and skills in using these materials.

BC materials is currently working on a large-scale project together with the Belgian Building Research Institute (BBRI) to transform excavation soil from the construction of the future Brussels metro line 3 tunnel. This endeavour, known as UTUBE, aims to produce and market over 27,000 m^2 of compressed earth blocks, massively expanding the company's capacity to produce and promote these materials.[21]

Standards: A Foundation for the Building Industry

Recognising the significance of standards, these three European stakeholders collectively acknowledge that the lack of standardised practices poses a significant barrier to the widespread adoption of these materials. Presently, Germany stands out as the only European country to have successfully incorporated such standards, a remarkable achievement realised in 2019 through the efforts of the Dachverband Lehm e.V., the German association for building with earth. The establishment of DIN (Deutsches Institut für Normung) standard 18945 for earth bricks or blocks, along with DIN 18946 and 18947 for earth masonry mortar, has now become a benchmark for other nations to draw upon. BC Materials is collaborating with the BBRI to translate and adapt these standards for implementation in Belgium. The availability of earth building standards provides a basis for stakeholders in the European construction industry to confidently employ earth building materials, as well as for insurers to offer corresponding building insurance coverage for these unconventional techniques. Furthermore, it paves the way for the efficient, sustainable mass production of unfired earth blocks. These operations are not just the result of industrialists' initiatives; rather, they stem from the dedication of passionate architects and engineers who firmly believe that a transformative shift in material culture cannot occur without their active participation in the development of new sectors. These sectors lie at the intersection of semi-industrialisation and the craftsmanship of low-carbon materials that possess qualities such as recyclability, affordability, accessibility, and aesthetic appeal.

15 Gernot Minke, *BUILDING with EARTH: Design and Technology of a Sustainable Architecture*, Birkhäuser 2007.
16 Martin Rauch et al., *Martin Rauch: Refined Earth, Construction & Design with Rammed Earth*, edition DETAIL, Institut Für Internationale Architektur-Dokumentation, Munich 2015.
17 Florie Dejeant/Philippe Garnier/Thierry Joffroy (eds.): *Matériaux locaux, matériaux d'avenir : Ressources locales pour des villes et territoires durables en Afrique*, CRAterre Éditions 2021.
18 Valerie Hoffmeyer, "Matériaux d'excavation, la grande évasion", in: *revue Tracés* 3517, February 2022, pp. 28–29.
19 Agnès Bastin, *Gouverner le métabolisme : les terres excavées franciliennes, collection Réflexions en partage*, éditions PUCA, February 2023, p. 7.
20 Canton of Vaud, General Directorate of the Environment (DGE), *Carrières, gravières et décharges – Compte rendu de la consommation, de la production et des réserves*, 2019, version 2, April 2021.
21 Annette Helle/Barbara Lenherr, *Beyond Concrete: Strategien für eine postfossile Baukultur/Strategies for a post-fossile Baukultur*, Zurich: Triest Verlag 2022.

Part II

Artefacts

A Visual Journey

From Brick Bonds to Linked Leaves

E

Clemens Waldhart, Martin Fröhlich

The Act of Stacking Stones

Masonry, an age-old craft, has been the backbone of architectural endeavours for millennia. The art of stone-laying and bricklaying, with its intricate patterns and robust structures, not only provided shelter and demarcated boundaries but also narrated the tales of civilisations, their aspirations and their technological progress. The process of constructing a wall, once a simple stacking of found stones, has evolved over time from hand-selected to quarried and ultimately to industrially produced stones. It reflects not only the changing technological landscape but also socio-economic considerations on the relationship between the time needed for construction, the technical methods involved, the costs associated with the degree of human labour, and geographical availability.
In the pre-industrial era, masonry was a labour-intensive process, relying heavily on the skill and expertise of the mason. This is reflected in the perception and social status of the professions: The master mason was once a multifaceted coordinator, responsible for design, administration and technical supervision. Masons crafted intricate stone patterns for windows, arches and vaults, drawing from prior works. They were masters not only in working stone but also of spatial transformation. Each stone was handpicked, shaped, and placed with precision, ensuring the stability and longevity of the structure. They managed finances and hiring, took care of material procurement and sought out new technical solutions. Their constant presence on site facilitated swift decisions and adaptations. In some cases, this role bridged innovative design with established tradition, embodying the fusion of creative vision, technical expertise, and leadership by shaping enduring architectural marvels. The walls, constructed using these mass-made small blocks, were not just simple barriers but symbolised a community's identity and its relationship with the surrounding environment.[22]

Brick Bonds and Mortar Mastery

The pivotal collaboration between architect and mason is a relationship profoundly evident in the masonry works of Sigurd Lewerentz. They are a testament to the meticulous craftsmanship and expertise of the masons he collaborated with.

Originating from an industrial milieu – his father managed a glasswork business that partnered with prominent architects of the later Deutscher Werkbund like Bruno Möhring, Theodor Fischer, and Richard Riemerschmid – he developed a deep appreciation for detail and the nuances of construction fostered by his diverse education: he trained as an engineer at Chalmers Technical School in Gothenburg and pursued architectural studies at both the Fine Arts Academy and the “Klara Skola” in Stockholm.[23] His works bear witness to a steadfast commitment to practical construction experiments and a close relationship with his masons, as he fervently embraced practical expertise while harbouring scepticism toward excessive theoretical speculations.

At that time, his pioneering approach to bricklaying, which simplified material usage while introducing a greater diversity of mortar joint thicknesses, led to a sequence of experiments conducted under the supervision of the construction engineer Professor Hjalmar Granholm. Granholm, a recognised authority on masonry techniques, detailed in a written dissertation how Lewerentz’s ambitious and complex brick structure designs featuring expansive wall openings and a uniquely shaped roof presented a number of intricate design challenges.

Lewerentz’s close rapport with his masons was again evident in the way he included his master mason, Jojje Anderson, in the discourse. Anderson was entrusted with reading Granholm’s dissertation and subsequently disseminating its insights to all fellow craftsmen on site. It was even made a condition that no mason could join the construction site without first becoming familiar with Granholm’s findings. Lewerentz was therefore keenly aware of the practical implications of Granholm’s experiments and their meaningful impact on his approach to masonry construction. This distinctive approach, which characterises Lewerentz’s work with bricks, is detailed in this book in the graphical study of St Peter’s Church in Klippan. Lewerentz’s legacy serves as a reminder of the profound synergy between visionary insight and skilled craftsmanship within architecture. His innovative masonry philosophy avoided cutting stone, prioritising instead varying the joint thickness for adaptability.

In contemporary masonry, the widespread use of cement mortar poses a sustainability problem as it limits the reusability of stone or brick units. However, as the graphical studies of the Headquarters for a Block Factory by Vao Architects and the Garage and Storage Facility by Bovenbouw Architectuur show, masonry constructed from such units holds an intrinsic potential for disassembly and reuse.

Alternatively, perceiving the wall as a layered composition of distinct stress zones presents the opportunity to formulate a nuanced response that addresses not just the wall assembly but also the choice of different brick types to serve different roles. The strategic allocation of bricks with varying properties to specific locations where their attributes are most advantageous, is what characterises Harquitectes’ remarkable contribution to our architectural artefacts. Here, the single-leaf wall serves a dual role, functioning as both a load-bearing structure and a spatial construct.

While Lewerentz’s work is an exemplary showcase of precision brick and mortar masonry, a product of both meticulously detailed drawings and hands-on collaboration with on-site craftsmen, it predated a distinct transformation of masonry construction that still endures today. Often characterised as stones floating in binder – “embedded in a matrix of mortar rather than laid in bonded courses of conventional joints”[24] – it paved the way for another paradigm shift in masonry construction.

Brickwork Unbound

Long before the demands of improved building performance led to the introduction of insulation standards for the building envelope, architects had already embarked on a transformative vision for masonry and construction. Rather than considering the combination of stones and mortar as an intricately interwoven whole, architects like Le Corbusier took the concept of “swimming bricks” and pushed it further, dismantling the traditional mortar web and reimagining the act of stacking stones. A wall was no longer a complex interplay of interconnected layers but rather a homogeneous leaf, a singular, unified structure. Walls began to be cast, and openings were not constructed but cut out. This phenomenon has persisted to the present day in CAD (Computer-Aided Design) software. The mass bears the load.

Among the critics of traditional masonry, Eero Saarinen emerged as a pioneer of the concept of arranging units in the construction of a cohesive component. For Saarinen, the labour-intensive nature of traditional masonry construction was one of its biggest disadvantages. For his architectural designs for four buildings on Yale University campus, Saarinen drew inspiration from Le Corbusier, seamlessly integrating large natural stones as a “floating” aggregate within concrete volumes. This innovative principle he called “modern masonry walls” built without the need of traditional masons.[25] The notion of a wall as a singular leaf was established. A further paradigm shift resulted from the desire to achieve increasingly thinner wall shells optimised for material and surface efficiency. Although the wall is still perceived as a “monochromatic mesh”, the appearance is deceptive: steel anchors, straps and wall ties are needed to achieve the required structural integrity that was traditionally the result of the wall bond composed of identical elements. In the context of evolving masonry practices, Ted’A’s courtyard house in Mallorca, which is also detailed in a graphical study in this book, represents a blend of both “masonry” perceptions. While the interiors feature walls with multiple courses of earth-toned bricks, the outer facade employs the above-mentioned modern approach of "cast masonry": Stones sourced from the site are embedded in their as-found state within the concrete framework of the wall. This transformative adaptation of the wall into separate systems for the load-bearing, insulation, and building envelope functions also reflects the standards that emerged after the European oil crisis of the 1970s in which insulation standards were introduced for building envelopes. These standards effectively rendered traditional, solid, exposed masonry walls impractical, leading to the gradual disappearance of this method.

The twin-leaf masonry wall, initially designed to shield against driving rain, became the standard. Construction methods were segregated into distinct layers serving specific functions and individually optimised to maximise their performance. The result was thinner wall leaves, improved insulation, better weather sealing, and cost efficiency. The visible outer leaf, predominantly constructed using half- or single-brick veneers, relinquished its load-bearing role and assumed a new purpose as protective cladding for the insulating and load-bearing layers. However, this shift came at a cost: the visual quality of the masonry bond was compromised in the process.

The Unleashed Leaf

Despite the emergence of masonry conventions and norms, architects continued to be fascinated with stacking bricks, continuously exploring inventive solutions and new means of expression.

Alvar Aalto is a compelling example of an architect who maintained a highly individualistic approach to experimenting with the visual quality of the bond. Aalto actively pursued the concept of "flexible standards", akin to the cells within a living organism, enabling a variety of forms to emerge. This idea culminated in the courtyard facade design of the Experimental House in Muuratsalo.[26] Its courtyard unfolds as a captivating canvas of various brick types and intricate patterns, emphasising the artistry of bricklaying. The wall's vertical expanse is thoughtfully partitioned into segments that mirror the architectural composition: the base, the room-height section, and the ascending triangle up to the inclined roof. The resulting effect is one of abstraction and potential continuity. In his design, Aalto emphasises primarily the brick quality and surface texture through different stacked and running patterns. The courtyard wall is a captivating experiment with brickwork that highlights a distinct aspect of reinforced masonry construction: the movement joint. As layered cavity walls expand and contract in response to thermal variations, it becomes necessary to prevent cracks emerging. Expansion joints ingeniously divide the wall at intervals into sections, allowing individual surfaces to move independently. While often considered an aesthetic challenge, Aalto's design transforms these joints into an artistic opportunity, celebrating the seams as the delineators of diverse patterns within the facade.[27]

But even as Aalto's ambition was to create a space of accommodation and deceleration and to take a stance against his own declared hell – *"Mechanisation takes command"*[28] – the construction still aligns with the prevailing tendency of the time: the multi-leaf wall.

As we delve further into the evolving realm of masonry, it becomes evident that its role is again undergoing a profound transformation. Once celebrated as a versatile and fundamental building technique, masonry increasingly serves a different role – that of a frequently employed cladding layer. This shift is driven in part by the growing scale of architectural projects and the associated economic challenges that manual labour poses. Contemporary building conventions lean toward rationalisation, often at the expense of traditional craftsmanship.[29]

This gradual transition raises poignant questions regarding the traditional structural role of masonry within architecture. As O. M. Ungers aptly articulated "with the waning emphasis on stone structures, architecture has, in a sense, shifted its focus from volume and space to the plane, the surface, and the visible veneer. Architects are left with the task of adorning and optimising these surfaces to the best of their abilities."[30]

This transformation prompts a critical re-evaluation of masonry's place in contemporary architectural discourse. Architects are inclined to incorporate masonry, not just out of structural necessity but also as a canvas for artistic expression. In this, they navigate the complex interplay between form, function, and aesthetic appeal, exploring creative methods to enhance and celebrate the architectural surface.

Masonry in Mind

Solid brick walls hold a captivating allure, not merely for their inherent homogeneity, where bricks seamlessly interlock in three dimensions, but also for their remarkable versatility in assuming multiple roles at once: separation, support, insulation, protection, and even thermal retention. These walls, once a fundamental part of architectural education, embody a holistic and interconnected approach to design. A masonry wall, meticulously crafted through continuous layers of interlocked elements, exudes a profound richness deeply intertwined with the tactile artistry of construction. As Fritz Schumacher eloquently articulated, those who work with bricks share an innate connection with the construction site, always present in the process.

In our contemporary era, however, the symbiotic relationship between practical construction and creative design is gradually eroding. The prevailing perception of a masonry wall, as reflected in drawing conventions, is that of a monolithic entity, even when it comprises an intricate assembly of interlocking elements. This disconnection from the actual construction process on site hinders the creation of meaningful space and the generation of diverse solutions. Even our most advanced digital tools often fall short in bridging this divide: We are in essence sketching with the aid of blocks and formless matter, rather than articulating the intention of physically erecting structures made of elements. Consequently, the act of modelling often becomes an end in itself, hindering the fundamental utility of the drawing process.

