IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

Material evaluation of earth block masonry in the context of Belgium: a survey

To cite this article: N de Vries *et al* 2024 *IOP Conf. Ser.: Earth Environ. Sci.* **1363** 012099

IOP Conf. Series: Earth and Environmental Science **1363** (2024) 012099 doi:10.1088/1755-1315/1363/1/012099

Material evaluation of earth block masonry in the context of Belgium: a survey

N de Vries[1], R Novais Passarelli[1], E Nuyts[1,2] and E Knapen[1]

[1]Hasselt University, Faculty of Architecture and Arts, Agoralaan Building E, B-3590 Diepenbeek, Belgium
[2]PXL University College, Elfde-Liniestraat 24, B-3500 Hasselt, Belgium

nijs.devries@uhasselt.be

Abstract. Earth block masonry (EBM) has a low embodied energy and a high circular potential, making it an environmentally responsible alternative to conventional building materials in Belgian mainstream construction. Additionally, its similarity with conventional equivalents makes EBM suitable to substitute large volumes of carbon-intensive building materials without drastic changes in the industry. Despite its potential, the application of EBM scarcely occurs in contemporary construction. While current research on EBM mainly focuses on technical properties and product development, insufficient research has been conducted on material evaluation, perception and experience by potential (end-) users. To understand which factors are important during the process of material evaluation, literature in this field is discussed, and a framework for material evaluation is formulated. Through a survey, this framework is employed to map the material evaluation of potential users, using five mock-up walls of EBM with various earth block (EB) types, earth mortars and jointing techniques. The results show that the most mentioned sensory attributes are the colour and roughness of the material. From an experiential point of view, respondents experience the walls as being (technically) trustworthy but often also as traditional or unstylish. Finally, most respondents indicate having a positive attitude towards potential implementation, even though plastering of the walls is preferred. These results are a first step in understanding users' perceptions and experiences and help identify aspects that need extra attention when further developing, commercialising, and communicating with regard to EBM in Belgium.

1. Introduction

Earth block masonry (EBM) can be essential in transitioning towards a more environmentally responsible building practice since raw materials are abundantly and locally available, have low embodied energy, and have a high circular potential [1, 2]. Despite their potential, earth blocks (EBs) are scarcely applied in contemporary construction because of numerous obstacles, such as high production and construction costs [2, 3], the lack of building codes and standards [4, 5], and the limited availability of skilled workforce [6, 7]. So far, current research on EBs mainly focuses on product development and resolving technical bottlenecks [8, 9]. Only limited research has been conducted from the point of view of the (potential) user; research on this topic mainly focuses on motives and barriers concerning the implementation process [9, 10] and less on the user's perception and experience of EBM. Therefore, the objective of this study is to address this knowledge gap by gaining a first understanding of how EBM is evaluated by the potential (end-) user and which are the most mentioned sensory and

experiential characteristics during this process of material evaluation. In this paper, literature on material perceptions and experiences from the fields of architecture and product design is discussed, after which a framework is proposed that is used to develop a survey to evaluate EBM through five mock-up walls. After presenting the main results of the survey, gained insights that are useful for further upscaling EBM are discussed, and recommendations are made for future research.

2. Development of a framework for material evaluation

2.1. Theoretical background

To better understand how potential (end-) users evaluate EBM, it is necessary first to determine which aspects are considered during material evaluation. In the last decades, considerable research has already been conducted in this field, mainly in the domain of product design and architecture. [11-15]. The following sections will briefly outline how materials can be interacted with and evaluated, after which a framework is presented that is used to develop the survey for this research.

In the field of product design, Ashby and Johnson [11] argue that a product or a material can be described and interacted with through different aspects or *attributes* of materials. Ashby and Johnson define three types of attributes. A first way of interacting with a product or material is through *technical attributes*, considering technical aspects of materials like their strength, water resistance and recyclability. A second way of interacting with products is through *aesthetic attributes,* relating to properties like colour, texture, and warmth. Both technical and aesthetic attributes are inherent material properties and are the same to whoever interacts with the material. However, how material characteristics are interpreted depends on the observer, defined by Ashby and Johnson as the perceived attributes of the material or attributes of experience. These experiential attributes can be subdivided into attributes relating to *association* (what a material reminds us of), *perception* (what a material makes us think of) and *emotions* (how a material makes us feel). Together with technical and aesthetic attributes, the attributes of experience are modes for a user to interact with a product and the material it is made of. Ashby and Johnson focus on product design. In the architectural context, however, materials are present on a much larger scale, and people might thus interact differently with building materials.

