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The implementation of earth blocks in Belgium and Luxembourg: A case study analysis

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ABSTRACT: In the search for building materials with a lower environmental impact, there is a resurgence of interest in earth construction. Due to their similarity with conventional materials, earth blocks (EBs) have a high potential to enter mainstream construction. However, to upscale their implementation in practice, better insights into the design and construction process are needed. This paper presents three cases with EBs, both stabilised and unstabilised, and for load-bearing and non-loadbearing applications. Through site visits and in-depth interviews, architects, clients, and contractors are asked to share their experiences on working with EBs and to compare with conventional construction practices. Considerations when choosing EB masonry and specific mortar/block combinations and on-site organisational and practical aspects are mapped. By documenting and analysing real-life cases and comparing with literature, a better understanding of the challenges and practical aspects of implementing EBs in contemporary constructions are obtained, as well as design implications and solutions.

1 INTRODUCTION

Despite its historical significance as a building material, earth has gradually fallen into disuse because of the widespread availability of concrete, fired bricks and steel (Schroeder 2015, Van Damme & Houben 2018). However, with growing awareness about resource depletion and climate issues, interest in earth as a circular building material is increasing (Christoforou et al. 2016, Fernandes et al. 2019, Morel et al. 2021). Especially earth blocks (EBs) have a high potential to enter mainstream construction as responsible alternative building materials because of their similarity with conventional materials, such as fired bricks and concrete blocks (Pelicaen et al. 2023).

In recent years, various initiatives have been taken to industrialise and standardise earth block production. In Western Europe, several material producers have started producing earth blocks with local and excavated soil, e.g. in Belgium (BC Materials), the Netherlands (OSKAM V/F), France (Cycle Terre, Briques Technic Concept, Argilus), Luxembourg (Geobloc), Germany (Claytec, Conluto,…), Switzerland (Terrabloc), Spain (Fetdeterra, Cannabric) and the UK (HG Matthews). Academic research into the properties and behaviour of earth-based materials is increasing, and progress has been made to improve and standardise traditional earthen construction techniques (Schroeder 2012, Fabbri et al. 2021, Fabbri et al. 2022).

Although earth blocks can be set in masonry walls, following typical masonry techniques, they have distinct material properties that differ from those of conventional building blocks. Their limited water resistance, specific structural and hygrothermal behaviour and high mass density raise additional challenges during both design and construction (Morton 2008, Beckett et al. 2020). Stabilisers, such as cement, are increasingly being added to earth blocks and earth mortars to overcome some of these shortcomings (Van Damme & Houben 2018). However, stabilisation increases the environmental impact, not only in the production stage but also

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complicates the material's end-of-life (Pelicaen et al. 2024). For some applications, these superior properties are not needed, or the design can be adapted to accommodate them, e.g. by avoiding direct contact with water. At the same time, construction sites should be arranged so that even during construction, the stored blocks and the executed earth block masonry are not exposed to direct rainfall.

To further upscale the implementation of EBs in practice, better insights into the design and construction process with EBs and the architects' considerations when choosing specific mortar block combinations are needed. Therefore, this paper presents a case study analysis of the design and construction process of three real-life cases with earth blocks. This case study analysis is part of a 3-year research project in which Hasselt University, a2o architecten, Democo (contractor) and Buildwise (building research institute) and material producers brickZ and BC Materials explore the application of earth blocks in construction projects. The results will be used to develop a framework for decision-making regarding EB application and guidelines for architects, contractors and clients to choose for and design and build with earth blocks. Additionally, they will provide input for earth block producers to develop their product range further.