In this context, *Studies on Assemblies* serves as a catalyst aimed at enabling a more holistic understanding of the intricate interplay between material, tectonics and construction. Through an array of diverse examples spanning from single-leaf to multi-leaf masonry, and a wide spectrum of materials and construction techniques, we investigate the perception of space. The distinction between the wall as masonry bond or a wall as a cohesive volume offers valuable insights into assessing and understanding their appropriate and versatile use, as well as their inherent qualities.

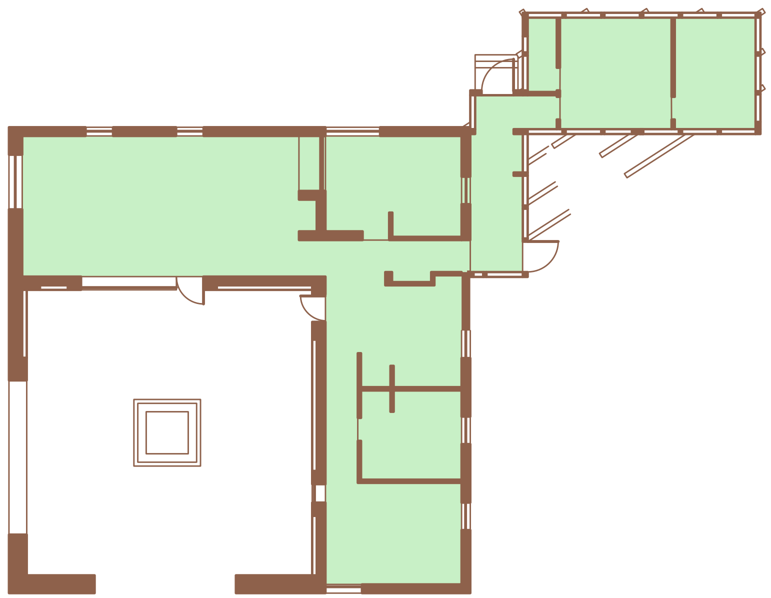
22 Melvin Kranzberg/Michael T. Hannan (Britannica), *"History of the Organization of Work – Monumental Construction, Labor, Crafts | Britannica Money"*, on: www.britannica.com, retrieved May 2, 2023.
23 Ingrid Campo-Ruiz, "Construction as a Prototype: The Novel Approach by Sigurd Lewerentz to Using Building Materials, Especially for Walls and Windows, 1920–72", in: *Construction History*, vol. 30, no. 2, 2015, pp. 67–86.
24 Colin St. John Wilson, "Sigurd Lewerentz and the Dilemma of the Classical." in: *Perspecta*, vol. 24, 1988, p. 68, on: https://doi.org/10.2307/1567123, retrieved January 12, 2020.
25 Andrea Deplazes, *Constructing Architecture: Materials, Processes, Structures: a Handbook*, Transl. by Gerd H. Söffker, Basel/Boston/Berlin, Birkhäuser 2005, pp. 28–29.
26 Ibid.
27 Georg Windeck et al., *Construction Matters*, Brooklyn: Powerhouse Books 2016, pp. 48–59.
28 "Mechanisation takes command" refers to the title of the publication by Sigfried Giedion, *Mechanization Takes Command: A Contribution to Anonymous History*, New York: Oxford University Press 1948.
29 Andrea Deplazes, *Constructing Architecture: Materials, Processes, Structures: a Handbook*, Transl. by Gerd H. Söffker, Basel/Boston/Berlin, Birkhäuser 2005, p. 50.
30 Oswald Mathias Ungers, interviewed by N. Kuhnert, "Detail: Das Tüpfelchen auf dem i", in: *Arch+*, 87, 1986, p. 57.

Artefacts

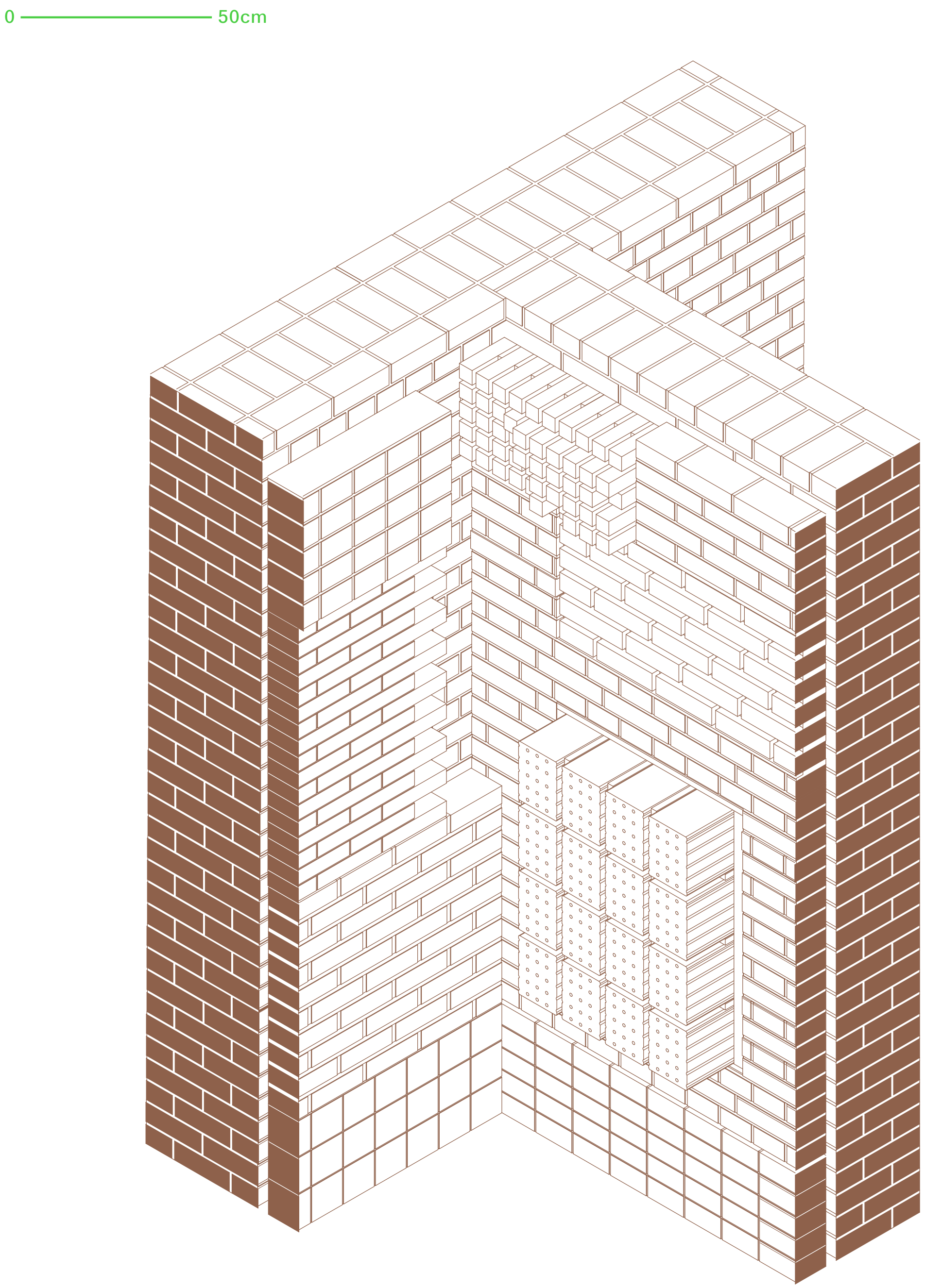
F

Muuratsalo Experimental House
Muuratsalo, Finland

Elissa Aalto, Alvar Aalto
1953



The external wall type that Alvar Aalto developed for his experimental house comprises parallel inner and outer leaves separated by an air cavity. This afforded Aalto the flexibility to create two different identities for one and the same architectural element. The walls of the courtyard-like composition, formed by an L-shaped building and a pair of enclosing walls, change from white stucco on the outside to exposed red brick masonry facing the courtyard. The inward-facing walls feature an experimental tapestry of different brick bonds, brick formats and mortar joints. The resulting mosaic-like composition of some fifty different brick masonry panels must, however, also withstand the harsh climate. The courtyard serves as a natural air-conditioning system: the high walls of the building shield the courtyard from cool winds, creating an internal microclimate, while the thermal retention properties of the brick panels when exposed to the sun are utilised for heating and cooling. The white stucco surfaces on the outside reflect the sun, while the exposed brick in the courtyard both absorbs solar radiation while providing sufficient thermal mass to keep the interior cool. The house has no insulation and was only used during the summer months.



Climate
Subarctic climate, Dfc*
no dry season, cold summer

Units
Clay brick, clinker brick, outer leaf
Different dimensions and types
of brick, facing brick

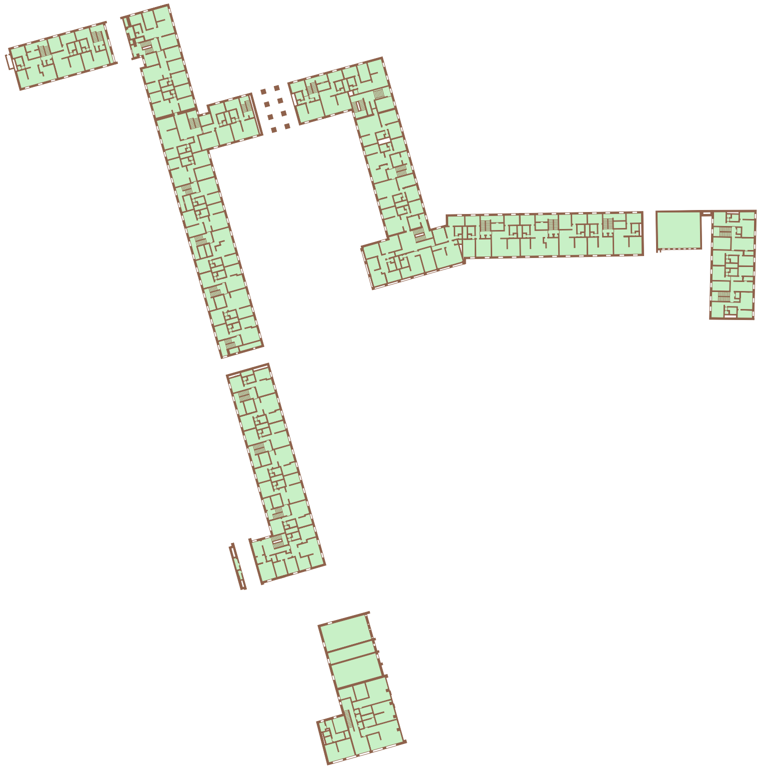
Clay brick, inner leaf
215/102/65 mm
Reinforced masonry, load-bearing

Wall construction: double leaf

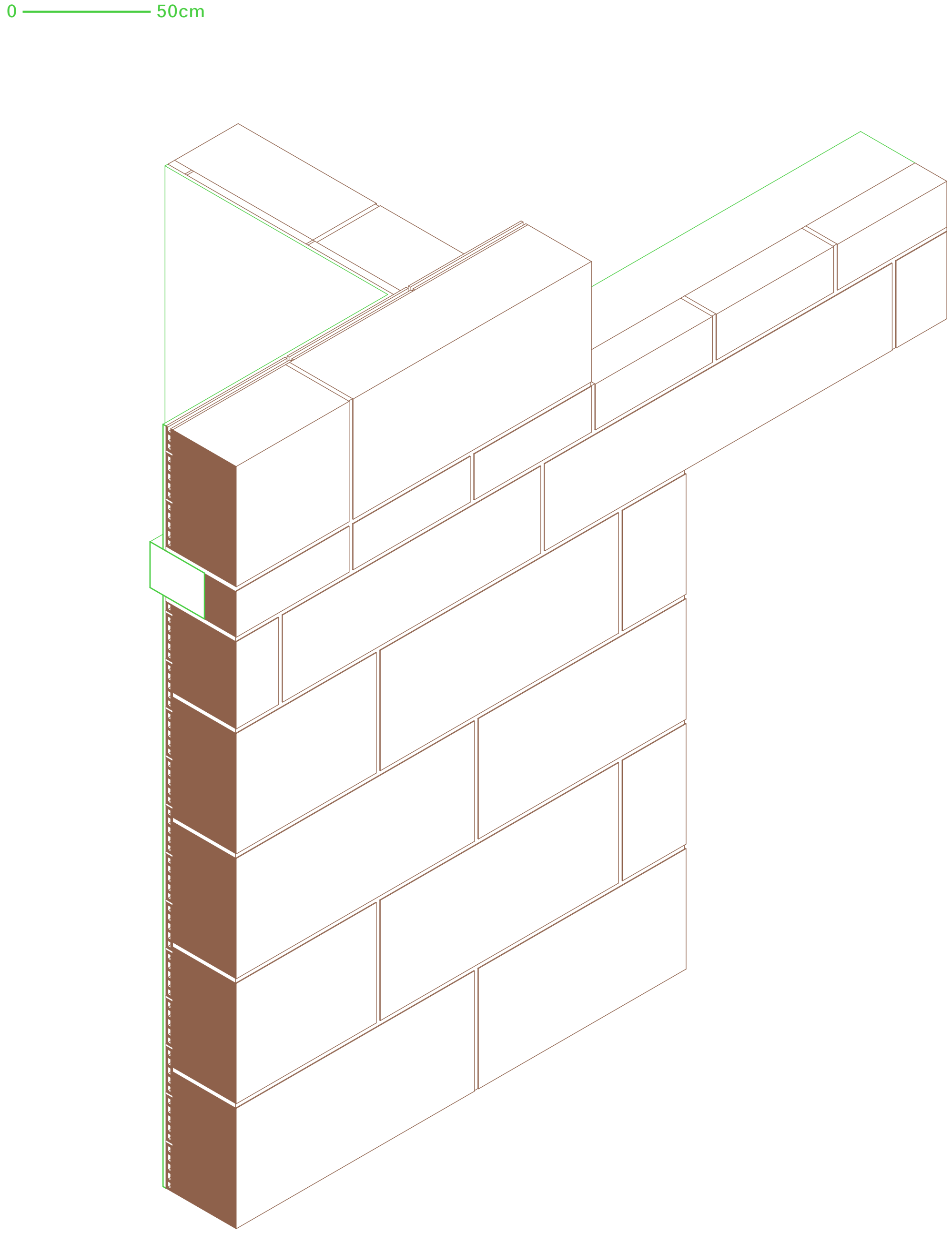
Patchwork of bricks	>100 mm
Air space	40 mm
Clay brick	340 mm
Total	480 mm

Residence Victor Hugo
Pantin, France

Ferdinand Pouillon, Roland Dubrulle
1961



The ensemble for a gigantic complex of 282 flats is characteristic of Ferdinand Pouillon's approach to designing closed urban figures with clearly legible spatial sequences, and for his compositional approach of structuring the predominantly five-storey apartment blocks according to the classical ordering principle of plinth, main body and crown. This façade structure determines the tectonics of the buildings. Pilasters arranged at regular intervals delineate a form of skeleton frame whose panels are lined with pink marble. The verticality of the composition is emphasised throughout, for example through the use of tall, storey-high windows. Like most of the buildings he built for the Comptoir National du Logement, the building complex is faced predominantly with natural stone sourced from Fontvieille in southern France. The stone was cut and processed at the quarry using heavy machinery and each block was custom-made ready for the construction site. Much like the ancient pyramids with their mathematically uniform blocks, here too a natural material is sourced and processed with industrial repetitiveness. On site, the imposing slabs of stone are assembled into a natural stone bond. The rough surface from the quarrying process was retained and partially augmented by traces of subsequent processing steps. The seams are articulated as hollow joints filled flush with a white cement mortar.