In the field of architecture, a similar stance is taken by Wastiels [12], who, in the 'framework of material attributes' defines descriptive categories that are important to the architect during the material selection process and which describe properties attributed to a material, ranging from technical and sensory material properties to experiential aspects. A parameter that should also be considered in the architectural context is how the building material is produced and assembled (i.e., the production method, the way of assembly, and the finishing technique used), which Wastiels defines as the *manufacturing attributes*. EBs can be interpreted differently depending on how they are produced (e.g. moulded, pressed, extruded). Likewise, the perception of EBM walls will be influenced by the masonry bonding, jointing and finishing techniques.

Hegger [13] defines three *material qualities* evaluated by users while interacting with materials in an architectural context: *inner material qualities* refer to the internal technical properties of architectural materials, *visible material qualities* refer to the interaction of the material with the senses, and *associative material qualities* refer to the meaning the material conveys after having perceived it. Even though a different terminology is practised, parallels are found between inherent material properties on the one hand and the experiences triggered by these material properties on the other hand. Wastiels and Hegger's models are thus similar to Ashby and Johnsons' description of material attributes, showing that these properties transcend the field of product design.

In the discussed models, a distinction is made between *objective* and *subjective* material attributes. This is not a clearly delineated division but gradually moves from objective material properties towards the subjective experience of the material. Attributes relating to technical behaviour and the way the material is manufactured and processed are purely objective: these are factual, and the characteristics can be objectively measured. However, for the sensory attributes, there is less consistency in definitions. Whereas Wastiels describes sensory attributes as "sensory perception of a material" [12, p. 85], Karana

[14] states in the 'descriptive categories of material appraisal' that these attributes encompass not merely the reporting of sensory information but also relate to the *aesthetic experience*, meaning that the sensory inputs lead to judgement of these attributes (i.e. ugly vs. beautiful). There is, thus, a gradient towards subjectivity for the sensory attributes. On the other hand, the experiential attributes of a material are purely subjective: perceptions, associations and emotions evoked by a material convey a meaning [13] and give the material its personality [11]. Karana [14] defines material experience as "the whole series of effects elicited by the interactions between people and materials in a particular context" [14, p. 50].

The subjective evaluation of a building material is influenced by the context of both the material and the perceiver. A distinction can be made between the *physical* context in which the evaluation is made and the *cultural and personal* context of the perceiver. In the 'model for analysing materials and their role in architecture' developed by Bejder [15], which allows for analysing and evaluating architectural materials, the former aspect is considered. The inclusion of contextual factors in the model provides different perspectives through which material attributes can be evaluated and which will influence the material evaluation. Indeed, EBM will be evaluated differently in a countryside barn and in an urban dwelling.

The fact that the cultural and personal context of the perceiver influences the material evaluation is mentioned by all authors. Bejder [15] states that "the experience, perception, and interpretation of the materials and the architectural object will always be marked by the personal background of the perceiver, just as the object will have been influenced by more or less known extrinsic factors, i.e. cultural, political, economic, etc." [15 p. 90]. Moreover, the meanings that materials convey change over time [11]. A remark has to be made here that materials can convey meanings which are evaluated similarly by most users regardless of their cultural context; a glass curtain wall façade will, for instance, most likely convey associations of business districts among the majority of people. On the other hand, the evaluation of rammed earth structures is more susceptible to various interpretations: it could convey associations of vernacular architecture by people living in warmer climates since it is where rammed earth construction has been traditionally used. However, among people living in Western European countries, rammed earth could convey associations with contemporary architecture, as shown in work by Martin Rauch and Herzog & de Meuron [16].