2 METHODOLOGY

This research adopts a case study approach to analyse the implementation of earth blocks in contemporary construction projects. The study focuses on three real-life cases in Belgium and Luxembourg, each incorporating a significant volume of earth blocks in their construction. The earth blocks used in the cases were all produced by a Belgian material producer, who transforms excavated soil into moulded earth blocks (MEBs) and vibro-compacted compressed earth blocks (CEBs) through industrial co-production with producers of fired bricks and concrete blocks. The MEBs are unstabilised and produced on the production lines of a fired brick producer. The CEBs are stabilised with 3,85% cement to improve water resistance, strength and fire resistance and are produced in an industrial facility that produces vibro-compacted concrete blocks. Although earth block masonry is still in its initial stage in Belgium and Luxembourg and only a few projects are realized at this moment, three cases were studied based on their varied use of EBs, i.e. both load-bearing and non-load-bearing applications, newly built constructions and renovation, and different types of mortar, ensuring a diverse representation of materials and applications.

Data was collected through, on the one hand, an analysis of construction plans and site visits complemented with insights from contractors and clients and, on the other hand, semi-structured in-depth interviews with the architects responsible for each project. The site visits and the analysis of construction plans provided first-hand observation of the on-site organisation of the construction process, material application, and technical detailing and execution. The interviews facilitated a deeper understanding of the decision-making process, motivations for choosing earth blocks, considerations when choosing specific mortar-block combinations and additional organisational and practical aspects associated with using earth blocks from the architect's perspective. This multi-method approach ensures comprehensive data collection, enabling a nuanced analysis of the practical and technical implications of earth block implementation in the Western European construction sector.

3 CASE STUDY ANALYSIS

3.1 *Case 1 - Scharphout: loadbearing and non-loadbearing masonry with CEB*

The first case (Figure 1), located at the Scharphout site in Bruges, Belgium, is designed by the architectural office Dertien12. The city of Bruges envisioned the design of a new community centre, with facilities such as a sports hall, library, spaces for youth associations and a local service centre, as a circular pilot project with a strong focus on sustainable material use through reusing materials, using materials with a low environmental impact and avoiding waste. Stabilised compressed earth blocks (CEBs) in combination with an M10 bastard mortar (based on lime and cement) with an earth additive are used for the interior part of the cavity walls and the interior walls. Some walls act as infill walls in a concrete skeleton, whereas others are load-bearing. To ensure air tightness, the interior part of the cavity walls will be plastered with earth plaster, whereas the interior walls will mainly be left unplastered.

Figure 1. Case 1 - Scharphout, loadbearing and non-loadbearing masonry with CEB (newly built).

3.1.1 *Motivations for choosing earth blocks*

The city of Brugge issued a tender which called for a circular pilot project. The architectural firm was assisted by C2C ExpoLab, Möbius and Howest to explore construction methods fitted to this purpose. The construction incorporates a mixed structural system, consisting partly of a wooden and partly of a concrete skeleton. The concrete skeleton is filled with walls made of compressed earth blocks (CEBs). In recent years, timber prices have risen significantly, prompting the architects to explore alternative sustainable construction systems, which ultimately led them to choose earth blocks. Additionally, the architect mentions that their high thermal mass, facilitating efficient heating, was an extra motive for choosing earth blocks. However, at a later stage of the construction, it was decided to use conventional concrete blocks instead of CEBs in the youth association spaces due to budgetary constraints and the lower fragility of concrete blocks.

Initially, the architects intended to transform the soil present at the construction site into earth blocks. However, as the required soil volume would be too excessive, it was decided to use industrially produced blocks based on excavated soil from elsewhere. As social participation was an important factor in the design and construction process, the city of Bruges, the architectural office and the material producer organised, prior to the construction works, four participatory workshops in which unstabilised moulded earth blocks were produced, using soil directly sourced from the project site. In one of the walls of the community centre, these earth blocks will be integrated together with the stabilised vibro-compacted earth blocks supplied by the manufacturer. Each workshop engaged a group of future end-users of the community centre, including judo practitioners, KSA youth group members, local school children, and residents from the surrounding community. This process illustrates an approach to the participatory use of earth blocks, fostering a meaningful engagement of end-users in the project. According to the architects, workshops like the one they organised for this project are essential in conveying the story of sustainable material use and circularity to users, maybe even more than just the building itself.