Climate
Temperate oceanic climate, Cfb*
no dry season, warm summer

Units
Limestone block, outer leaf
1200/320/525 mm
1200/320/380 mm
Load-bearing

Hollow clay brick, inner leaf
unknown

Wall construction: double leaf

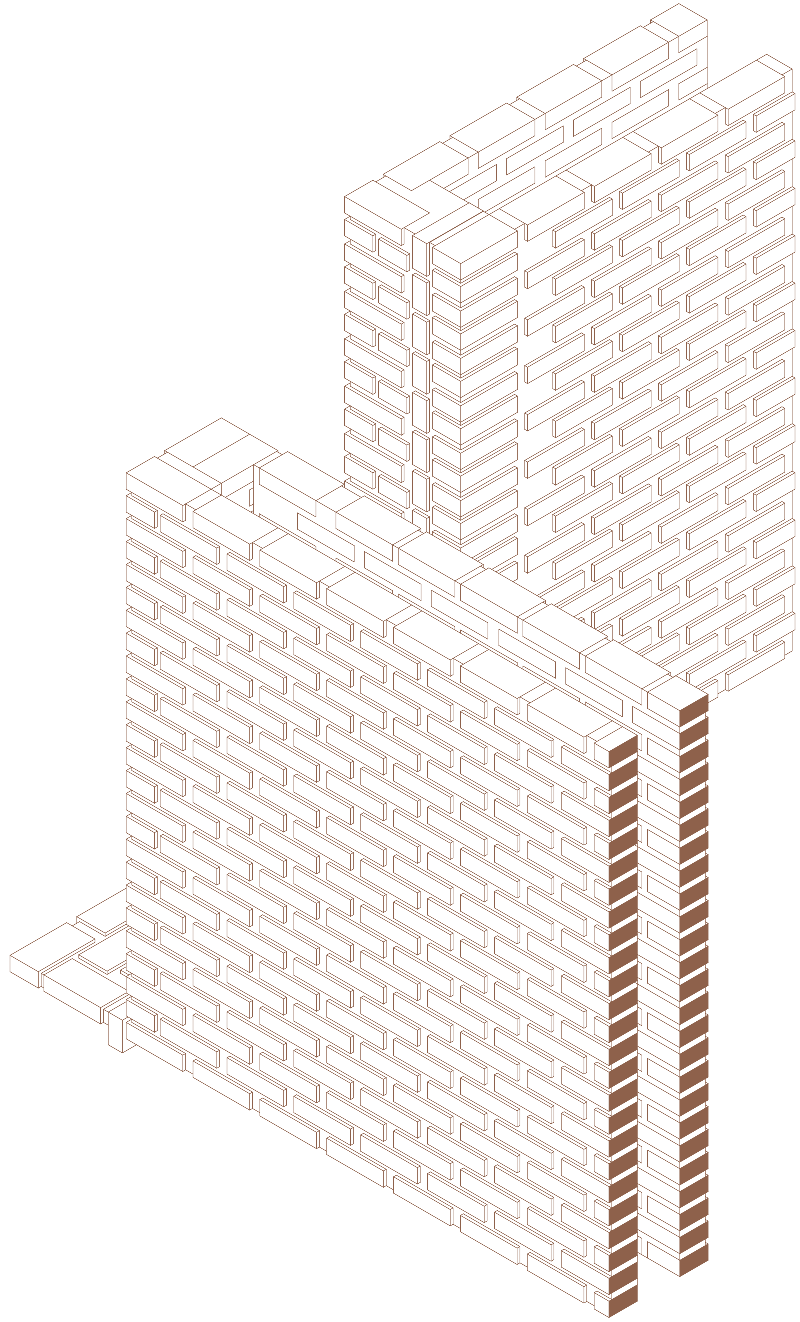
Limestone blocks	320 mm
Hollow clay brick	35 mm
Painted gypsum plaster	5 mm
Total	360 mm

St Peter's Church
Klippan, Sweden

Sigurd Lewerentz
1966

Not only in his late work on St Peter's Church did Lewerentz insist on building according to his self-proclaimed statement without cutting a brick. Also, out of respect for the material, which was rare and expensive in the far north at the time, he confronts himself and those working on the building with an ongoing mental task. Details such as connections, corners, deviations from the square form had to be rethought. Each individual brick seems to float, allowing the classic joint mortar to swell into an equal mass. Working closely with engineers such as Hjalmar Granholm and Sven Peger, they collaborated against the academic brick bond and modified the classical mortar with additions of powdered slate to prevent cracks caused by shrinkage. Lewerentz leaves us with a work that should not be seen as an important contribution to Scandinavian sacred architecture, but rather shows us what we can create from the repetitive unity of an industrial mass product and the passion of craftsmanship, an aesthetic of respect in the field of tension between repetition and particularity.

0 —— 50cm



Climate
Warm-summer humid continental climate, Dfb* no dry season, warm summer

Units
Clinker brick – outer and inner leaf
250/120/65 mm
Facing brick

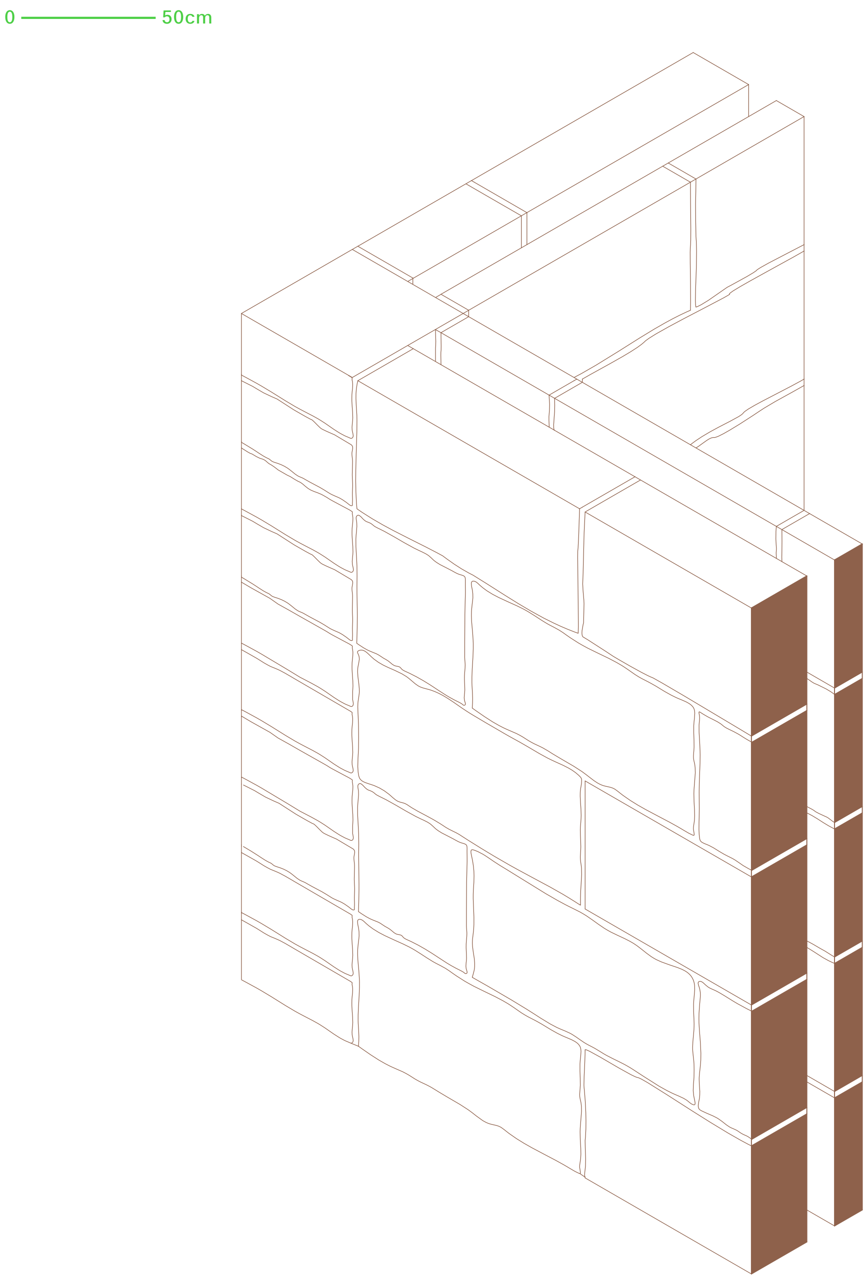
Wall construction: double leaf

Clinker brick	120 mm
Air space	200 mm
Clinker brick	120 mm
Total	400 mm

Can Lis
Mallorca, Spain

Jørn Utzon
1972

The house that Jørn Utzon built for himself and his family on a cliff overlooking the Mediterranean reinterprets traditional Majorcan building methods and uses local materials such as marés sandstone for the walls and columns, santanyi sandstone for the floors, internal walls and kitchen counters and Madera Norte, a Majorcan pine, for all the woodwork. The house's narrow site between the road and the sea prompted the architect to erect four separate pavilion-like buildings, each with its own ideal orientation and function: bedroom, living room, and a kitchen and dining room. After studying traditional wall construction methods, Utzon developed a cavity wall construction with a 20 cm thick outer leaf, a 10 cm air cavity and a 10 cm thick inner leaf – a system that perfectly reflects the modular basis of his building philosophy: the whole house is based on a 2.4-metre module, and the walls are made of 80 × 40 × 20 cm blocks. The locally occurring marés sandstone used for the walls is porous and has properties very similar to those of aerated concrete in that it is easily worked and can be cut to size with a saw.



Climate
Cold semi-arid (steppe) climate, BSk*
Steppe, cold

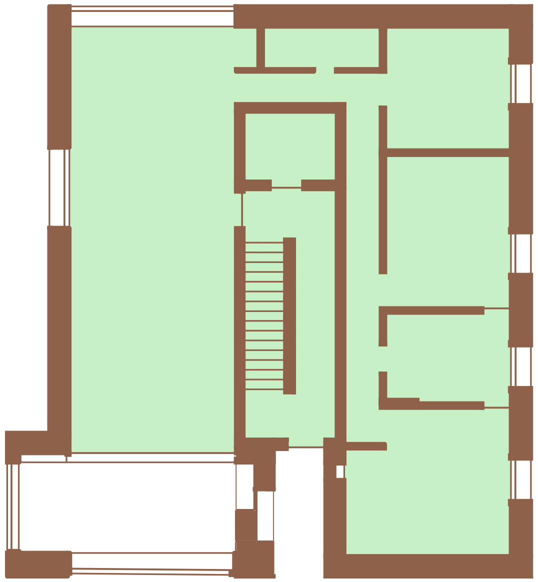
Units
Sandstone block – outer leaf
800/200/400 mm
400/200/400 mm

