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# Potential of contemporary earth architecture for low impact building in Belgium

Van der Linden J<sup>1</sup>, Janssens B<sup>1</sup>, Knapen E<sup>1</sup>

<sup>1</sup> Faculty of Architecture and Arts, Hasselt university, Belgium

jasper.vanderlinden@uhasselt.be

**Abstract.** Earth architecture during the 21st century has resurfaced worldwide as a sustainable, low environmental impact material with expressive aesthetics and textures. Contemporary projects attempt to modernize the traditional techniques of building with earth in order to adapt them to today's projecting needs. Examples of such techniques are unfired earth bricks and rammed earth. In order to disclosure and highlight future possibilities of earth construction, advantages and limitations of earth construction in a contemporary Western-European context are reviewed, based on a literature study. Because it is hard to generalise due to the case-specific context and constraints, a case study analysis of earth utilization in two contemporary architectural projects is presented. To assess if these contemporary projects meet the environmental benefits associated with traditional earth construction, several environmental aspects are taken into account, such as material sourcing proximity, production process, reuse potential, etc. Based on the literature study, case study analysis and current evolutions in neighbouring countries, promising applications for future development of earth construction for low impact building in Belgium are highlighted.

## 1. Introduction (context)

Earth has been used as a building material for millennia. Architecture in the ancient cultures of Egypt, the Middle East, China, Central Asia, and Latin America was closely tied to this material. In Central Europe, there is archaeological evidence of the use of earth as a building material for thousands of years [1-3]. In Belgium, after the industrial revolution, the development of brick factories contributed to the gradual replacement of the earth building construction. Nowadays, earth construction is still used significantly in developing countries. Roughly one-third of the world's population lives in buildings made from unfired earth [3-5]. Lack of advanced technology and often the availability of labour and local materials encourages the use of simple earth building techniques [6].

But also in the developed world of the 21<sup>st</sup> century, there is an interest in building with earth. Earth architecture has resurfaced worldwide as a sustainable, low environmental impact material with expressive aesthetics and textures [7, 8]. Contemporary projects attempt to modernize the traditional techniques of building with earth in order to adapt them to today's projecting needs.

Such projects have appeared also in Western-Europe countries; Germany, France and Austria (among others). In Belgium, contemporary projects have been built with earth, but in limited numbers. Despite the potential of contemporary earth architecture in the achievement of environmental sustainability, there is no widespread use of earth in Belgium. Based on a literature study and a case study analysis, in this paper, the advantages and limitations of earth construction in Belgium are studied and the potential of using the material for low impact building is discussed.



## 2. State of affairs: literature

### 2.1. Earth construction techniques

Earth suitable for building is generally a well-graded subsoil with a good distribution of clay, silt, sand and aggregate. It should be noted that the clay component is essential for providing cohesion and plasticity during construction, and strength during service [9]. The inevitable variation in subsoils, including the moisture content, has resulted in a number of manufacturing and construction techniques. According to Reeves et al. [9], it is this versatility of techniques that makes it possible to build with earth in cold wet climates such as Britain and hot dry climates such as Morocco. Among the different construction techniques are e.g. wattle and daub, adobe, cob and rammed earth [6, 8, 10]. In this paper, a project with rammed earth (RE) and one with compressed earth bricks (CEB) are studied. Rammed earth is the product of compacting (ramming) consecutive soil layers in a formwork by using a manual or pneumatic rammer [8]. The unshaped earth mixture is slightly moist [10]. A variation of the rammed earth technique consists in the fabrication of compressed earth bricks, also using the technique of compacting a slightly moist earth mixture. But as opposed to rammed earth, bricks are produced which are subsequently assembled to form masonry structures. Other construction elements are also gaining popularity including extruded raw earth bricks (mixture in plastic state put into shape by extrusion [11]) and prefabricated rammed earth panels [8].