3.1.2 *Considerations for choosing CEBs with bastard mortar*

The architect points out that the size of the blocks, and therefore the cost of masoning, was the main reason for selecting CEBs instead of MEBs. Because the MEBs are much smaller, the execution cost of the masonry is much higher.

In general, for load-bearing walls, a bastard mortar with an earth additive or an earth adhesive mortar is typically specified, as a pure earth mortar is not recommended for these applications. In this case, a bastard mortar with earth additive was selected. The bastard mortar is a standard bastard mortar, based on cement and lime, but with an earth additive (3 bastard mortar: 1 earth additive) to render the mortar compatible with the hygrothermal and mechanical behaviour of the earth block, accommodating shrinkage and dilatation of the masonry and preventing crack formation. The bastard mortar also has a higher water resistance than an earth mortar, reducing the dependency of masonry construction on favourable (dry) weather conditions. However, as demonstrated by Pelicaen et al. (2024), the strong bond strength between CEBs and the bastard mortar with earth additive may significantly complicate, or even prevent, the dismantling of the masonry at the end of its service life, making it less suitable for reuse than for demolition and recycling.

3.1.3 *Organisational and practical aspects*

According to the architect, the design process did not differ significantly from conventional practice. However, since the architectural office had never worked with earth blocks before, extra attention was given to specific applications and, e.g. in the youth association spaces, they opted for a more well-known, durable and less fragile material, i.e. conventional concrete blocks, to avoid damage to walls during youth activities.

This project was also the contractor's first experience working with earth blocks. As earth blocks are more vulnerable to damage during transport, e.g. resulting in chipped corners, the contractor was initially concerned that this would give rise to future discussions. For the first delivery, he wanted to explicitly mention the damaged blocks in the site report, but after working with the CEBs and getting more familiar with their properties, his initial concern disappeared. As earth block implementation is still in its initial phase in the Belgian construction sector, the architects and the contractor were actively guided during the design and construction phase by the material producer, who visited the construction site multiple times to explain the procedure of making mortar and masoning the blocks.

Additionally, the CEBs require extra attention during storage and handling on-site due to their heavy weight and water sensitivity. According to the architect, in this large project, this was not a problem, as pallets could be easily transported on-site by means of the available construction crane. Open pallets could be protected from the rain at all times. However, at smaller project sites, he argues that this could be challenging, as space is limited, a crane is not available, and pallets are stored at one location while blocks are distributed over the construction site.

The masoning was done in a small team that worked very precisely. The architect states that the aesthetic quality of the masonry is better than expected and that, together with the client, they have decided to leave more masonry in sight. Although the stabilised CEBs have a higher water resistance than the unstabilised MEBs, the material producer advises protecting the walls' top surface from rainwater infiltration during construction. The architect explicitly stated in the specification text that the contractor was responsible for this, and the contractor was very keen on this aspect. The architect mentions, however, that this is also common practice with regular masonry. Due to the poor water resistance of unstabilised MEBs, the wall with the MEBs made during the participatory workshops was entirely shielded from weather conditions during the construction phase.

Stabilisation with cement induces chemical reactions within the earth blocks, preventing the material from returning to its original raw constituents at the end of its service life and being disposed of in nature. This modification also presents challenges on-site during construction, particularly concerning construction waste management. The material producer is actively researching methods to recycle stabilised blocks for use in the production of new blocks. However, in this initial phase of earth block implementation in the Belgian construction sector, the current volumes of construction waste render this approach economically unfeasible at this moment.

3.2 *Case 2 - Ostend: Non-loadbearing masonry with CEB*

The second case (Figure 2) is a renovation project in Ostend, designed by BOB361 Architects. In this project, a former youth centre is being transformed into a co-housing project with ten residential units distributed between the existing front building and the rear extension. The client wanted to develop a co-housing project with shared spaces, multiple patios and rooftop gardens to foster a collective and social use and atmosphere. Additionally, the intention was to apply sustainable materials and minimise the project's carbon footprint. Consequently, the decision was made to renovate the existing building and the hall behind the main building rather than pursue new construction. Stabilised compressed earth blocks are used throughout the project in combination with an unstabilised earth mortar. The walls between separate residential units will be plastered for acoustical reasons. Initially, it was intended to plaster all walls, but for aesthetic reasons and to save costs, architects and clients are considering leaving some interior walls in sight.