Sandstone block – inner leaf
800/100/400 mm
400/100/400 mm

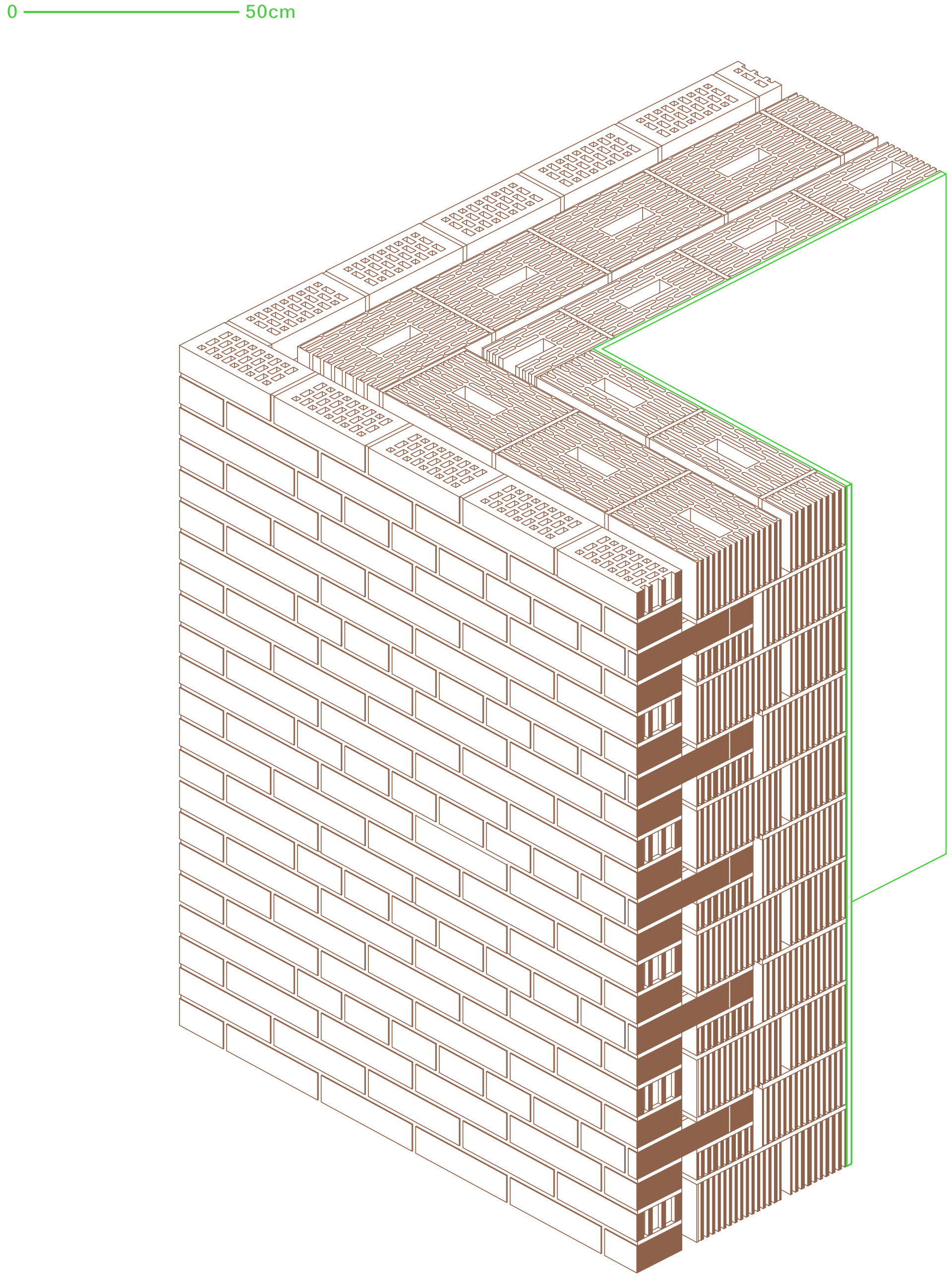
Sandstone block – corner
400/400/200 mm

Wall construction: double leaf

Sandstone blocks	200 mm
Air space	100 mm
Sandstone blocks	100 mm
Total	400 mm



The project strategy exploits the inherent interlocking modularity of brick masonry to form a set of joined twin-skin porous walls that simultaneously serve to enclose space, bear loads and articulate the tectonics of the façade. The sculptural quality of the two townhouses can be attributed largely to the absence of expansion joints. Conventional twin-leaf masonry with an outer facing brick leaf typically exhibits joints at intervals along a façade and at the corners. By contrast, the masonry system developed by the architects Burkard and Meyer combines both perforated insulating bricks and facing bricks: a 40 cm thick bond of Optitherm blocks of a sufficient load-bearing capacity and 12 cm “Kelesto” bricks (fired to below the sintering point to ensure adequate vapour diffusion). The two skins are laid in parallel and are joined at every fourth course by a row of header bricks that forms an interlocking bond between the two skins. As there is no ventilated cavity, it is important that the external mortar joints are sufficiently impermeable to prevent rainwater penetrating the masonry. The wall does not require any additional insulation (U-Value 0.38 W/m²K) and therefore also benefits the internal room climate alongside eliminating the need for expansion joints.



Climate
Temperate oceanic climate, Cfb*
No dry season, warm summer

Units
Clinker brick – outer leaf
250/120/65 mm
Facing brick

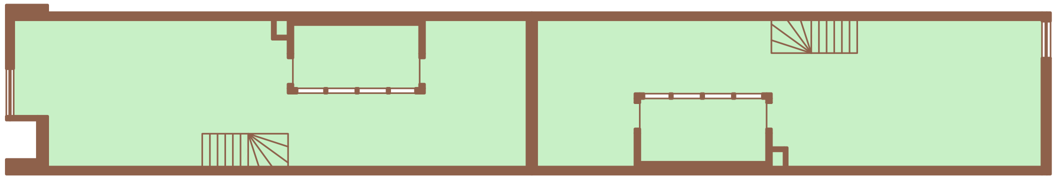
Clay block – inner leaf
300/150/140 mm
300/225/140 mm
Load-bearing, insulating

Wall construction: double leaf

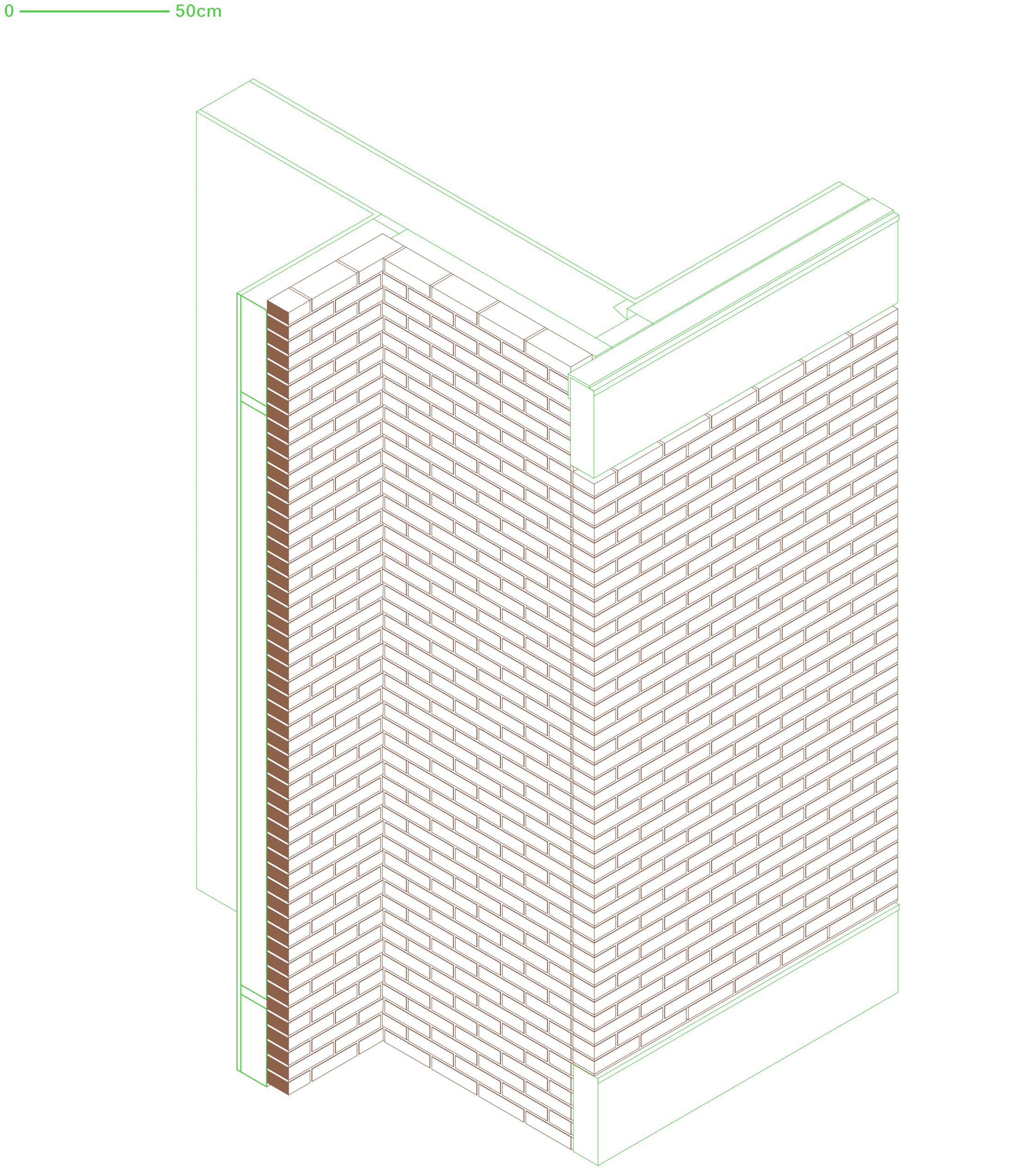
Clinker brick	120 mm
Air space	40 mm
Clay block	225 mm
Air space	25 mm
Clay block	150 mm
Coloured silicate plaster	15 mm
Total	575 mm

Sporenburg II
Amsterdam, The Netherlands

Atelier Zeinstra Van der Pol
1999



Borneo-Sporenburg exemplifies the spirit of Dutch housing in the 1990s, not just due to the undeniable qualities of its urban planning and architecture but also because it so clearly reflects the economic, political and cultural circumstances of its time. In particular, it reveals the changing role of planners in the shifting field of public and private-sector interests. The houses were designed within the strict constraints of a low-budget project and a master plan of narrow streets and narrow, deep building lots of three-storey buildings. An economical arrangement of parallel party walls with standard axial dimensions serves as the load-bearing structure. In addition, the façades are uniformly designed and clad with the same type of bricks. The basic module of the housing block designed by Atelier Zeinstra Van der Pol is back-to-back flats with short spans that make it possible to employ 190 mm thick reinforced concrete slabs arranged crosswise. The proportion of external wall per unit is therefore minimal. These are a lightweight glulam timber post and beam construction, with the panels between filled with 110 mm facing bricks.



Climate
Temperate oceanic climate, Cfb*
no dry season, warm summer

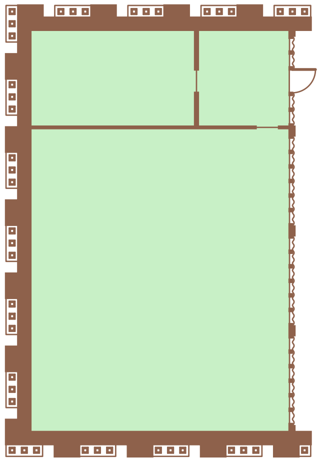
Units
Clinker brick, outer leaf
210/100/40 mm
Infill panel, facing brick

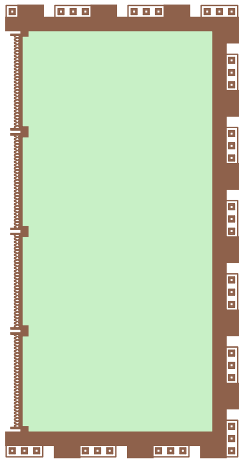
Wall construction: double leaf

Clinker brick	100 mm
Air space	48 mm
Foil, water-repellent, open to diffusion timber post-and-rail construction	119 × 38 mm
Insulation	120 mm
Vapour barrier	
Plasterboard	12.5 mm
Total	290.5 mm

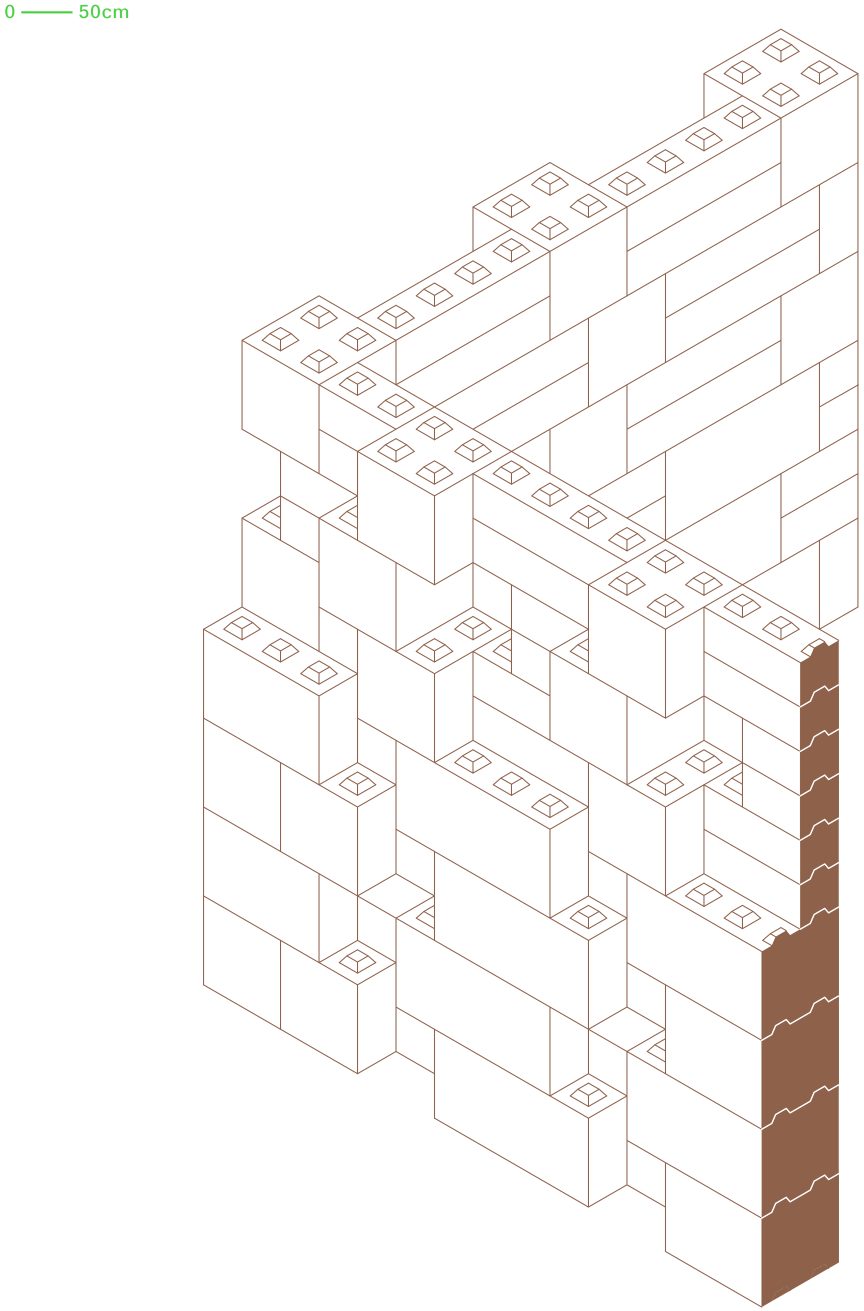
Garages and Storage Facility
Destelheide, Belgium

Bovenbouw Architectuur
2009





The project for a garage and storage facility employs stackable precast concrete blocks of the kind normally used to create noise barriers or retaining walls. The large size of the blocks requires the use of machinery to assemble them but shortened the construction time considerably to just four months. The unreinforced blocks are cast using residual concrete mixtures. Much like LEGO bricks, the blocks are only stacked and interlocked. A thin layer of mastic epoxy 2K coating as used in boat building, as well as a layer of silicone, were applied to achieve a seal but do not bond the blocks together. They can be removed later, making it possible to dismantle the structure and reuse the blocks. Four main shapes are used to create a rhythmic stacked wall composition that is visible on the inside and outside. In addition to their function as façades, the walls also serve as retaining walls, overcoming the slope of the terrain. After completion of the walls, the timber flat roof construction was added on top. The roof has a span of 8.5 m, permitting the interior to be free of columns.