### 2.2. Advantages and limitations of earth architecture

Egenti & Khatib [12] did a literature review towards the advantages and limitations of earth construction (table 1). They give a comprehensible overview of advantages and limitations commonly associated with earth construction. Although this review was done rather recent (2016), some elements need further research. Firstly, this review seems to be done without keeping a particular context in mind and is based on research in contexts varying from Europe (e.g. UK, Germany, France) to Africa (e.g. Sudan, Southern Africa, Nigeria) to Asia (India) to Oceania (Australia, New Zealand). Secondly, it is hard to generalize such aspects since each project is different, each earth construction type differs. So, some of the listed aspects depend on the contextual reality (e.g. economic, social, climatological,...conditions). In this paper, some of the listed advantages and limitations will be evaluated for contemporary Western European applications, based on an analysis of two recent projects in Belgium.

**Table 1.** advantages and limitations of earth construction  
as listed in sustainability of construction materials, chapter 13 by Egenti & Khatib [12]

Advantages	Publications
Low cost	Guillaud et al. (1985), Lal (1995), Easton (1998), Minke (2006), Morton (2007), Walker et al. (2005), Zami and Lee (2007)
Encourages self-help with less skilled labour	Adam and Agib (2001), Minke (2006), Maini (2005), Hadjri et al. (2007)
Good sound insulation	Morton (2007) and Hadjri et al. (2007)
Good heat insulation and fire resistance	Binici et al. (2007), Taylor et al. (2008), Hadjri et al. (2007), Adam and Agib (2001), Walker et al. (2005)
Capable of providing strong and secured structure	Lal (1995), Rigassi (1985), Walker et al. (2005)
Promotes culture, natural material	Frescura (1981)
Improves indoor air quality	Minke (2006), Hadjri et al. (2007), Lal (1995), Walker et al. (2005)
Low impact	
Reusable	Minke (2006)
Low embodied energy	Keefe (2005), Venkatarama Reddy and Jagadish (2003)
Saves energy and no emission of CO <sub>2</sub>	Minke (2006), Glavind (2009)
Sufficiently available	Easton (1998), Adam and Agib (2001), Hadjri et al. (2007), Lal (1995)
Limitations	Publications
Non-standardised material	Head (1980), Minke (2006)
Non-resistant to water and less resilient	Minke (2006), Lal (1995), Walker et al. (2005)
Needs high maintenance	Hadjri et al. (2007)

Structurally limited	Hadjri et al. (2007), Maini (2005), Adam and Agib (2001)
Suitable only for in situ construction	Walker et al. (2005)
Special skills (required for plastering)	Hadjri et al. (2007)

### 3. Materials and methods

In the introduction of this paper (section 2), an overview of contemporary earth construction techniques was presented, together with commonly associated advantages and limitations of earth construction, based on a literature review by Egenti & Khatib [12]. In Section 4, two projects using unfired earth, will be presented (table 2). These selected projects were recently built in Belgium and contain main walls of unfired earth. Meanwhile, they reflect an image of contemporary material use. Both are public tenders, therefore needing to fulfil common standards for Belgian construction.

A semi-structured interview was done with the architects of both projects to identify important financial, technical and environmental aspects of building with earth in Belgium. A preparatory and subsequent analysis was done based on the architectural plans and technical reports and through site visit(s) of the projects.

**Table 2.** project case studies and interviewed architects

# Project type (earth construction technique)	Interviewed architect (affiliation)	reference
I Watchtower (rammed earth)	Jan Thys (de gouden liniaal architecten)	JT2019
II Bioclass (compressed earth bricks)	Nicolas Coeckelberghs (BC architects&studies)	NC2019

In the next chapter (section 5), the validity of the commonly mentioned advantages and limitations, as extracted from literature (table 1), will be discussed, based on the case studies. Complimentary, literature is used to compare with current insights in neighbouring countries within a similar context. The application potential of unfired earth in a contemporary Belgian context will be discussed as three reflections, i.e. on the financial cost of earth construction, its technical aspects, and the environmental impact (including energy use and transportation). In the last chapter (section 6), the reflections are combined, highlighting the importance of balance between ecological, technical, practical and economic aspects.

## 4. Case study projects

### 4.1. Case study I: watchtower, rammed earth

The first case study is a rammed earth watchtower in Negenoord, on a former gravel extraction area. The watchtower is designed as a concrete core with external rammed earth walls, with in between concrete prefab spiralling stairs resting onto the stabilized rammed earth walls of 80 cm thick and 12 m high (figure 1). The surface area of the rammed earth external walls will slowly erode, so the gravel will become visible after a while [13].