Figure 2. Case 2 - Ostend, non-loadbearing masonry with CEB (renovation).

3.2.1 *Motivations for choosing earth blocks*

In the architects' search for sustainable and local materials for the construction, they came into contact with the material producer, who was searching for a pilot project to implement their newly developed CEB. The architect welcomed this opportunity and was willing to take the risk of adopting an innovative construction material for the project. As a result, the use of CEBs was introduced at a later stage of the design process, meaning the project was not initially conceptualised with earth blocks in mind.

3.2.2 *Considerations for choosing CEBs with earth mortar*

Since the material producer was looking for a project to implement this specific type of earth blocks (i.e. stabilised vibro-compacted), alternative types were not considered. The architect recognises that the construction industry is typically slow to adopt new materials, and he was, therefore, enthusiastic about contributing to the broader effort of introducing an innovative product.

The CEBs are combined with an unstabilised earth mortar as the walls are non-loadbearing indoor walls. The pure earth mortar is also a more circular choice with a lower environmental impact. The architect acknowledges that, in that case, the earth mortar is the weakest spot in the wall. Even when hardened, the joints remain crumbly and fragile, which is a disadvantage when the walls are left in sight afterwards. From a practical point of view, pure earth mortars need more time to harden, slowing down the masonry work significantly.

3.2.3 *Organisational and practical aspects*

Currently, earth block production in Belgium is still in the early stages, where the demand for blocks is rather low, and production occurs only at specific times. Since construction schedules often change, predicting the exact timing for block delivery on-site is challenging, creating storage issues for both producers and construction sites, especially in densely built areas. However, these challenges are related mainly to introducing a new material to the market, where production, supply chain and application still require scaling up rather than being inherent to earth blocks themselves. However, the blocks' heavy weight and need for protection from rain add further complexities in storage and handling.

For the bricklayers, it was their first experience with earth mortars that have a different workability when compared to conventional masonry mortars, i.e. being extremely sticky, leading to slower work progress. To overcome this, the bricklayers initially intuitively added soap to the mortar as they are used to improve the ease of applying them. However, this resulted in a serious decrease in adhesion strength between mortar and EB and after consultation with the material producer, they carefully followed the technical specifications of the earth mortars.

The CEBs are produced in a production facility of vibro-compacted concrete blocks. The dimensions of these blocks are different from the dimensions of conventional concrete blocks used for masonry walls. Especially in renovations, where new walls complement existing walls, the height difference induces challenges when the new and existing materials have to interlock, e.g. at corners, or when applying reinforcements.

In this case, earth mortar was used which is suitable for non-loadbearing indoor applications. However, due to planning issues, the masonry walls were exposed to the external environment for nearly a year before the building skin was made wind- and waterproof. To prevent the mortar from being washed out during the construction phase, the walls were covered. Because this process took nearly a year, some water inevitably seeped in, which washed out of the joints in several walls and made repairs necessary.

3.3 *Case 3 - Betzdorf: Non-loadbearing masonry with MEB*

Near Luxembourg city, the municipality of Betzdorf decided to turn the construction of a new childcare centre for children between the ages of 0 and 4 into a pilot project with sustainable materials (Figure 3). The project is designed by the architectural office Valente, supported by Schroeder & Associés (engineering office) and ZRS Architekten Ingenieure, Christof Ziegert and Andrea Klinge (earth and sustainability engineering). Health-related aspects, circularity, locality and low-tech design principles (e.g., no mechanical ventilation) were key to the design process. Custom-made unstabilised moulded earth blocks (MEB), developed by BC Materials and produced through a partnership between BC Materials and Vande Moortel Brickworks, are used as infill walls within a wooden skeleton. The primary load-bearing structure of the project is constructed in cross-laminated timber (CLT). Some EB walls will remain in sight, while others will be covered with an earth plaster.

