Construction and Building Materials 170 (2018) 485–497

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

A new methodology to identify and quantify material resource at a large scale for earth construction – Application to cob in Brittany

Erwan Hamard [a,b,*], Blandine Lemercier [c], Bogdan Cazacliu [a], Andry Razakamanantsoa [d], Jean-Claude Morel [b,e]

[a] IFSTTAR, MAST, GPEM, F-44344 Bouguenais, France
[b] Coventry University, Faculty of Engineering, Environment and Computing, Centre for the Built and Natural Environment, Coventry, CV1 5FB, UK
[c] UMR SAS, AGROCAMPUS OUEST, INRA, F-35042 Rennes, France
[d] IFSTTAR, GERS, GMG, F-44344 Bouguenais, France
[e] UMR 5513 LTDS, ENTPE University of Lyon, 69518 Vaulx en Velin Cedex, France

HIGHLIGHTS

- Proposed methodology is based on cross-referencing of spatialized pedological and heritage data.
- The earthwork waste reuse capacity for earth construction is estimated at regional scale.
- The first map of earth construction material availability at regional scale is proposed.
- Five texture classes of suitability for cob soils are defined for Brittany.
- Texture results call into question recommendations available in the literature.

ARTICLE INFO

Article history:
Received 22 January 2018
Received in revised form 9 March 2018
Accepted 12 March 2018
Available online 23 March 2018

Keywords:
Cob
Earthwork waste
Earth construction
Rammed earth
Adobe
Pedology

ABSTRACT

A new methodology based on the cross-referencing of spatialized pedological and heritage data is proposed to identify and quantify soil resources available for earth construction. The paper underlines the pedological particularities of areas containing earth heritage and uses these particularities to propose criteria to assess the suitability of soils for modern earth construction. The methodology applied at the regional scale in France (for a given area of 27,200 km^2 in Brittany) enabled to specify five new texture classes (balance between clay, silt, sand and gravel content) of suitability for cob soils. This result calls into question recommendations available in the literature.

The methodology also provides data on the scale of availability of the resource to repair earth built heritage (cob) or to build new low impact buildings with integrated modern cob walls. In the studied area the potential waste recovery of 2.8 Mt per year is measured, highlighting the large availability of materials for earth construction. At least 23% of earthwork wastes of Brittany are suitable for earth construction (0.7 Mt). However, earth remains a non-renewable material and this resource has to be properly managed, requiring an appropriate building design and maintenance in order to increase longevity and to avoid the use of admixture, preventing earth reversibility at end of life.

1. Introduction

The construction sector consumes a large volume of natural resources and is responsible for about 50% of wastes production in the European Union [1–5]. These wastes have a negative environmental impact [2–4] and it is increasingly difficult to find suitable landfill areas [4,5]. Among these construction wastes, about 75% are soils and stones [1,6]. Earth construction is a possible market for earthwork wastes, but no data is available about the quantification of local stocks and flows of soils suitable for earth construction. Therefore, the resources to get a low impact building must be found locally, a mission that is challenged by the local soil variability [7]. Overall, this situation prevents modern earth building markets to develop.

The aim of this paper is to propose a novel methodology to identify and quantify soil resources available for earth construction

* Corresponding author at: IFSTTAR, MAST, GPEM, F-44344 Bouguenais, France.
E-mail address: erwan.hamard@ifsttar.fr (E. Hamard).

https://doi.org/10.1016/j.conbuildmat.2018.03.097
0950-0618/

in order to assess the potential market share of the earth construction sector and waste reduction by the construction industry.

Suitability of earth for construction purposes is usually determined using a geotechnical approach, aimed at enhancing the mechanical strength of earthen specimens carried out in the laboratory [8–10]. The most cited criterion to assess earth suitability is texture, i.e. balance between clay, silt, sand and gravel content [11]. Consequently, grading envelopes adjusted to each earth construction technique were proposed in the literature [8,12–17]. However, textures of materials collected in vernacular earth heritage buildings do not fit inside those grading envelopes [18–23]. Thus, grading envelopes available in the literature failed to give full account of the diversity of earth employed for construction [24].

Another approach to identify material suitability for construction is to analyse materials traditionally used in heritage buildings [18–21]. Soils for vernacular earth construction were excavated directly on-site or at a distance less than 1 km away from the construction site [19,21,24–29]. As a consequence, the presence of earth heritage highlights the presence of soils suitable for construction [19,21]. A high proportion of earth building heritage indicates a priori (1) a large availability of earth, (2) a good quality of earth allowing easy implementation, (3) a high longevity of cob buildings and (4) a favourable cultural context. Vernacular soil selection is the result of time-tested empirical experimentations and the proposed methodology aimed at rediscovering this past know-how and to consider it for modern earth building.

Several authors identified material sources through comparison between materials inside walls of heritage buildings and available local materials using geological analysis [18–20,22,27] and, more rarely, pedological analysis [19,21]. Geological maps are preferred to pedological maps for material source identification as they provide more detailed and homogeneous cartographic information [21]. However, pedology is considered as more relevant than geology for identification of earth material sources [13,19,21]. Recently, in France, the completion of regional pedological maps offers new opportunities to analyse soils next to earth heritage.