Building	watchtower
Location	Negenoord, Limburg
Year of construction	2016
Earth construction technique	Rammed earth
Architect	De gouden liniaal architecten
Earth consultant	BC studies, Craterre, Vessiere&Cie
Available documentation	interview with architect, plans, technical report
Site visit(s)	25 <sup>th</sup> of August 2015

The tower is one of the first contemporary public earthen building in the Benelux region. At the moment of writing, there are no standards for earth construction technique, which makes it difficult to describe rammed earth for use in a public project.

To guarantee the quality of the earth construction, the design and construction team was supported by an international team of experts in rammed earth. These consultants defined a material mix (20% gravel, 40% sand, and 40% loess, stabilized with 6% hydraulic lime), using materials from nearby excavation sites (Section 5.3). Also, they advised on how to organize the construction site for in-situ earth mixing and rammed earth construction. Despite the consultancy, training of the contractor and follow-up, some issues arose during construction. This resulted in the use of cement instead of lime as stabilizer. The rammed earth works took 7 weeks, carried out by a professional contractor.



**Figure 1** Watchtower on a hill in natural reserve (left) rammed earth walls with concrete base and core (images: ©Filip Dujardin)

#### 4.2. Casestudy II: bioclass, compressed earth bricks

The bioclass, a class for nature education built in an existing warehouse (figure 2, right), was constructed with compressed earth bricks (CEB). These bricks, masoned into one floor high walls, are the loadbearing construction of the building. Towards the inside, the bricks are left apparent without extra finishing (figure 2, left). An insulating exterior façade and roof of hempcrete is left apparent as exterior finishing (figure 2, right).

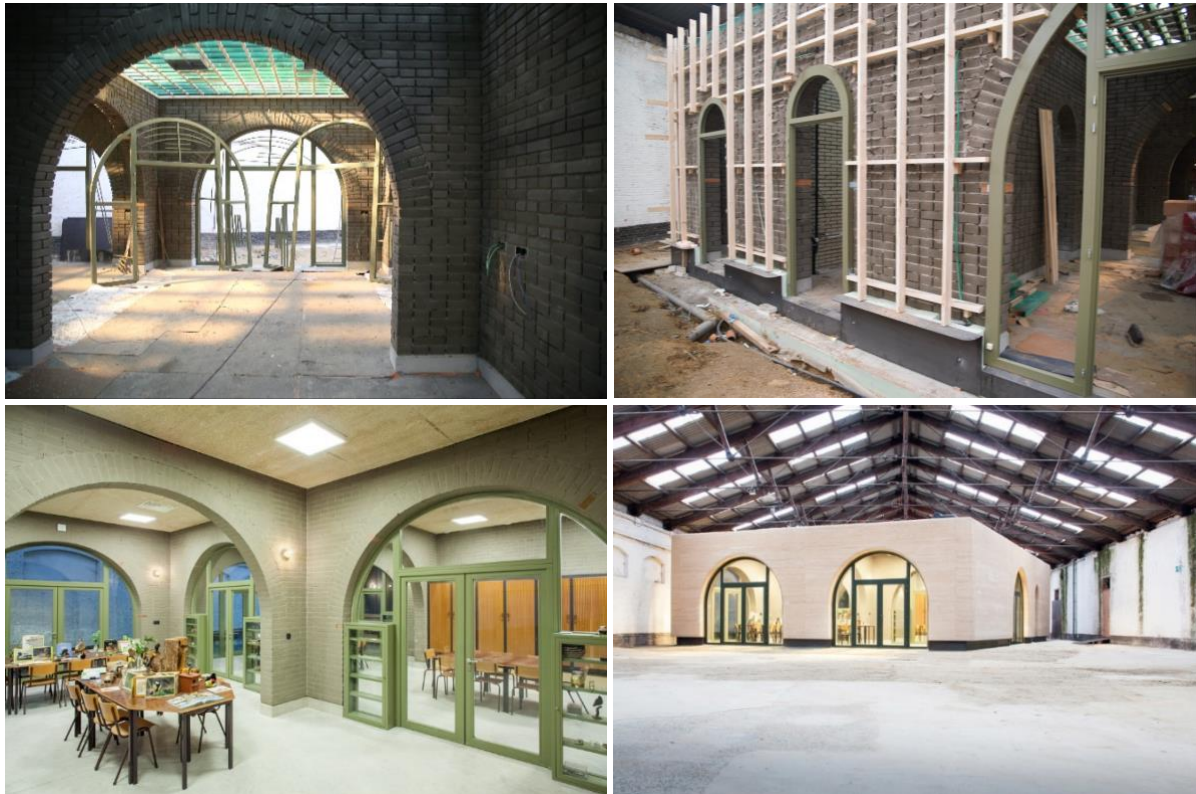
Building	bioclass
Location	Edegem, Antwerp
Year of construction	2017
Earth construction technique	compressed earth brick (CEB)
Architect	BC architects
Structural engineer	Util
Available documentation	interview with architect, plans, technical material report
Site visit(s)	15 <sup>th</sup> of December 2017, construction site visit 10 <sup>th</sup> of July 2018, tour by architect