2.2. Development of a framework

In the previous sections, the aspects relating to material evaluation are briefly outlined. The discussed concepts distinguish several material attributes, as summarised in Figure 1. Some authors make more detailed distinctions than others, but a consensus can be found on materials having both objective and subjective properties, the evaluation of the latter being influenced by both the physical and the cultural and personal context.

This paper uses the above-discussed theoretical framework to map the potential (end-) user's material evaluation of EBM through a survey. The framework of material attributes by Wastiels [12] is considered to be most suitable for this research since it contains most of the discussed material attributes and is situated in the realm of architecture. Moreover, this model is developed with the *material selection* process in mind. Even though material selection is not the focus of this paper, using the material attributes used by Wastiels can already provide valuable insights for future research on material selection. Missing in this framework is the element of aesthetic experience (attractiveness of sensory attributes), as stated by Karana [14]; this aspect differs from the sensory attributes described by Wastiels in the sense that it adds a measure of appreciation to the sensory attributes. Mapping the aesthetic experience of the potential (end-) user is considered valuable for this study and will also be included in the survey.

This leads to seven material attributes used in the survey, as presented in Figure 2. In this scheme, the sensory attributes defined by Wastiels are positioned more towards the objective side, and the aesthetic experience formulated by Karana is positioned more towards the subjective side. As previously mentioned, the subjective evaluation will be influenced by the respondent's cultural and personal context and the experiment's physical context, as stipulated by Bejder [15]. This contextual influence

of subjective evaluation is not specified explicitly in the framework of Wastiels but is relevant for this research and, therefore, mentioned in the overview.

A better understanding of the material evaluation by potential (end-) users will make it possible to pinpoint the perceived and experienced qualities and shortcomings of EBM. This can be useful for the further development, commercialisation and communication of EBs in practice. Additionally, the results of this survey will pave the way for planned future research on this topic. To translate the discussed theory into a manageable yet comprehensive survey, several (practical) considerations have to be made that will be addressed in the following chapter.