Hence, the new methodology proposed in this paper is based on the cross-referencing of spatialized pedological and heritage data. Pedological particularities of areas containing earth heritage are highlighted and these particularities are used to propose criteria to assess the suitability of soils for vernacular earth construction and scale of availability of the resource to repair earth built heritage or to build new low impact buildings with integrated modern earth walls. This new methodology is exemplified in this paper in Brittany (France) but can be extended to regions having heritage and soil information. For this study, Soils of Brittany [30] and the Cultural Heritage of Brittany databases [31] were used.

In Brittany the vernacular earth construction technique is cob. The cob technique employs earth elements in a plastic state, implemented wet and stacked to build a monolithic and load-bearing or freestanding wall [24]. The paper deals with cob, but the use of the methodology can be expanded to other earth construction techniques, like rammed earth or adobe masonry for example.

2. Methodology description

2.1. Soil suitability determination

The relative densities of earth buildings are an indicator of suitability of soils for earth construction [21]. Relative densities were calculated by cross-referencing between heritage and soil databases covering the same geographical area. The spatialized heritage database must provide homogeneous information on the vernacular architecture of the studied area and must concern all vernacular materials (timber, stone, earth, solid bricks). The described methodology is designed for the French soil cartographic representation called "*Référentiel Régional Pédologique*" (RRP), but can be adapted to other cartographic representations.

Soil cartographic representation by the RRP is a set of polygons, spatially delineated, defining Soil Map Units (SMUs) [32]. Since soils show rapid variations in three dimensions, each SMU corresponds to a soil landscape, i.e. a collection of soils, defined as a Soil Type Unit (STU), developed in a common environment. Each SMU includes 1 to 10 STUs which are not spatially delineated [30,33] (Fig. 1). Each STU is divided into strata, representing the vertical variability of soil. Pedological characteristics of SMUs, STUs and strata (such as depth and thickness, texture and Cation Exchange Capacity) are gathered in a semantical database (Fig. 1).

The aim of the calculation is to identify the pedological characteristics (clay, silt, sand, gravel content and Cation Exchange Capacity) of soils according to their suitability with earth building. This calculation is carried out in 3 steps: (1) calculation of the frequency of earth heritage building for each Soil Type Unit, (2) exclusion of Soil Type Unit which can be regarded as outlier values, (3) calculation of minimum and maximum values of pedological characteristics of the Soil Type Units of a same frequency class. The calculation is detailed below and parameters are detailed in Table 1.

Heritage and pedological data are combined in a Geographic Information System so that the total heritage and earth heritage number of buildings, respectively *TOT_SMU* and *EARTH_SMU*, can be determined for each SMU. The total and earth heritage building numbers of a SMU are attributed to the STUs that compose the SMU with respect to the surface proportion of STUs in the SMU ($SURF\_STU_{SMUi}$). The total numbers of heritage and earth heritage buildings of a STU, respectively *TOT_STU* and *EARTH_STU*, are the sum of total or earth heritage buildings of the STU on the SMUs inside which it is present (Fig. 1):

$$TOT\_STU = \sum_i SURF\_STU_{SMU_i} \times TOT\_SMU_i \quad (1)$$

$$EARTH\_STU = \sum_i SURF\_STU_{SMU_i} \times EARTH\_SMU_i \quad (2)$$

In order to discuss the relative densities of vernacular earth buildings of the studied area, the frequency of earth buildings ($FREQ_{STU}$) are calculated for each STU:

$$FREQ_{STU} = \frac{EARTH\_STU}{TOT\_STU} \quad (3)$$

This calculation is exemplified using a theoretical case in Fig. 2.

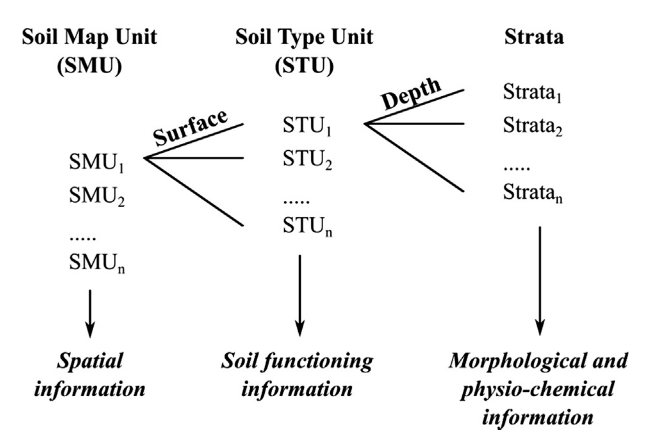

Fig. 1. Pedological database: Soil Map Units (SMUs) are a spatialized depiction of soil landscapes at a scale of 1:125,000, SMUs are composed of a proportion, expressed in surface, of various Soil Type Units (STUs) and STU consist of several strata. Only SMUs are delineated.