The bricks are made in-situ using clay from a nearby quarry (Section 5.3), mixed with sand (Benor, 0/8) and without addition of a chemical stabiliser such as lime or cement. During a 3 week workshop with volunteers, 19000 bricks were produced [14] using a hydraulic CEB machine [15].

The bioclass demonstrates that it is possible to construct with unstabilised CEB in a loadbearing way if construction conditions are dry. The design and detailing takes into account the nature of the material



by using its compressive strength (3,3MPa) through arches and by avoiding contact with water. This was done by offsetting the brick from the floor (figure 2, left) and not using it near the bathroom.



**Figure 2** bioclass during construction (top), as finished building (bottom)  
(top images: author, bottom images: ©Thomas Noceto)

## 5. Reflections on the application of earth in Belgium

### 5.1. Reflection on the financial cost

Whereas Eghenti & Khatib [12] present the use of earth in construction as an economic advantage, in an industrialized country with high labour costs, such as Belgium, low-quantity, non-industrial production for on-demand projects results in a significantly higher cost. In both case studies, earth was mixed on-site and processed in small amounts for the specific projects. When preparing construction materials on-site, the organization of the construction site becomes more complex and costly. Such on-demand material processing in small quantities is very different from the large-scale industrial production of conventional building materials.

Depending on the size, a non-industrial CEB would be around 30-40% more expensive than a conventional industrially produced fired brick (NC 2019). However, with greater demand the unit cost of production would reduce [16] and through industrial mass production it might be possible to make unfired bricks which are cheaper than the fired brick (NC 2019). A rammed earth construction, rammed on site, would be around 60% more expensive than exposed concrete [17].

Self-help can potentially lower the cost, but it is not always evident to do so. In the case of the watchtower, the involvement of unskilled labour in the construction process was impossible because the public client did not allow it. For the bioclass, workshop sessions with unskilled labour lowered the price of on-site brick production. During the workshops, the participants were offered practical experience and knowledge sharing. However, the cost to organize such workshop on a high level, as including the training of the participants and preparation, should be taken into account.

Although self-help is mentioned as an advantage, Schroeder warns that people should only execute the construction work under professional guidance. Earth as a building material can only be accepted by society if it is seen as a “normal” building material [1]. This requires the existence and application of current building regulations. At the moment, earth is not a conventional building material in Belgium and advice and study work of experts is needed when designing and constructing with earth. Especially when dealing with a public construction, as is the case of the two studied projects, a professional expertise is necessary to fulfil building regulations, deliver a high quality construction and provide the technical certainties necessary for a public tender. This expertise also leads to an additional cost.