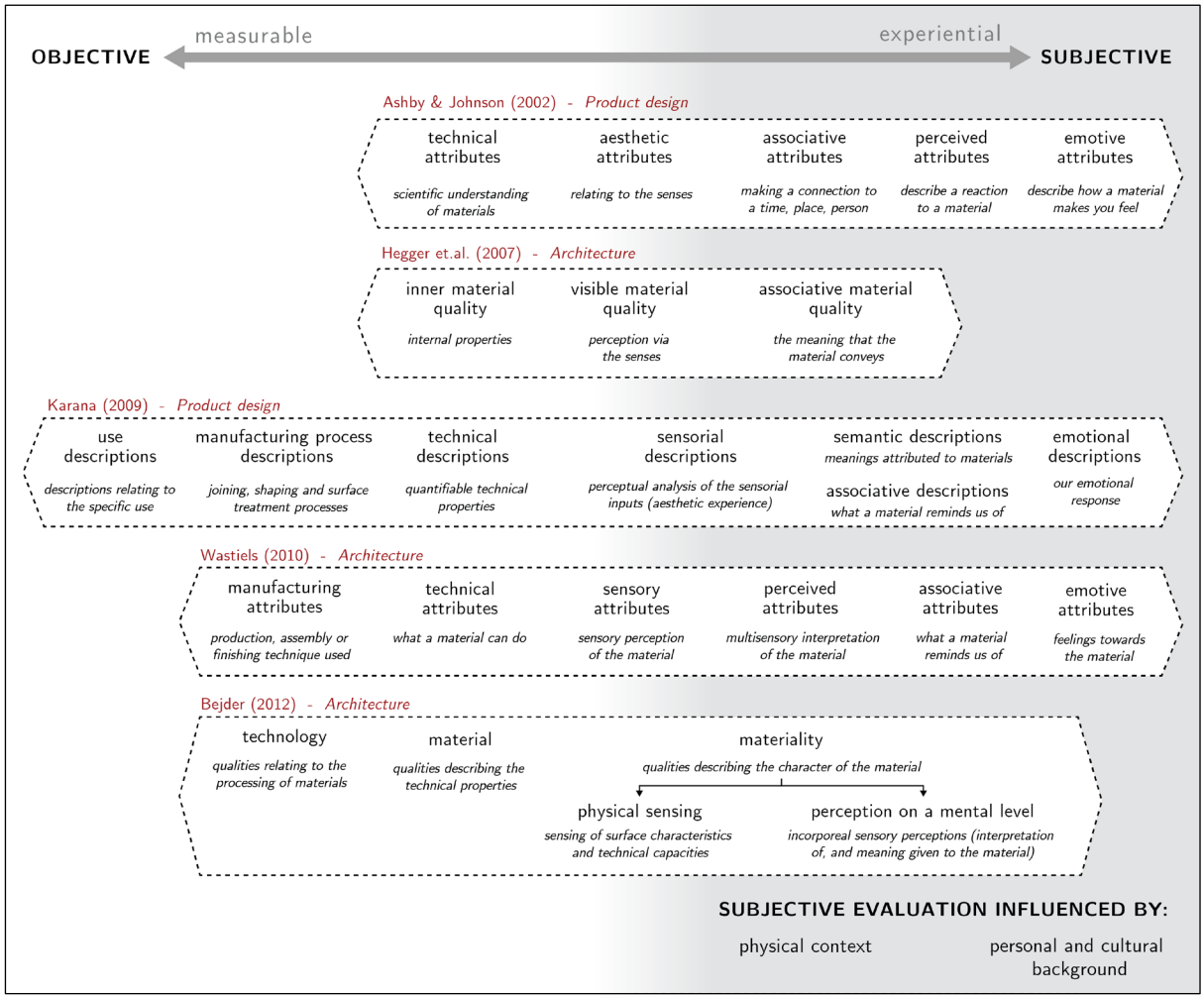

Figure 1. Models of material attributes. Based on [11-15].

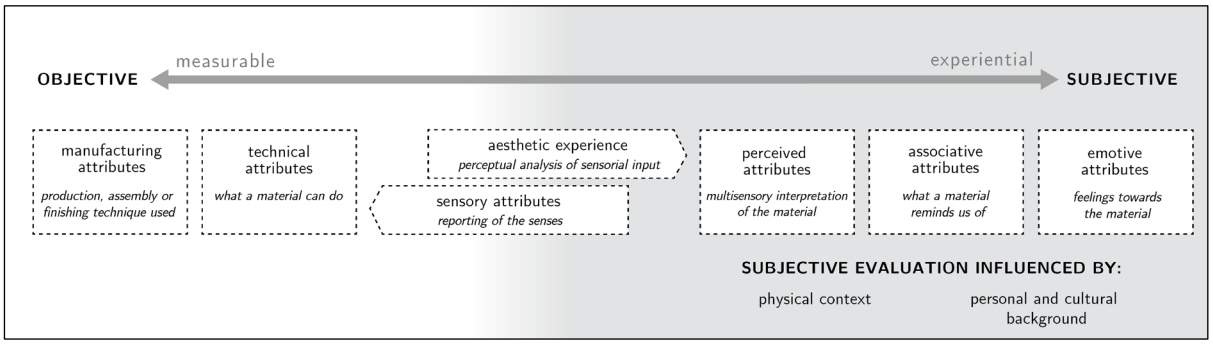

Figure 2. Material attributes considered in the survey.

3. Materials and methods

This study aims to investigate EBM's material evaluation by potential (end-) users. Respondents are asked to evaluate one of five EBM mock-up walls through a questionnaire. The questionnaire was developed based on the material attributes presented in Figure 2. Before the final survey was conducted, four pre-studies were organised. During the pre-studies, different settings and questions were tested: often recurring themes were incorporated in the final survey, whereas questions not leading to relevant answers were discarded.

The guidelines formulated by Veelaert, Moons and Du Bois [17] were taken as a starting point in designing the experiment. For systematically setting up the experiential material characterisation experiments, they distinguish five methodological factors that should be taken into account: (i) stimuli, (ii) interaction modalities, (iii) dependent variables, (iv) assessors, and (v) method. The following sections explain in detail how these factors are incorporated during the design and execution of the survey.