Climate
Temperate oceanic climate, Cfb*
no dry season, warm summer

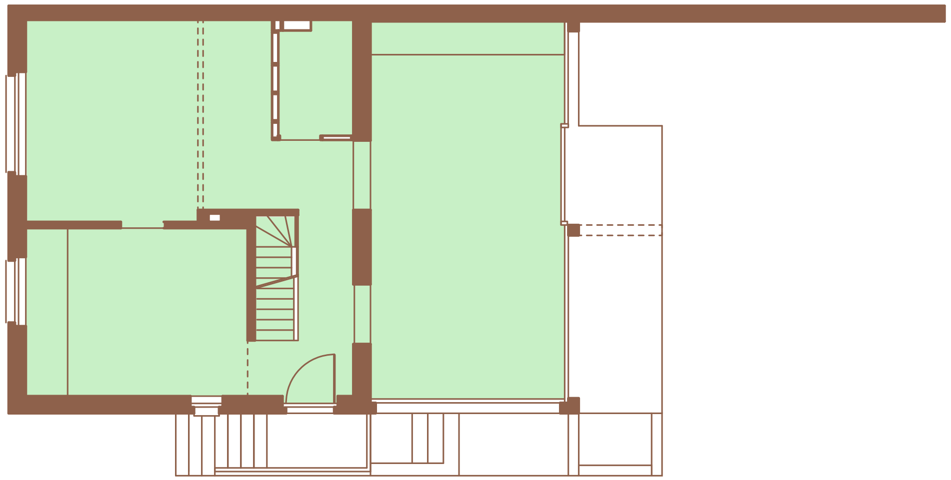
Units
Interlocking concrete blocks
160/80/40 mm
120/80/40 mm
160/40/40 mm
80/80/40 mm
80/40/40 mm
40/40/40 mm
Load-bearing

Wall construction: single leaf

Piled concrete block	400 – 800 mm
Total	400 – 800 mm

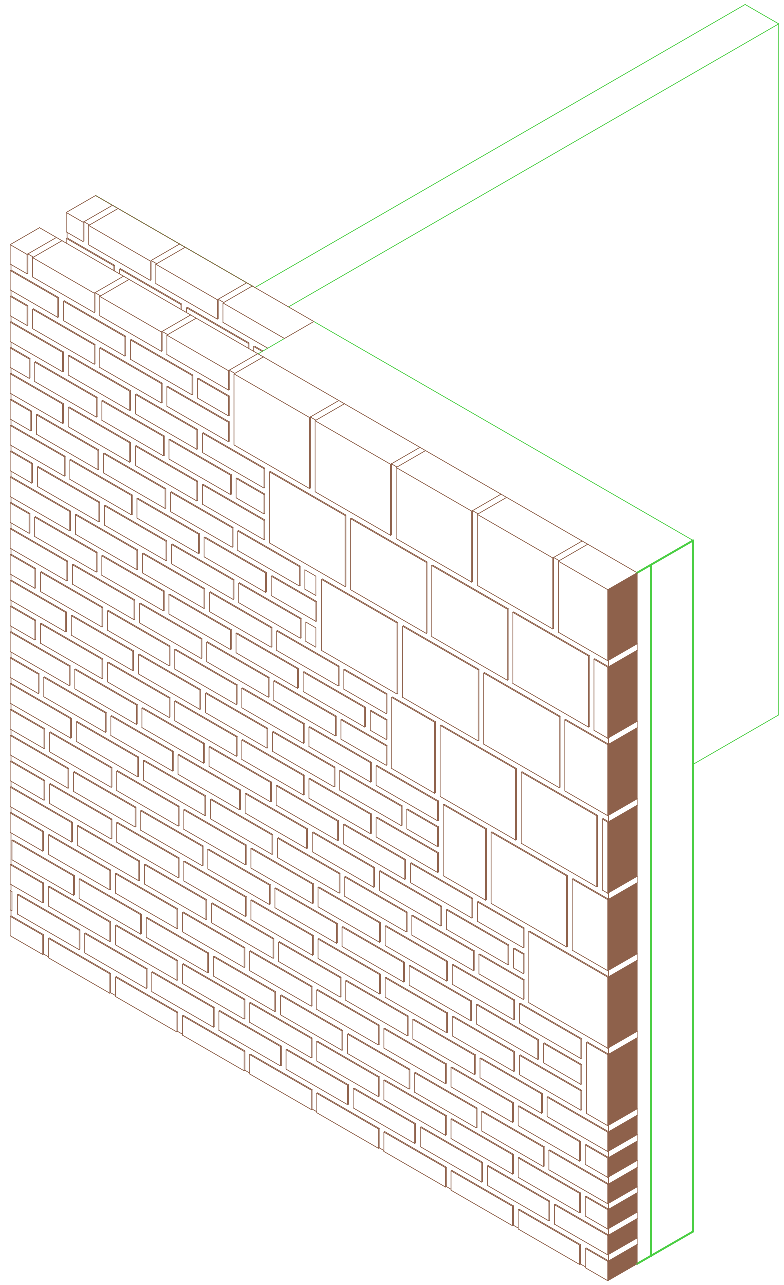
Schreber House
Aachen, Germany

AMUNT
2011



A small, semi-detached house in a 1920s estate was enlarged through the addition of an extension to almost double its floor space. The original building is a simple brick building with regular window openings and twin-leaf external walls comprising an inner load-bearing leaf of lightweight concrete block and an outer leaf of facing clinker bricks. The existing building is left almost untouched: the windows, stairs, room layout and materials remain unchanged and define its character as before. The extension, by contrast, employs an open concrete skeleton frame for its inner load-bearing structure that permits the creation of expansive window fronts on the ground floor, affording an unobstructed view of the garden and surroundings. The façade reveals exactly where the new meets the old: the dark red clinker façade of the original building interlocks with the red-brown pumice and lightweight concrete bricks of the extension, the two colours combining to form a whole. The unrendered façade means that the seam between the old and new substance remains legible, an effect further heightened by the clash of different brick formats within the same octametric system.

0 50cm



Climate
Warm-summer humid continental climate, Dfb* no dry season, warm summer

Units
Clinker brick – outer leaf
240/115/52 mm
Facing brick, existing

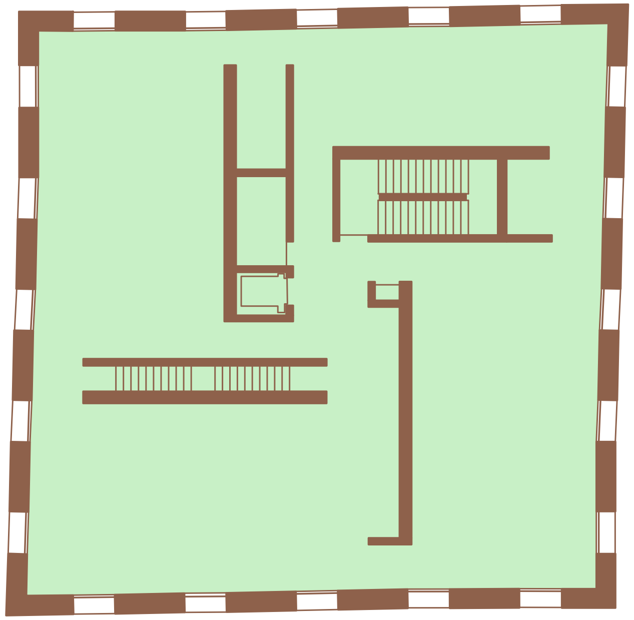
Concrete brick – outer leaf
240/113/175 mm
Facing brick

Wall construction: double leaf

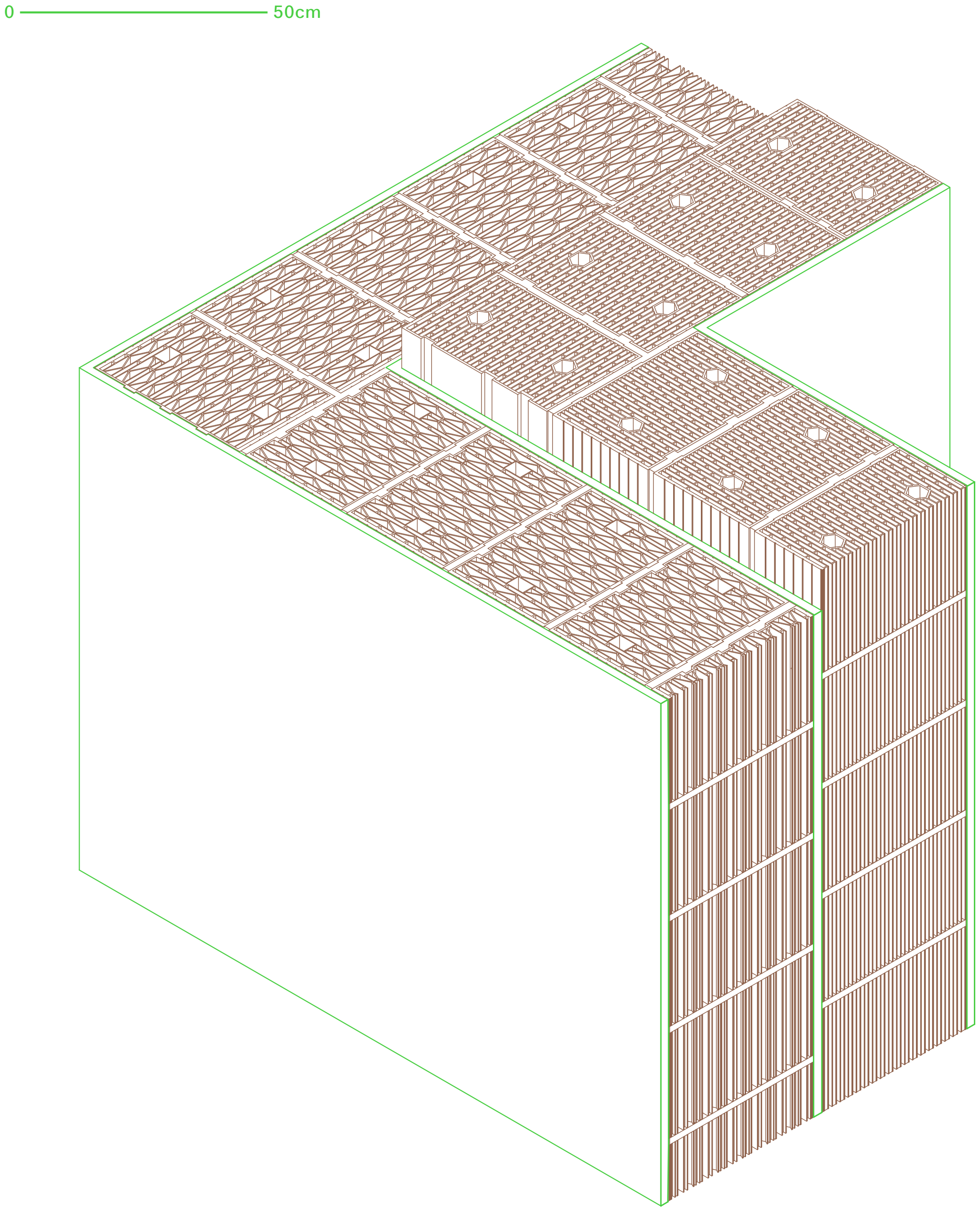
Double leaf	
Facing brickwork	115 mm
Air space	20 mm
Insulation	30 mm
Internal load-bearing concrete wall	150 mm
Total	315 mm

Haus 2226
Lustenau, Austria

Baumschlager Eberle Architekten
2013



The need to tackle energy wastage led the building industry to pursue a strategy of equipping buildings with highly insulated, airtight envelopes and complex, high-tech heating and ventilation systems. The architecture office Baumschlager Eberle presents an alternative to this trend and the accompanying standards, by creating a building that draws on vernacular traditions such as monolithic masonry that serves both as load-bearing structure and thermal mass, and no cooling. The building shell comprises two layers of 36 cm thick brickwork: a denser inner leaf for sustaining compressive loads and an outer leaf for insulation. This construction also obviates the need for heating. The façades are defined by a grid of well-proportioned identical wood-frame windows with triple glazing and sensor-controlled window vents for night-time cooling – the only technological system in this minimalist concept. Similarly counter-intuitive is the seemingly wasteful floor height, which ranges from 3.40 to 4.50 m – far higher than building codes require. Nevertheless, the project promises its occupants indoor room temperatures of between 22 and 26 °C in a climate zone that is cold in winter and hot in summer – hence its name. The 2226 concept appears to run contrary to all energy-saving regulations, as well as the investment market's fixation with maximum floor areas. After more than 10 years of controlled monitoring, however, it has shown that its claim to sustainability is justified.