### 5.2. *Reflection on the technical aspects*

Interviews with the architects of both projects did not indicate any technical reasons for not using earth construction in Belgium. But, where and how the material is applied should correspond to the potential and limitations of the applied earth construction technique. This means that in the design and detailing, the material properties should be taken into account, such as the low water resistance and low strength when compared to more conventional building materials [1, 18]. Some examples:

Water resistance:

- (case I+II) Use of a concrete plinth to prevent capillary water rise
- (case I) Specific attention to water drainage on the inside of the tower to avoid excessive contact with rainwater, special attention went to the detailing of drainage along the concrete stairs
- (case II) Earth for interior use only
- (case II) Glazed bricks instead of CEB in the bathroom area

Strength:

- (case II) Arches, loading the bricks with only compressive stresses
- (case II) The limited height of one level avoids high loads
- (case I) Wall thickness of 80cm to carry the 12meter high massive walls
- (case I) Concrete plinth to prevent that the cows grazing around the tower scrape the RE wall

Meanwhile, the limited amount of regulation, standardization and experienced craftsman might form a barrier for implementation [19]. In both projects, it was emphasised that the need of an expert in earth construction is essential. Since standards and norms are currently lacking, each project should be followed up by an expert to avoid mistakes by stakeholders that are less familiar with the material. One architect mentioned the need for a building team, with the architect, constructor, client that includes an earth consultant to follow up the project from the very start till the process of maintenance. This makes it possible to avoid mistakes in a building environment where earth construction is not common knowledge and which is not guided (yet) by standards and regulations. Among other standardization initiatives, the RILEM Technical Committee 274-TCE is critically examining current experimental procedures to propose appropriate testing methods that could be adopted as standards.

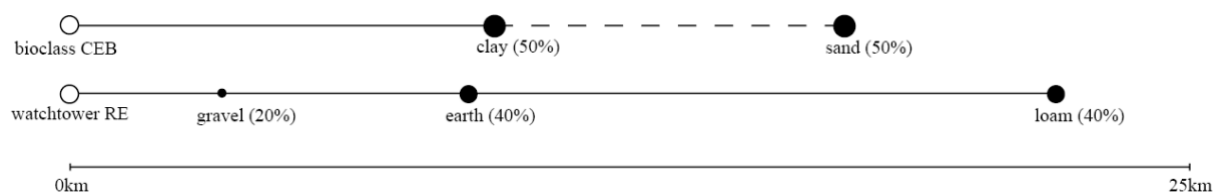
### 5.3. *Reflection on the environmental impact*

In the literature review (table 2), it was mentioned that earth construction has ‘low embodied energy’ and ‘no emission of CO<sub>2</sub>’. Such claims have been nuanced for contemporary earth construction by Schroeder [1]. He mentions that “the traditional manual processing of suitable excavation material into earth building materials and structures on the building site was and still is the ideal situation as far as the embodied energy is concerned”. He continues with the analysis that “contemporary earth building is largely mechanized and characterized by the physical separation of building material production and product use on the building site. This automatically leads to energy consumption and transportation.”

This is also the case for the studied projects. The material on the site of the watchtower was a priori not suitable for construction. The former gravel extraction area where the tower is situated has been refilled and the earth was therefore inconsistent (JT 2019). Also for the bioclass, no earth from the site has been used for the same reason. Additionally, it was practically difficult to specify a local earth mix

already during the public tender phase since it would need an allocated budget for local soil investigation and specification of a reformulated earth mix (NC 2019).

However, in both projects, special attention went to the transportation distance between the excavation site of the earth materials and the construction site. The architect of the watchtower project mentioned that pre-mixed earth with specified material characteristics can be bought (e.g. from a producer in Germany), but they preferred a mix of locally sourced materials. Testing was done with different mixtures of material in the region resulting in an earth mix with material taken from within a range of 25km (figure 3). For the bioclass, clay was bought from a nearby quarry, sand was bought at a local distributor. As the exact sand source is unknown, the distance on figure 3 represents the distributor.



**Figure 3** distance from site to material source

Both projects used material from quarries; such choice is made because it is practical, the continuous availability is assured and the quality guaranteed. Sand, clay and gravel are indeed sufficiently available (in those regions) but are originating from finite resources. An alternative for this would be the industrial processing of suitable ‘excavation soil’—into earth building. This could result in a lower demand for landfill space and lower transportation impacts, both for excavation soil and for construction materials, which could be major environmental benefits for contemporary earth building ([1], NC2019).