3.1. Stimuli

A total of five EBM mock-up walls were used with various EB types and jointing. The EBs have been provided by two manufacturers; four walls are constructed using EBs from a Belgian manufacturer, and one wall is built using EBs from a German manufacturer. The EBM walls are approximately equal in size (ca. 70 x 60 cm); further details on the EBM walls are provided in Figure 3. The walls are presented on tables in a neutral room in the faculty of Architecture and Arts of Hasselt University, hereby trying as much as possible to eliminate any contextual influences, allowing for better experimental control [18]. To exclude the context entirely is, however, impossible; therefore, a similar study in a real-world context would be a valuable addition.

During the survey, respondents are directed towards a wall and are asked to only evaluate that wall. Even though this study aims to understand which factors are important during the material evaluation of EBM in general, keeping evaluations per wall separate allows the comparison between walls.

3.2. Interaction modalities

Each respondent was asked to answer questions considering one specific wall. The mock-ups were positioned so the respondents could not see the other walls when filling out the survey. However, due to practical reasons, it could not be prevented that the respondents may have glimpsed at the other walls as they entered the room. Even though this survey uses small mock-up walls, it is important to allow users to interact with the walls as naturally as possible. The experience one might have in a building should be simulated using all five senses. Nevertheless, for practical reasons, this study only considers vision and touch since these are the sensory modalities recognised to be most dominant in appraising materials [13, 19, 20].

Figure 3. Frontal view of the mock-up walls used in the survey.

3.3. Dependent variables

The manufacturing and technical attributes are hard to evaluate without former knowledge of the subject. Since respondents are not expected to be acquainted with these aspects, a meaningful evaluation of these aspects by them is considered unlikely. Therefore, respondents are not asked to evaluate the objective manufacturing and technical properties of the EBM walls. However, since the objective material attributes are measurable per wall, these properties will be used to put the subjective evaluation of respondents into perspective. The dependent variables in this study are, therefore, the subjective material attributes and can be subdivided into the factual reporting of the senses (the sensory attributes), the attractiveness of sensory attributes (aesthetic experience) and the three experiential attributes (perceptions, associations, emotions).

Next to the above, the questionnaire also contains several other elements. At the start of the questionnaire, a set of demographic questions is asked to get a grasp of the personal background of the perceiver (e.g., age, gender, professional background), followed by a conditioning stating that "the EBM mock-up walls are made using *earth blocks* and earth mortar, which are unfired to *limit their carbon footprint*. The earth blocks are similar to conventional bricks and used for *interior walls*." This gives all respondents an equal information base about the EBM walls.

At the end of the questionnaire, respondents are asked to state their 'verdict' towards EBM. Firstly, respondents are asked if they are positive or negative towards potential implementation, followed by whether they would plaster an EBM wall or leave it in sight. Afterwards, they were asked to describe their attitude towards EBM. This verdict can help put the material evaluation in perspective while analysing the results.

Respondents are also asked to rank their priorities regarding technical material attributes when selecting building materials. The results of these questions are not discussed in this paper but will be

used in further research. Figure 4 presents the structure of the final questionnaire, showing the sequence of the themes discussed above.

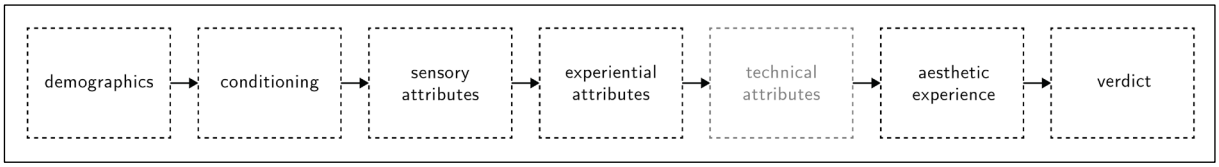

Figure 4. Structure of final questionnaire, the section concerning technical questions is greyed out since the results of this section are not discussed in this paper.