Climate
Warm-summer humid continental climate, Dfb* no dry season, warm summer

Units
Clay block – outer leaf
250/380/238 mm
Insulating

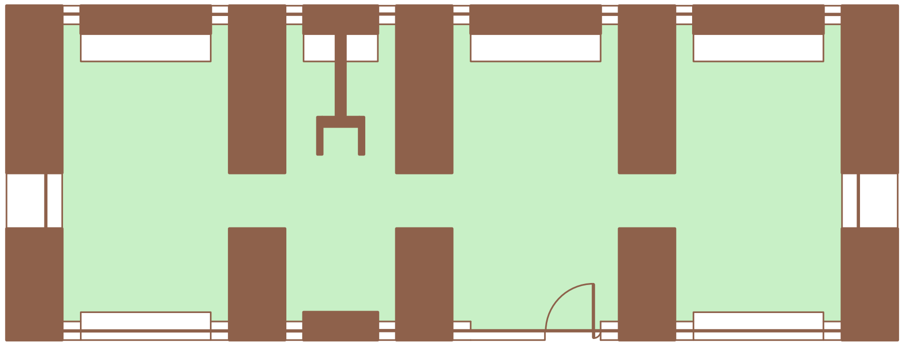
Clay block – inner leaf
250/380/238 mm
Load-bearing

Wall construction: double leaf

Lime plaster	8 mm
Lime-cement base plaster	12 mm
Clay block	380 mm
Mortar joint	18 mm
Clay block	380 mm
Lime-cement base plaster	15 mm
Lime plaster	5 mm
Total	818 mm

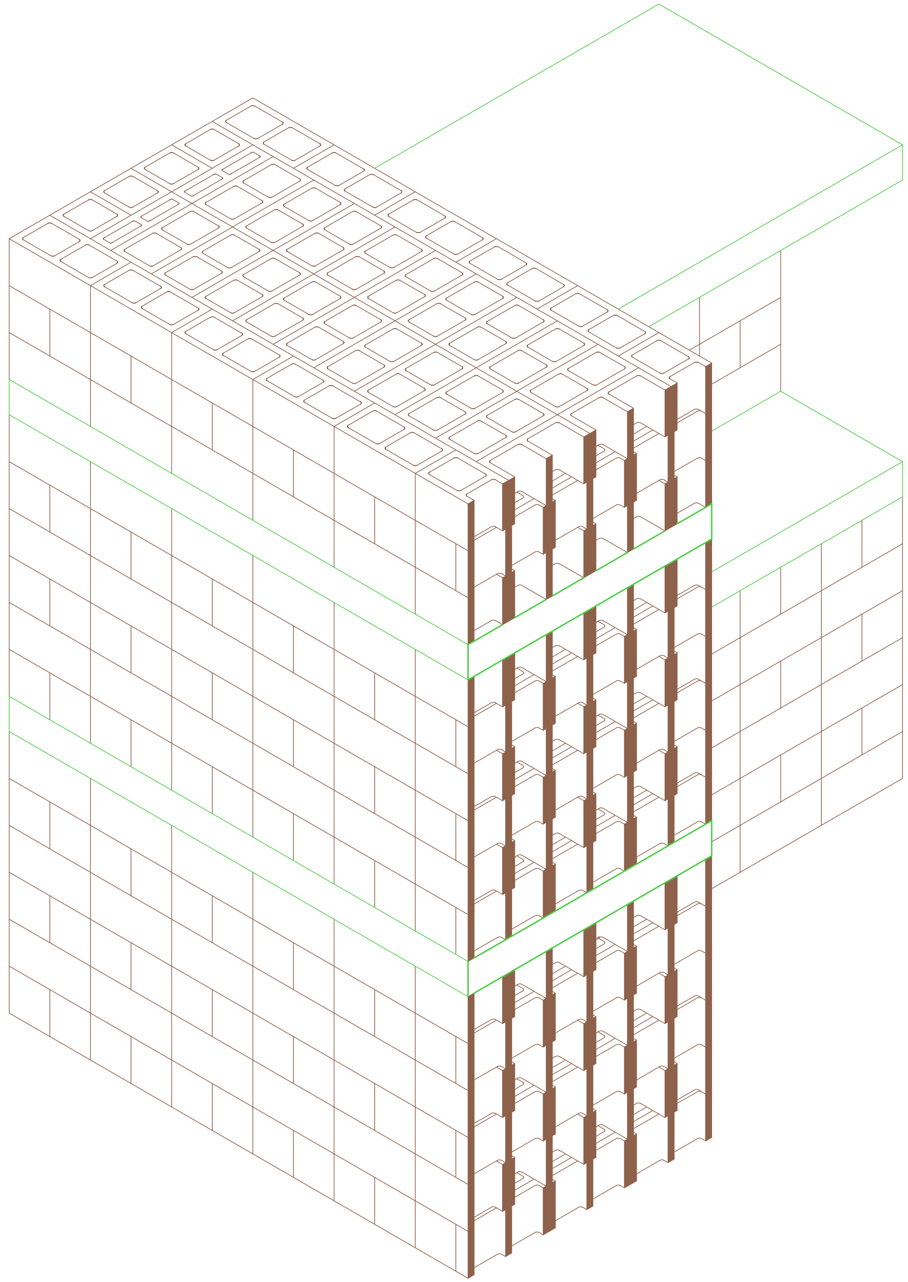
Headquarters for a Block Factory
Avaré, Brasil

Vao Architects
2016



The signature feature of the head office and showroom for a block factory is that it is made of the materials it produces. The building's unconventional construction results from an analysis of the system for storing and transporting the concrete blocks on pallets stacked to a height of 3.60 m. The building system developed by the architects echoes that of ancient megalithic constructions in which gravity was the main stabilising element. The mortarless construction is both quick to assemble as well as to disassemble and reuse should the building need to be relocated. Since the architects could use as many blocks as they wished, they opted to improve stability by significantly thickening the walls. The relationship of height, weight and connection of the blocks led to the development of two primary configurations of interlocking blocks: longitudinal walls with a width of 0.6 m and 1.20 m thick transverse walls. To connect the walls, the architects drew on the logic of the storage system: in place of the wooden pallets, they inserted precast concrete slabs every six courses. The modular principle of the blocks also determined the pattern of openings for ventilation and lighting.

0 50cm



Climate
Humid subtropical climate, Cfa*
no dry season, hot summer

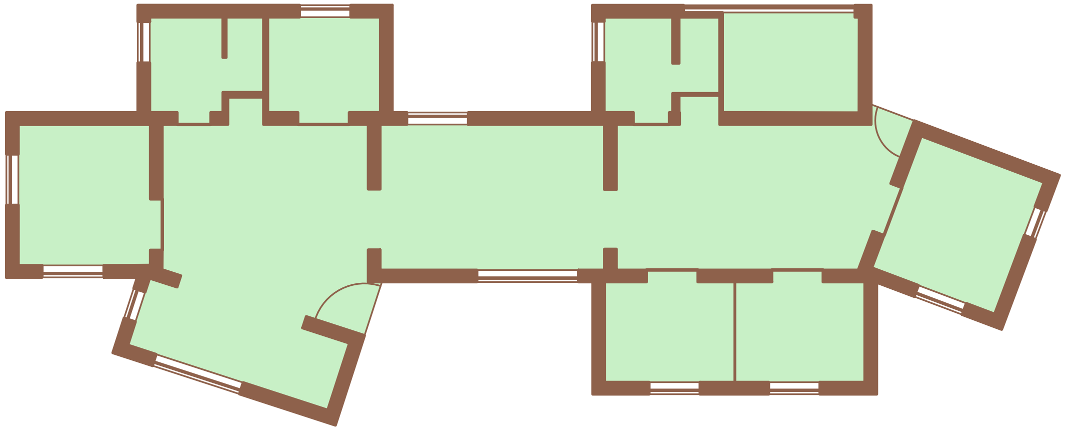
Units
Hollow concrete block
400/200/200 mm
Load-bearing

Wall construction: single leaf

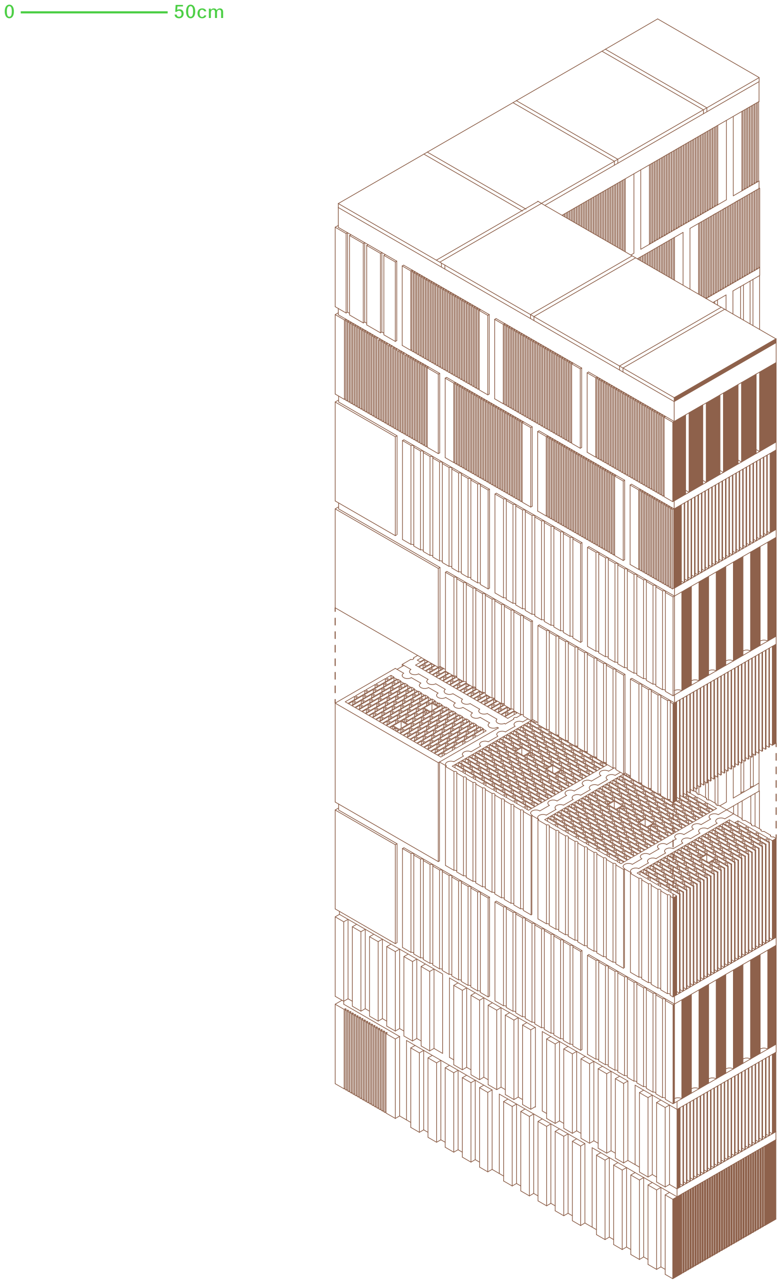
Hollow concrete block	200 mm
Hollow concrete block	400 mm
Hollow concrete block	400 mm
Hollow concrete block	200 mm
Total	1200 mm

12 Casa 1311
Castelldefels, Spain

HARQUITECTES
2016



The residence comprises two main rooms that are conceived as a bioclimatic extension of the garden and are illuminated from above to avoid the interior being overshadowed by the surrounding trees. All the walls are single-leaf constructions: there is therefore no distinction between external and internal walls, and the walls must satisfy both structural and thermal performance requirements. Made of 30 cm thick coarse, perforated ceramic bricks (Poroton-Planziegel T-10, Wienerberger), this simple construction also passively regulates hygrothermal exchange between indoors and outdoors, ensuring a high level of indoor room comfort all year round. The horizontal division of the wall into three layers – base, main wall and crown – allows lightweight bricks to be used in areas with lower thermal requirements. The perforated cavities in the hollow bricks not only improve thermal performance but also reduce their weight. The bricks have been milled to a precise size on both sides to ensure a uniform pattern of vertical joints, which is especially relevant for the unrendered building as the brickwork is exposed.



Climate
Hot-summer Mediterranean climate, Csa* dry summer, hot summer

Units
Clay block
248/300/249 mm
Base of the wall

Clay block
175/300/249 mm
Middle of the wall

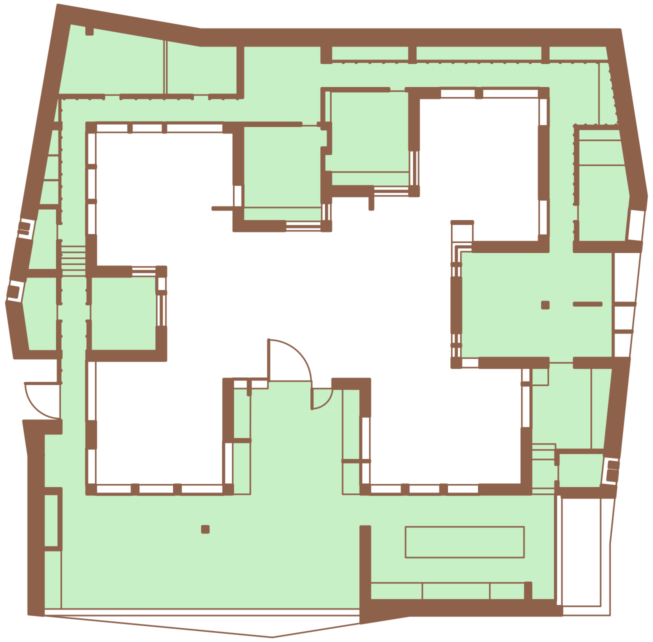
Clay block
240/300/249 mm
Head of the wall