In both projects, parts of the production and construction process have been mechanized. In the case of CEB, Schroeder [1] reports a duplication of the CO<sub>2</sub> emission as well as a tripling of the energy demand when mechanically instead of manually producing CEB’s. However; it is clear that this are still very low amounts compared to fired bricks or concrete. Schroeder [1] claimed a CO<sub>2</sub> emission that is 63% lower for a mechanically produced and stabilised CEB compared to a fired brick.

For the rammed earth watchtower, 6% of cement has been added. Despite the absence of cement in the proposed mix of the earth consultants, cement was added. This to avoid any risk after a series of irregularities took place at the start of construction. The used mixture was differing from the prescribed mixture, either by being more wet or not respecting the prescribed particle size distribution. Although the amount of added cement is less than a common concrete construction, the 12m high walls of 80cm thick contain a not negligible amount of cement. This is negatively impacting the CO<sub>2</sub> emissions during production.

A last topic concerns the possible future reuse and recyclability of the material. For the bioclass, a simple wooden structure and hempcrete is mounted on the CEB. This should make it easy to take apart the pure earth material, which can then be recycled or reused. If unstabilized, reversible clay binding allows a complete and low-energy reuse of earth at end of life [18, 20]. Therefore, the lack of cement or lime as a stabiliser in the mixture is of significant importance. In the bioclass, a small amount of lime was added to the mixture, it has not been studied if this would negatively affect the recycling options. For the watchtower on the other hand, cement is contaminating the earth mixture, which eliminates the reversible binding process. Although the architect aimed to make a solid structure that will survive for a long-time, in the worst case needing some retouches (JT2019), the end of life should be taken into account. In that context not stabilizing earth to improve recyclability is an important consideration, that could be of particular value for applications which are typically changed in a shorter time span, such as indoor walls.



## 6. Conclusion and discussion

In the context of a renewed interest in building with earth, resurfacing worldwide as a sustainable, low environmental impact material, the potential of contemporary earth architecture in Belgium is investigated by means of a literature study and a case study analysis of two projects using unfired earth, recently built in Belgium. The architects of both projects were interviewed to investigate the economic, technical and environmental aspects of building contemporary projects with earth. By confronting the commonly mentioned advantages and limitations in literature (table 1) with the results of the case study analysis, a reflection on the application of earth in Belgium is presented from an economic, technical and environmental perspective. Some inspiring potential suggestions for a more successful future development of earth architecture in Belgium are derived.

Firstly, the two studied projects made it clear that earth construction is not necessarily cheaper than conventional construction, even on the contrary. One way of lowering the costs would be to scale-up the production of earth material products, doing this in a more industrialized and standardized way. Another way of dealing with it could be to accept the additional price and approach earth as a unique building product, which reflects certain values such as locality and craftsmanship.

Secondly, it was clearly mentioned that earth expertise is essential in all phases of the project. Material knowledge is essential in any architectural project, but in the case of earth, it is especially important since norms and standards are lacking, and since the limits and possibilities of the material are not common knowledge. A project using earth should be designed with intelligent details and appropriately combined with other materials. This should avoid excessive contact with water, and take into account the compressive strength and its vulnerability to abrasion or erosion. Also during the phase of construction and maintenance, it is important to have access to specific technical knowledge of the material. Therefore, a good knowledge transfer and the building up of expertise, norms and standards is important.

Thirdly, earth does offer potential to construct with low environmental impact. Although zero transportation through the use of on-site excavated material was not achieved in the studied projects, clearly an effort has been done to keep the sourcing within the region. Although part of the process is mechanized and in the watchtower project some cement stabilization was used, primary energy use and CO<sub>2</sub> emission still is rather low compared to fired bricks or concrete. For the further development of earth as a sustainable construction material, smart sourcing and processing seems a key-point to avoid finite material excavation. Gathering suitable excavation soil and processing it to earth building products or mixtures, in a semi-centralized way, might be a useful next step in the field of earth construction.