3.4. Assessors

This survey focuses on potential (end-) users of EBM. The survey was conducted during two events: 1) an event for students to get acquainted with various building materials and 2) a 'science day' where the general public is introduced to academia. During the first event, interior architecture students from the Faculty of Architecture and Arts at Hasselt University participated in the survey, resulting in a large share of respondents with a design background. This can influence the results, but it is also interesting because designers are used to evaluate materials and to verbalise their material perception. The survey was conducted a second time with a more broad and diverse group of respondents during the 'science day' to increase the variety of respondents. It took approximately ten minutes to complete the survey.

3.5. Method

The most common way to evaluate material attributes quantitatively is through descriptive scaling [16], also used in this survey. Additionally, respondents are encouraged to describe the material in their own words in certain sections of the questionnaire so as not to limit them in their answers. For the descriptive scaling, a list of sensory and experiential attributes was composed from literature [12, 14] and tested for relevancy during the pre-studies. The final list of attributes is subdivided into 11 sensory attributes and 12 experiential attributes and is shown in Figures 6 and 7 in the result section (the survey was conducted in Dutch; only the translated attributes are shown). Mapping the aesthetic experience is done similarly: respondents are first asked which elements of the EBM and EBs are found (un)attractive in their own words. Subsequently, several characteristics are listed and evaluated via descriptive scaling in terms of attractive vs. unattractive. This latter element is not featured in this study since it will figure in a forthcoming publication focussing on user preferences.

4. Results

4.1. Demographics

The survey was conducted during two moments, yielding a total of 223 responses. Since one of the moments was conducted during an event organised specifically for students of interior architecture, the majority of respondents are (young) designers; furthermore, 71% of respondents are female (n=158), 27% male (n=61), 2% other (n=4), see Figure 5. Wall no. 1 was evaluated 43 times, and walls no. 2, 3, 4, and 5 were evaluated 48, 48, 62, and 22 times, respectively.

4.2. Sensory attributes

Respondents were first asked to evaluate one of the five walls through the selected set of sensory attributes using a five-point Likert scale. An overview of evaluations of all walls is presented in Figure 6. Most notably, the EBM walls are evaluated as having a uniform, mild, and light colour. Furthermore, the EBM walls are evaluated as being easy to scratch and are considered somewhat brittle and heavy. Concerning the sensory attributes softness, roughness, warmth and massiveness, answers were quite

diverse, and no distinct evaluations were made possible based on the answers of the group of respondents.

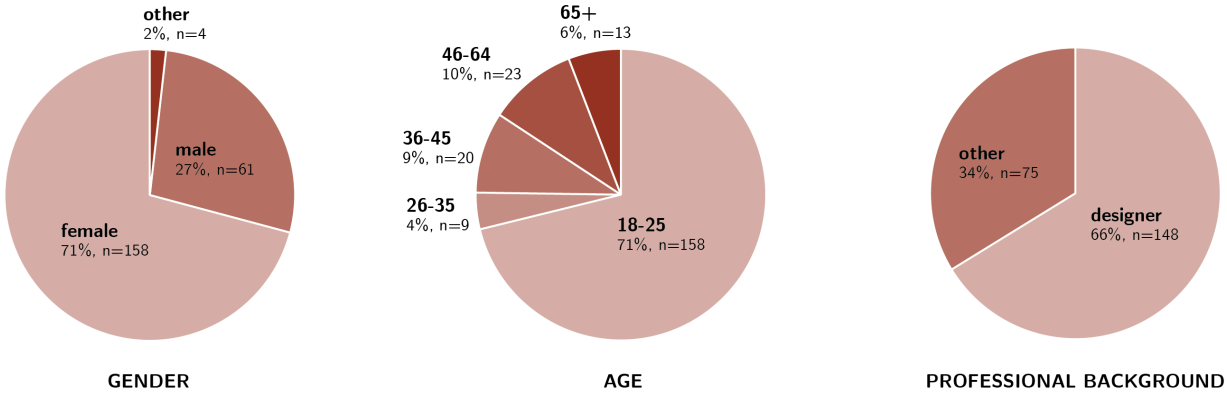

Figure 2. Demographics of respondents (n=223).