Wall construction: single leaf

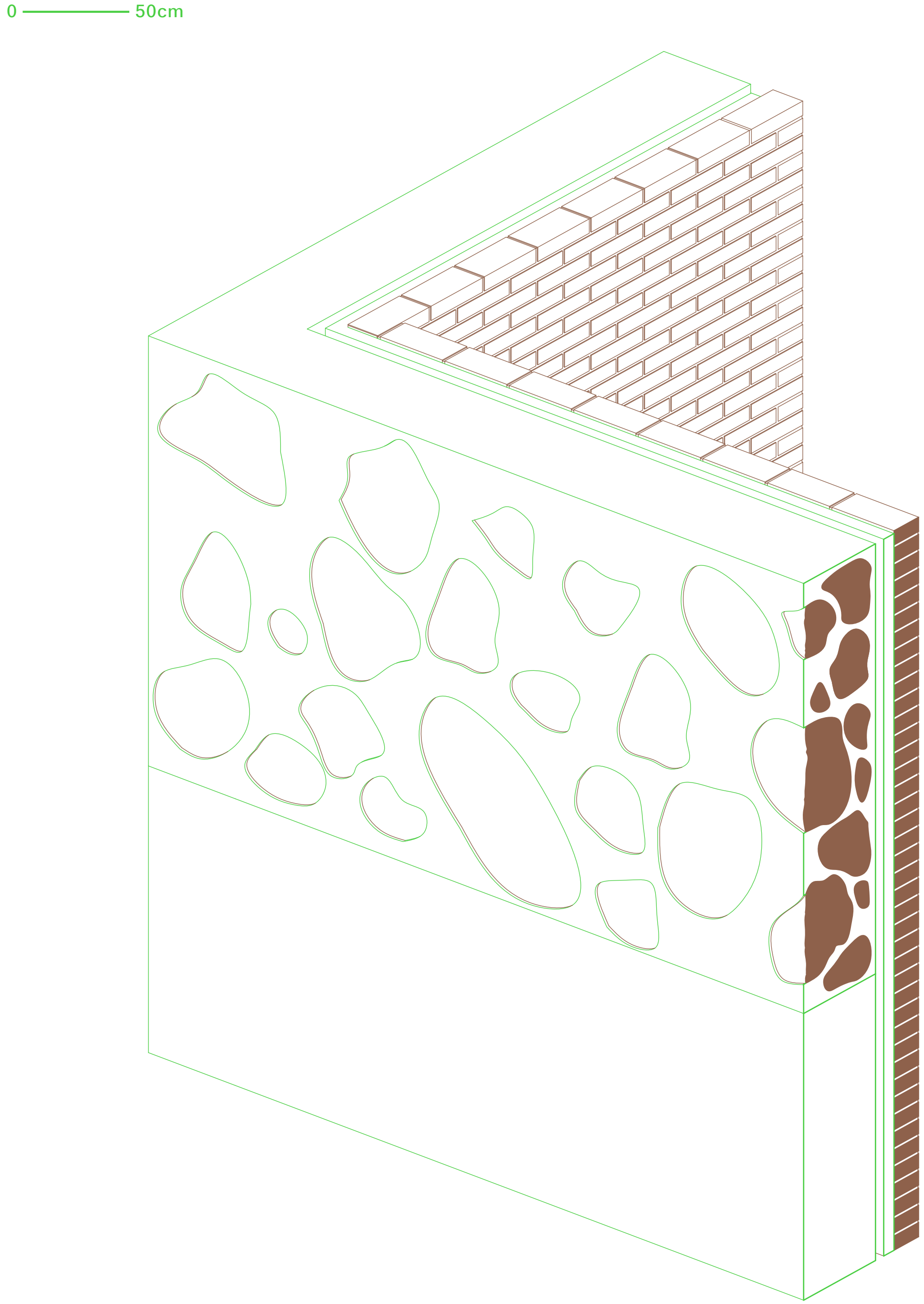
Clay block	300 mm
Total	300 mm

Jaime and Isabelle's Home
Palma, Spain

TEd'A arquitectes
2018



Patio houses are part of a Mediterranean tradition that incorporates means of climate control in their design and construction. For centuries, they have employed methods that help keep their houses pleasantly cool in summer and sheltered against excessive cooling in the winter months. The patio serves here to provide valuable shade in summer and protect the plants in winter. Its thick external walls act as thermal mass. This project for a single-family home in Mallorca sits in this tradition. Its perimeter walls convey the impression of a fortress – impenetrable and robust. Designed as a twin skin construction with a central air cavity and thermal insulation, it has a thickness of 0.56 m. The outer skin is concrete with embedded 'Cyclopean' stone blocks collected from the site. The use of larger stones in the concrete mix reduces the proportion of smaller aggregates. Thermal insulation is applied to the outer face of the inner leaf of exposed brick, with an air cavity between it and the outer leaf. Air circulation ensures that any condensation accumulating on the other shell can dry.



Climate
Cold semi-arid (steppe) climate, BSk*
steppe, hot

Units
Clinker brick – inner leaf
240/120/50 mm
Facing brick

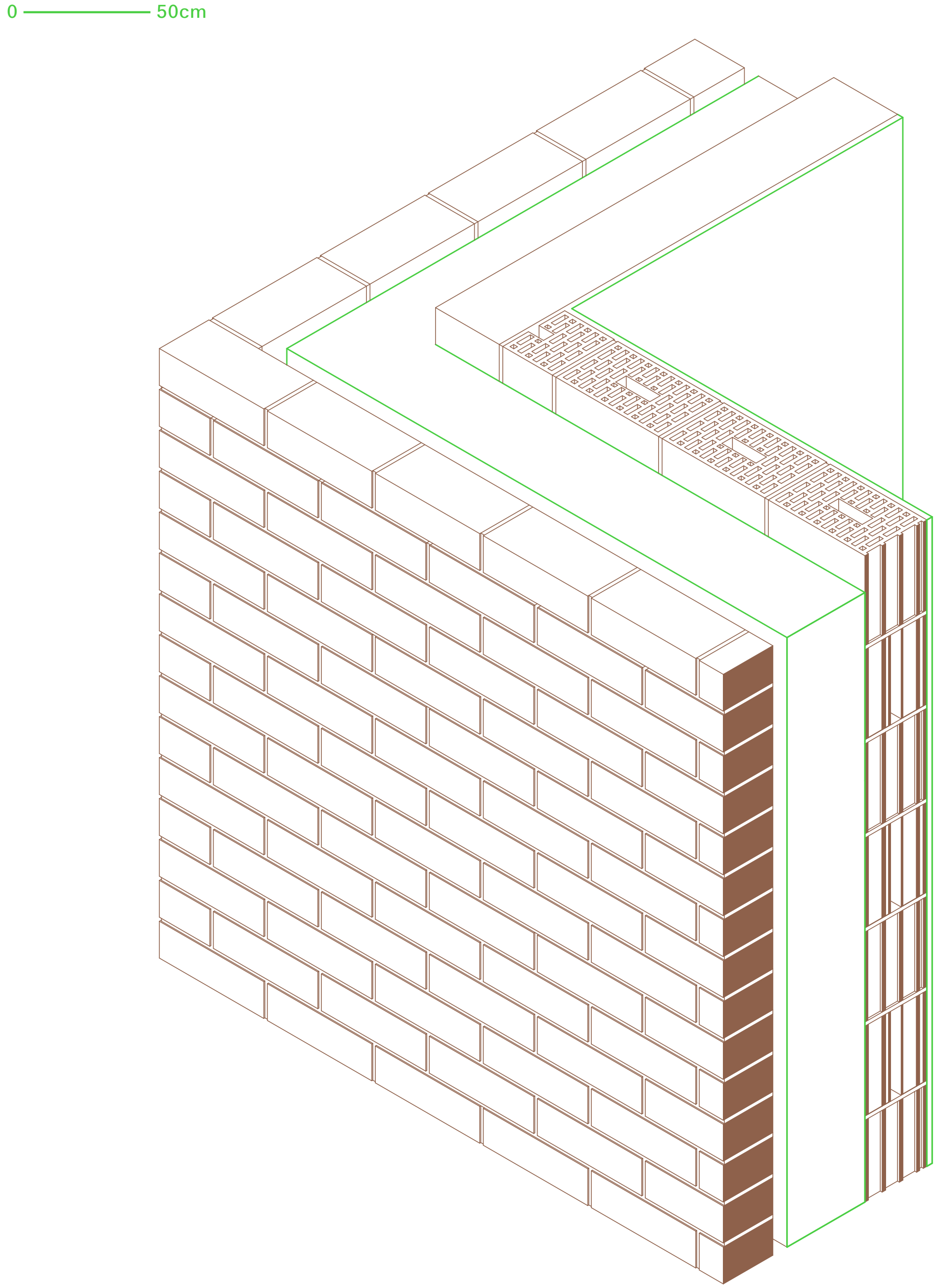
Wall construction: double leaf

Cyclopean concrete wall	350 mm
Air space	40 mm
Insulation	50 mm
Facing brick	120mm
Total	560 mm

Extension and Rehabilitation
Chexbres, Switzerland

LVPH
2020

The retirement and nursing home “La Colline” stands at the edge of the village of Chexbres where it transitions into the terraced vineyards of Lavaux over-looking Lake Geneva. LVPH extend the existing building down the slope by incorporating the design of the retaining wall structures that serve to terrace the protected landscape area. The new living areas additionally complement the landscape by providing horizontal gardens on their roof surfaces. The man-made structures that form the terraces in the landscape were tradition-ally made of local quarry stone, and since the 1950s of concrete or reinforced concrete. The project sparked a renewed debate on the materiality of these retaining walls. The walls facing the lake are made of a layer of structural, perforated bricks, a layer of insulation, a cavity and earth block facing ma-sonry. The earth blocks are produced in a local blockwork production facility, where they use the same production chain but using earth sourced locally from construction sites so that the result is a locally produced, low-carbon building material.



Climate
Temperate oceanic climate, Cfb*
no dry season, warm summer

Units
Stabilised block of raw earth (CSEB) – outer leaf
295/140/90 mm
Facing self-supporting brickwork

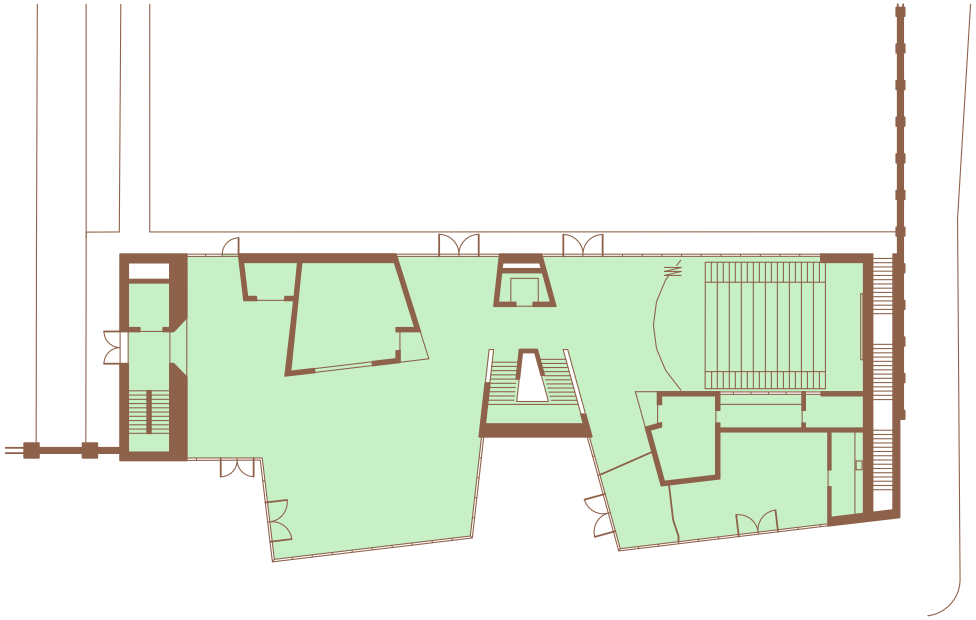
Clay block – inner leaf
290/175/190
Loadbearing

Wall construction: double leaf

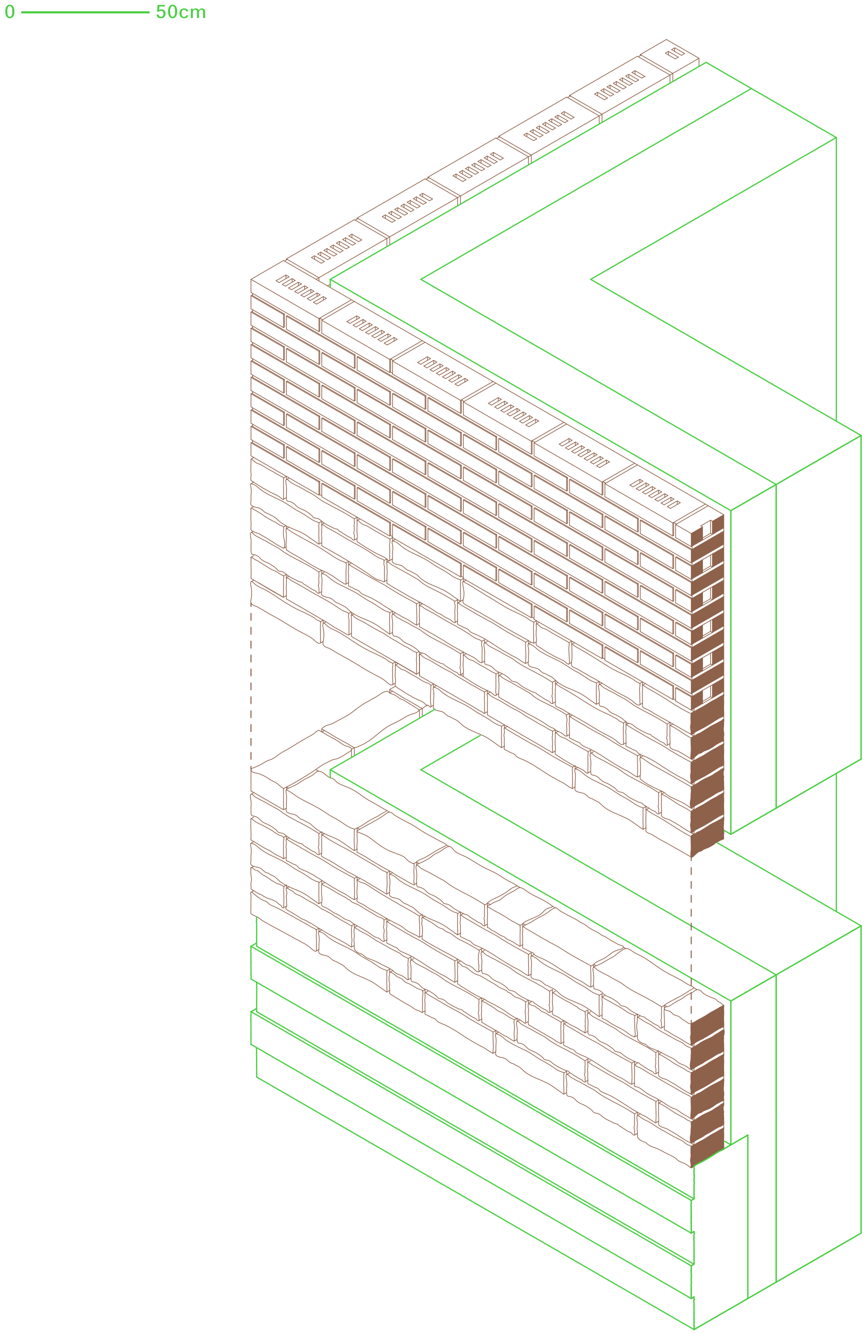
Stabilised block of raw earth	140 mm
Air space	30 mm
Insulation	220mm
Vapour barrier	
Clay block	175 mm
Mineral plaster	10 mm
Total	575 mm

Spore Initiative
Berlin, Germany

AFF Architekten
2023



Concrete constructions gave architecture the freedom of the simultaneity of rigid and flexible free floor plans, of spaces that can flow over many storeys, and of structural systems that dissipate loads in ways that seem to contradict the usual force of gravity. The previously dominant form of brick-on-brick masonry has been unjustly displaced rather than utilising the strengths of each to achieve new qualities. The Spore Initiative combines both approaches. The structural load-bearing concept allows the ground floor to act as an extension of urban space, creating two large exhibition spaces whose solid external walls support the smaller-scale residential floors above. The external skin of concrete facing, reclaimed clinker and new fired clinker bricks not only divides the volume into plinth, bel étage and "attica" zones but also puts the varied materiality of the different surface zones to the test. The conflict seen in curtain wall designs from the past decades in which the hermetic solidity of walls of masonry is interrupted periodically by expansion joints is resolved in this project through the use of flexible, movable wall ties that link the two leaves, along with fibre-reinforced mortar joints. The use of bricks reclaimed from other demolished buildings was accepted by the client after seeing the results of laboratory tests on the frost resistance of randomly selected brick specimens.