3.3.1 *Motivations for choosing earth blocks*

One of the client's main drivers in the project's development was the emphasis on health-related aspects. Additionally, the municipality of Betzdorf aimed to maximise the building's circularity by using locally sourced materials as extensively as possible. A lecture on earth construction inspired them to transform the soil of a nearby construction site into a building material and develop a fully circular, locally harvested, unstabilised moulded earth block.

3.3.2 *Considerations for choosing MEBs with earth mortar*

In combination with unstabilised earth blocks, unstabilised earth mortar is a logical choice from both an environmental and compatibility perspective. The earth blocks (MEBs) were specifically developed for this project based on the soil available at a nearby construction site. This soil contains a high clay content, making the production of compressed blocks unfeasible, leading to the decision to use moulded earth blocks instead. Still, a significant amount of sand needed to be added to the local mixture to ensure the required quality of the blocks. The

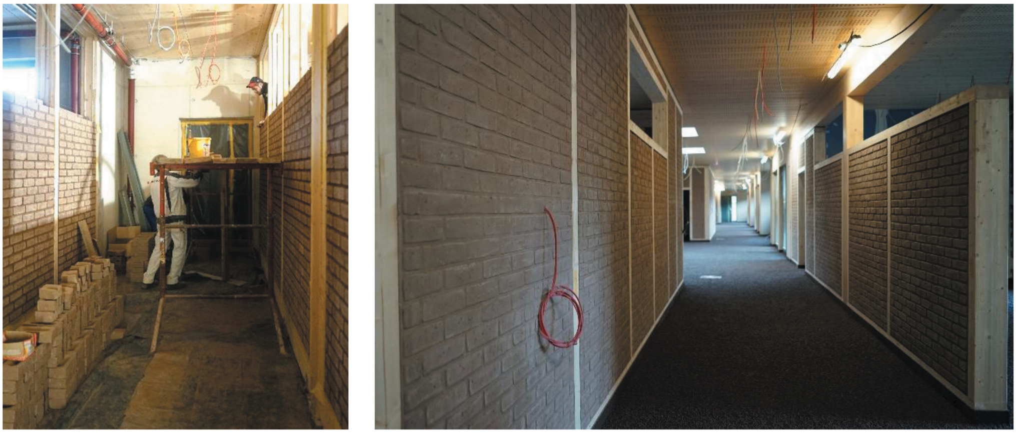

Figure 3. Case 3 - Betzdorf, non-loadbearing masonry with MEB (newly built).

excavated soil was transported to the brick factory, where the MEBs were produced on the fired brick production lines, which are also used to produce the standard commercially available MEBs. Although the raw materials were harvested locally, they needed to be transported to the west of Belgium (and back) to be transformed into earth blocks (approx. 300 km). However, extraction of raw materials from new quarries was avoided by using excavated soils that would otherwise be disposed of.

3.3.3 *Organisational and practical aspects*

The architect mentions that the limited water resistance of EBs requires careful consideration during design. Extra precautions were taken, e.g. to prevent water intrusion through the floor slab (elevated concrete floor and rubble base) or during cleaning (extra wood thickness at the lower part of the frame). During construction, the poor water resistance of the blocks did not cause any problems on-site, as the building was already watertight when the blocks arrived on-site.

Waste disposal was also not a concern in this case. Despite the lower strength of the MEBs, no significant damages during transport to the site and on-site were reported. While not all blocks were perfectly shaped during production, these imperfect blocks were set aside to be used in walls that would be plastered afterwards. As a result, nearly all produced earth blocks were utilised, and the minimal waste that was generated was used as infill material on site, as neither the blocks nor the mortar are stabilised.