Specific characteristics stand out when evaluations of the individual EBM walls are compared. For instance, the perceived roughness of the walls differs significantly (Chi²-test, df=4, chi²-value=34.7, p<0.0001). Walls no. 5 and 2 are more often considered to be (very) rough, by 81% and 58% of respondents, compared to the other walls (no. 4: 29%, no. 1: 28%, no. 3: 21%). Furthermore, the perceived weight differs significantly between the walls (Chi²-test, df=4, chi²-value=14.4, p=0.006). Wall no. 3, the only wall constructed using glue-mortar, is considered relatively light compared to the other walls (27% considered wall no. 3 as at least somewhat heavy as compared to 46%, 50%, 63% and 54% for wall no. 1, 2, 4 and 5 respectively).

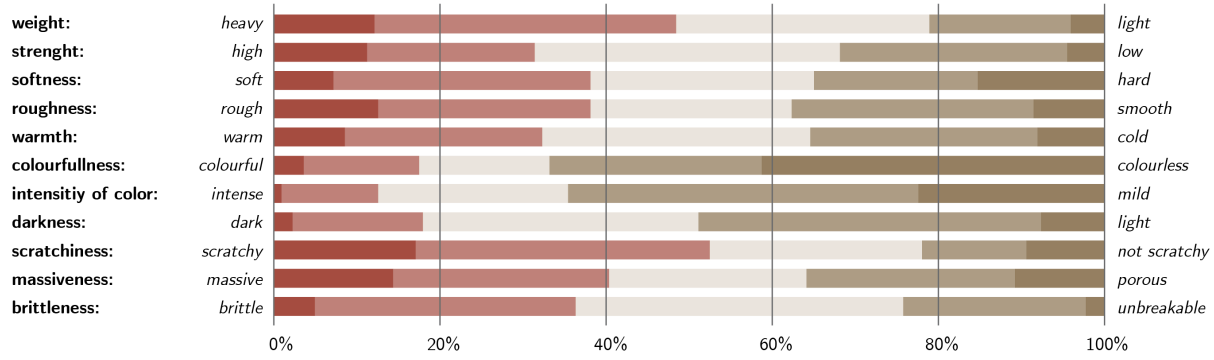

Figure 3. Evaluated sensory attributes of all walls (n=223).

4.3. Experiential attributes

The same approach was taken for mapping the experiential attributes. Respondents were asked to evaluate the walls through the selected set of experiential attributes using a five-point Likert scale. The results for the evaluations of all walls are presented in Figure 7. The walls are generally evaluated mainly as ecological, sturdy, reliable, robust and able to last a long time. On the other hand, the EBM walls are also experienced as foremostly artisanal, traditional, primitive and cheap. The walls are experienced to be unstylish but pleasant, neither formal nor inviting.

When individual walls are compared, differences between the walls become evident. Wall no. 4 was evaluated as the most industrial compared to the other walls (Chi²-test, df=4, chi²-value=36, p<0.0001), with 53% of respondents perceiving the wall as (very) industrial (no. 5: 9%, no. 2: 13%, no. 1: 14%, no.

3: 21%). This wall is constructed using cement-stabilised compressed earth blocks, which evokes associations with concrete and cheapness but is also experienced as sturdy and reliable by respondents.

On the other end of the scale, a significant difference can be found between how walls no. 5 and 2 are perceived in terms of (very) primitive as opposed to the other walls (Chi²-test, df=4, chi²-value=23.7, p<0.0001): 82% and 73% for wall no. 5 and 2, respectively (wall no. 4, 3 and 1 are perceived as (very) primitive by 39%, 40% and 56% respectively).