Climate
Temperate oceanic climate, Cfb*
no dry season, warm summer

Units
Recycled clinker brick, outer leaf
240/115/65 mm
Facing brick

Clinker brick, outer leaf
240/115/40 mm
Facing brick

Wall construction: double leaf

Facing brickwork	115 mm
Air space	25 mm
Insulation	160 mm
Reinforced concrete wall	300 mm
Total	600 mm

Appendix

G

Image Sources

P. 1, 93
© Clemens Waldhart

P. 2, 94–96
© Martin Fröhlich

P. 38–41
Lehm Ton Erde Baukunst GmbH, © Hanno Mackowitz

P. 42–43
© David Reffo Architecte

P. 44
Terrabloc, © Laurent de Wurstemberger

P. 45
© Tolila + Gilliland Atelier d'Architecture

P. 16
© Atelier Archiplein

P. 12–15, 17, 18
Atelier Archiplein, © Leo Fabrizio Photography

P. 26–28
© BLAF Architecten

P. 25–29
BLAF Architecten, © Stijn Bollaert

P. 31–33
Illustration by EAST LABORATORY. Data according to: G. P. Hammond/C. I. Jones, *Embodied energy and carbon in construction materials. Proceedings of the Institution of Civil Engineers – Energy*, 161(2), 2008, pp. 87–98, on: https://doi.org/10.1680/ener.2008.161.2.87, retrieved June 6, 2023.

P. 34
Illustration by EAST LABORATORY. Photo digitally upscaled and altered: LC³, "House in Jhansi, India", on: lc3.ch/wp-content/uploads/2023/02/LC3-A-sustainable-alternative-EN.pdf, retrieved September 26, 2023.

P. 24
Wilko Potgeter, *Die Erfindung des Verblendsteins: Bautechnik des Backstein-Rohbaus im Zeitalter der Industrialisierung*, Petersberg: Michael Imhof Verlag 2022.

P. 37
J. L. Breton/Raoul Mortier, *Science et Travail. Grande encyclopédie illustrée des nouvelles inventions*, Paris: Aristide Quillet 1927, p. 549.

Bibliography

Joseph Alchermes, "Spolia in Roman Cities of the Late Empire: Legislative Rationales and Architectural Reuse." in: *Dumbarton Oaks Papers*, vol. 48, 1994.

Agnès Bastin, *Gouverner le métabolisme: les terres excavées franciliennes*, collection Réflexions en partage, éditions PUCA, Février 2023.

D. Bernstein/J.P. Champetier/F. Pfeiffer, *La maçonnerie sans fard: Méthodes récentes de maçonnerie apparente* (Collection Architecture et technologie), Paris: Editions du Moniteur 1982.

Ingrid Campo-Ruiz, "Construction as a Prototype: The Novel Approach by Sigurd Lewerentz to Using Building Materials, Especially for Walls and Windows, 1920–72", in: *Construction History*, vol. 30, no. 2, 2015.

Nathan Claeys, *30 Ways to build a wall*, master's thesis, Ghent University 2019.

Florie Dejeant/Philippe Garnier/Thierry Joffroy (eds.): *Matériaux locaux, matériaux d'avenir : Ressources locales pour des villes et territoires durables en Afrique*, CRAterre Éditions 2021.

Andrea Deplazes, *Constructing Architecture: Materials, Processes, Structures: a Handbook*, Transl. by Gerd H. Söffker, Basel/Boston/Berlin, Birkhäuser 2005.

Lionel Devlieger, "L'architecture à L'envers", in: *Criticat*, 18/2016 autumn, 2016.

Udo Garritzmann, *Modes of Tectonic Thinking: Proposal for a Non-Dualistic Understanding of Tectonic Expression in Architecture*, doctoral thesis, Aarhus School of Architecture 2021.

Sigfried Giedion, *Mechanization Takes Command: A Contribution to Anonymous History*, New York: Oxford University Press 1948.

Guillaume Habert, *"The hidden value of stone: Life cycle assessment of the construction and refurbishment of a 60-year-old residential stone building"*, in: Ruben Paul Borg/Paul Gauci/Cyril Spiteri Staines (eds.), SBE 16 Malta: Europe and the Mediterranean Towards a Sustainable Built Environment, conference lecture on March 17, ETH Zurich 2016.

Annette Helle/Barbara Lenherr, *Beyond Concrete: Strategien für eine postfossile Baukultur/Strategies for a post-fossile Baukultur*, Zurich: Triest Verlag 2022.

Arnaud Hendrickx, "The (under)searching practice" in: Isabelle Blancke et al. (eds.), *When attitudes take shape*, Antwerpen: Flemish Architecture Institute (Architectuurboek Vlaanderen) 2020.

Valerie Hoffmeyer, "Matériaux d'excavation, la grande évasion", in: *Tracés* 3517, February 2022.

Melvin Kranzberg/Michael T. Hannan (Britannica), *"History of the Organization of Work – Monumental Construction, Labor, Crafts | Britannica Money"*, on: www.britannica.com, retrieved May 2, 2023.

Bruno Marchand et al., *Matières 14 – L'oeuvre et le temps*, Lausanne: EPFL Press 2018.

Gernot Minke, *BUILDING with EARTH: Design and Technology of a Sustainable Architecture*, Birkhäuser 2007.

Lieven Nijs, "Brick: Building Block Of Paradoxes", in: *A+*, Back to Brick, 294/2022.

Lieven Nijs/Bart Vanden Driessche, *BLAF architecten. First notes on the building system and product development for the construction of sustainable and energy-efficient, brick faced buildings*, September 2014.

Martin Rauch et al., *Martin Rauch: Refined Earth, Construction & Design with Rammed Earth*, edition DETAIL, Institut Für Internationale Architektur-Dokumentation, Munich 2015.

Colin St. John Wilson, "Sigurd Lewerentz and the Dilemma of the Classical." in: *Perspecta*, vol. 24, 1988, p. 68, on: https://doi.org/10.2307/1567123, retrieved January 12, 2020.

Oswald Mathias Ungers, interviewed by N. Kuhnert, "Detail: Das Tüpfelchen auf dem i", in: *Arch+*, 87, 1986.

Wilko Potgeter, *Die Erfindung des Verblendsteins: Bautechnik des Backstein-Rohbaus im Zeitalter der Industrialisierung*, Petersberg: Michael Imhof Verlag 2022.

Canton of Vaud, General Directorate of the Environment (DGE), *Carrières, gravières et décharges – Compte rendu de la consommation, de la production et des réserves, 2019*, version 2, April 2021.

Griet Verbeeck, *Optimization of extremely low energy residential buildings*, KU Leuven 2007.

Georg Windeck et al., *Construction Matters*, Brooklyn: Powerhouse Books 2016.

Jan Peter Wingender, *Brick: an exacting material*, Architectura & Natura Press 2016.

Authors

Alia Bengana
founded her architectural practice in Paris in 2009. She has specialised in using natural materials, particularly focusing on earth-based construction. Since 2015 she has been teaching in Paris and, from 2021, at EPFL ALICE LAB and the Joint Master of HEIA Fribourg. Additionally, Bengana contributes to the Swiss French architecture magazine Tracés and is working on a comic book based on her exploration of concrete.

Anja Fröhlich
is associate professor for Architectural Design at EPF Lausanne, where she heads the EAST Laboratory together with Martin Fröhlich. She holds a PhD from Bauhaus University Weimar on the typology of the growing house. Her ongoing research focuses on typologies in architecture and their possibilities for the future.

Martin Fröhlich
is associate professor of Architectural Design at EPF Lausanne and co-director of the EAST Laboratory. He is also co-founder of AFF Architects Berlin/Lausanne and of the AFFECT research laboratory on circular building.

Hisham Hafez
is a post-doctorate researcher specialising in performance-based Life Cycle Analyses of sustainable building materials currently at the University of Leeds under the £ 5M funded TransFIRe hub to model the transformation of the UK's foundation industries to achieve the circular economy and net-zero targets by 2050.

Francis Jacquier and Marlène Leroux
founded the Geneva based Atelier Archiplein in 2008. Francis Jacquier is a heritage architect trained at the École de Chaillot in Paris, specialising in heritage assessment and interventions in existing buildings. Marlène Leroux holds a PhD from EPFL and continues to develop her expertise in urban planning. Atelier Archiplein is characterised by intellectual rigour and the ability to combine the global and the local, underpinned by a constructive pragmatism that draws on both the study of history and their own experience.

Beatrice Malchiodi
is a post-doctorate researcher at the Laboratory of Construction Materials (LMC) of EPF Lausanne. She worked as a civil engineer and obtained her PhD in construction materials. Her research focuses on the application of LC³ at the concrete scale aiming to contribute to the decarbonisation of the construction sector.

Lieven Nijs
founded the architectural practice BLAF in Lokeren (Belgium) together with Bart Vanden Driessche in 2003. Since 2008 he has been affiliated with Ghent University. In 2022 he was granted an FWO Special PhD

Fellowship to report on the practice-based research of BLAF (ongoing). He is currently appointed Guest Professor of Architectural Design at RWTH Aachen.

Karen Scrivener
is a full professor at the Institute of Materials at EPF Lausanne and head of the Laboratory of Construction Materials (LMC). Her research focuses on the chemistry, micro-structure, and sustainability of cement-based materials. Since 2004 she has been pioneering the breakthrough LC³ (limestone calcined clay cement) technology.

Clemens Waldhart
is an architect and educator. He studied at Graz University of Technology and Berlin University of the Arts. After teaching at the FH Potsdam and UDK Berlin, he joined Laboratory EAST at EPF Lausanne in 2020. He is co-founder of AFFECT research laboratory, which focuses on responsible construction methods.

Acknowledgements
We would like to thank all authors, guest speakers, assistants and students for their research and insights that contributed to the intellectual rigour and substance of this publication.

EPF Lausanne
ENAC EAST
Institute of Architecture
Laboratory of Elementary
Architecture and Studies of Types
Prof. Dr. Anja Fröhlich and
Prof. Martin Fröhlich

Team 2022–2023
Tiago P. Borges
Lara Monti
Vanessa Pointet
Maria Sivers
Clemens Waldhart

Conferences
Petrus Aejmelaeus-Lindström
Thibaut Barrault
Mario Galiana Liras
Francis Jaquier
Anupama Kundoo
Björn Martenson
Susanne Mühlhaus
Lieven Nijs
Tristan Pestre
Amin Taha
Baukje Trenning
Roger Tudò Galí

Participating Students
Zoé Aymon
Alexandre Bai
Louis Baldy-Moulinier
Maxime Blanc
Laurie Castella
Pablo Castellón Arévalo
Maïna Cazenave Cloutier
Nieves Clavien
Valentine Crettex
Joanna Druey
Enzo Fontanella
Eddy Friedli
Arthur Gigon
Noémie Goehry
Patrick Grandjean
Magali Hölzl
Aris Karara
Emeline Ludwig
Darius Michoud
Nikola Milanovic
Paul Schaffner
Gabriel Treyer
Nathan Wanner

Editor
Laboratory EAST

Text Coordinator
Clemens Waldhart

Graphic Layout of the Projects
Lara Monti

Graphic Adaptation of the Projects
Noémie Perregaux-Dielf
Abigail Riand

Copy Editing and Proofreading
Julian Reisenberger
Y'plus, Katharina Pils

Translations
Julian Reisenberger
(texts Anja Fröhlich, Martin Fröhlich; Lieven Nijs, revision text Beatrice Malchiodi with Hisham Hafez, and Karen Scrivener, Alia Bengana, Martin Fröhlich and Clemens Waldhart)
Fionn Petch
(text Francis Jacquier and Marlène Leroux)

Graphic Design
Omnigroup, Lausanne

Lithography
Christian Ertel

Typeface
Integrale, Omnitype

Triest Verlag receives a grant for the years 2021 to 2024 from the Federal Office of Culture as part of the Swiss publishers' subsidies.

ISBN 978-3-03863-084-5

DOI: 10.61037/TVA00020

Printed version available:
https://www.triest-verlag.ch/en/produkte/book-26/architecture-139/mass-made-units-3028


ARÃO