The contractor notes that no specific training was required for masoning the earth blocks, though there are particular points of attention to consider. Only a limited height (approximately one metre) can be laid at a time, and these layers need to dry for seven days before proceeding, which is considerably longer than in the case of concrete blocks. If drying times are not respected, cracks may appear at the top of the masonry due to settling, as also occurred in case 2. The architect also mentions that combining the wooden structure with earth blocks was challenging due to the differing shrinkage behaviour of the two materials. Therefore, to prevent cracks between the wooden structure and the earth block infill wall, joints adjacent to the wood were left open until the wall had fully dried and were filled afterwards. After construction, it was found that vibrations from closing doors caused cracks in the earth blocks; an earth block with a higher thickness might help mitigate this issue in the future.

Although the architect is enthusiastic about using unstabilised moulded earth blocks in the project, he has some concerns about their durability, as the building's users will be children between the ages of 0 and 4. Nonetheless, he was willing to accept this risk in this project, and time will reveal how the blocks perform during the usage phase.

4 CONCLUSION

Through a case study analysis, this paper investigates the design and construction of three diverse projects with earth blocks. All cases were conceived as circular projects, focussing on local materials with a low environmental impact, which was the primary motivation for selecting earth blocks. In two cases, the intention was to use excavated soil from the construction site or its surroundings. Due to a lack of available soil in one of these cases, commercially available blocks were used in the end, but these were combined with a small amount of blocks produced from local soil during participatory workshops involving the project's future users.

Unstabilised earth blocks and mortars have a lower environmental impact, as they contain no stabilisers. This results not only in lower carbon emissions in the production stage but also makes them fully circular. The chemical composition of unstabilised mortars and blocks remains unaltered during hardening, allowing them to revert to their original constituents at the end of their life cycle. Additionally, previous research has demonstrated that when stabilised earth blocks are combined with unstabilised earth mortars instead of bastard mortars, they can be more easily reclaimed during deconstruction due to the lower bond strength between mortar and blocks.

However, stabilised blocks show higher strength and water resistance than unstabilised blocks. For this reason, stabilised blocks are frequently recommended for load-bearing applications. Although water resistance must be considered for both stabilised and unstabilised blocks, unstabilised blocks, in particular, should always be carefully protected from direct contact with water. The design can be adapted to address this concern (e.g., through the use of plinths, elevated floor levels, and restricting applications to indoor environments), but also additional precautions are necessary during construction (e.g., dry storage of blocks and protecting walls), which can be challenging on small construction sites or when earth block masonry must be erected before achieving a watertight building envelope. Consequently, stabilised blocks are sometimes selected to reduce dependency on favourable (dry) weather conditions during construction, despite their higher environmental impact and although their enhanced properties may no longer be needed once the construction is complete.

For load-bearing walls, a bastard mortar with an earth additive or an adhesive mortar is typically specified. Bastard mortar has a higher water resistance than earth mortar, again reducing dependency on favourable weather during construction. The contractors and bricklayers mention that earth mortars are more challenging to work with. Their workability differs from conventional masonry mortars since they are extremely sticky, slowing down masonry work and increasing construction costs. Additionally, earth mortars require a significantly longer drying time than bastard mortars, further extending the construction time. The case studies illustrate that it is also important for contractors and bricklayers to become familiar with the specific characteristics of earth blocks to allow them to better manage the practical requirements during masonry work.

Currently, little is known about the long-term behaviour of earth block masonry when exposed to user activities. However, in one of the cases, unstabilised moulded earth blocks are used in a daycare centre for young children. In another case, concerns about the durability and fragility of the earth blocks led the architect to ultimately choose concrete blocks for the space for the youth associations, where the nature of activities could pose a risk of wall damage.

Site visits and in-depth interviews provided valuable insights into the motivations for selecting earth blocks and specific mortar/block combinations, as well as into the on-site practical and organisational aspects. These findings will be used to develop a framework to support architects, contractors, and clients in their decision-making regarding earth block applications and will inform practical guidelines for design and construction with earth blocks.

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