To conclude, the findings of this study, and even more the discussed projects themselves, show that there is potential for contemporary earth architecture in Belgium. Using earth can be a low impact building solution, but this should not be taken for granted. It is the role of the architect, material producers and constructors to balance between ecological, technical, cultural, practical and economic aspects. For example, processing material on-site might lead to less transport but turns out to be rather expensive and complex in construction site organization. This could be a trigger to look more into prefabrication of earth building elements. Improving the compressive strength and water resistance by adding chemical stabilisers should be done with care as it negatively impacts the environmental impact and recyclability. Designing smartly with the right material where necessary and possible should be a priority when using earth. This preferably with a team that includes the different project stakeholders and earth construction experts, collaborating from concept phase till maintenance.

## References

- [1] Schroeder H. 2016 *Sustainable building with earth*. Basel, Switzerland: Springer.
- [2] Correia M, Dipascuale L, Mecca S. 2011 *Terra Europae. Earthen Architecture in the European Union*. Pisa: Edizioni ETS.
- [3] Avrami E, Guillaud H, Hardy M. 2008 *Terra literature review: an overview of Earthen architecture conservation*. Los Angeles: The Getty Conservation Institute.
- [4] Hall MR, Lindsay R, Krayenhoff M. 2012 Preface. *Modern Earth Buildings*: Woodhead Publishing. p. xxvii-xxxi.
- [5] Houben H, Guillaud H. 1994 *Earth construction: a comprehensive guide*. London: Intermediate Technology Publications.
- [6] Costa C, Cerqueira Â, Rocha F, Velosa A. 2018 *The sustainability of adobe construction: past to future*. *International Journal of Architectural Heritage*:1-9.
- [7] Bestraten S, Hormías E, Altemir A. 2011 *Earthen construction in the 21st century*. *Informes de la Construcción*;63:5-20.
- [8] Fabbri A, Morel J-C, Gallipoli D. 2018 *Assessing the performance of earth building materials: a review of recent developments*. *RILEM Technical Letters*;3:46-58.
- [9] Reeves GM, Sims I, Cripps JC. 2006 *Earthen architecture. Clay Materials Used in Construction*: Geological Society of London.
- [10] Hall MR, Lindsay R, Krayenhoff M. 2012 *Modern earth buildings: Materials, engineering, constructions and applications*: Woodhead Publishing. 776 p.
- [11] Cagnon H, Aubert J-E, Coutand M, Magniont C. 2014 *Hygrothermal properties of extruded earth bricks*. *Energy and Buildings*;80:208-17.
- [12] Egenti C, Khatib J. 2016 Sustainability of compressed earth as a construction material. *Sustainability of Construction Materials (Second Edition)*: Elsevier. p. 309-41.
- [13] De Gouden Liniaal Architecten. Uitkijktoren Negenoord, Dilsen-Stokkem [cited 2018 jul 27]. Available from: [www.degoudenliniaal.be/index.php?/albums/uitkijktoren-negenoord-dilsen-stokkem/](http://www.degoudenliniaal.be/index.php?/albums/uitkijktoren-negenoord-dilsen-stokkem/).
- [14] BC architects. Regional house edegem [cited 2019 jan 22 ]. Available from: <http://architects.bc-as.org/Regional-House-Edeghem>.
- [15] Oskam. compressed earth block machines [cited 2019 jan 21]. Available from: [www.oskam-vf.com/persmachines%20-compressed%20earth%20block%20machines.html](http://www.oskam-vf.com/persmachines%20-compressed%20earth%20block%20machines.html).
- [16] Williams C, Goodhew S, Griffiths R, Watson L. 2010 *The feasibility of earth block masonry for building sustainable walling in the United Kingdom*. *Journal of Building Appraisal*;6(2):99-108.
- [17] Coeckelberghs N. 2014 *du pisé en Belgique*: ecole nationale superieure d'architecture de Grenoble.
- [18] Röhlen U, Ziegert C. 2011 *Earth Building Practice: Planning-Design-Building*: Beuth Verlag.
- [19] Minke G. 2007 *Building with Earth: Design and Technology of a Sustainable Architecture*: Birkhäuser Basel.
- [20] Hamard E. 2017 *Rediscovering of vernacular adaptative construction strategies for sustainable modern building: application to cob and rammed earth* [PhD thesis]: Lyon.