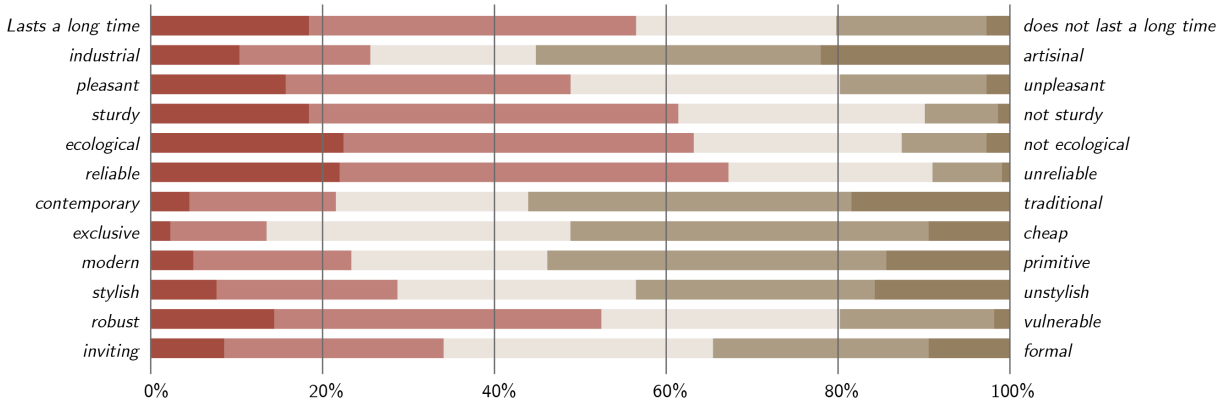

Figure 4. Evaluated experiential attributes of all walls (n=223).

4.4. Aesthetic experience

For mapping the aesthetic experience, respondents were asked which elements they considered attractive. The most given answers include the (pleasant) colour of the EBM (n=26), followed by the answers concerning the (smooth) texture of the EBs (n=20), simplicity (n=16), natural or traditional look (n=9 and n=8 respectively), and warm appearance (n=8). When asked which elements are considered *not* attractive, the most common answers concern the (blandness of the) colour (n=34), the (rough and porous) texture (n=19) or the joints (n=8).

4.5. Verdict

The questionnaire ends with asking respondents for their 'verdict' of the evaluated walls by giving them several options describing their attitudes towards the EBM walls, as shown in Figure 8. This indicates that the EBM walls are regarded overall as a realistic alternative to conventional products and, by many, also as attractive. Moreover, 71% of respondents (n=159) answered positively when asked about being open to potential implementation. However, 55% of those respondents (n=88) indicated they would rather plaster the walls than leave them in sight, see Table 1.

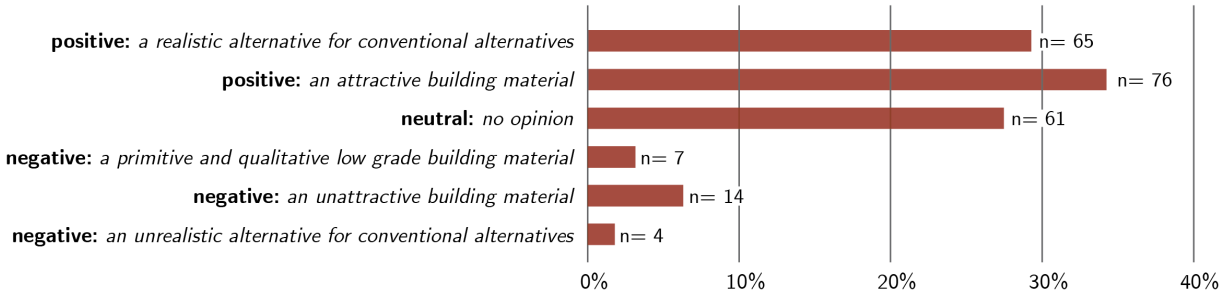

Figure 5. Mapped attitudes of respondents (n=223).

Table 1. Respondents readiness to implement vs. readiness to leave EBM walls in sight (n=223).

n = number of respondents % = column percentage		would you consider implementing earth blocks yourself?	
		yes	**no**
would you leave this interior wall in sight, or rather plaster it?	**leave in-sight**	n=71 (45%)	n=11 (17%)
	apply plaster	n=88 (55%)	n=53 (83%)

5. Discussion

This study tries to understand which factors are important during material evaluation by letting respondents evaluate EBM walls. During the survey, respondents were asked to evaluate their subjective perception of one of five presented walls: first, sensory and experiential attributes were questioned, followed by aesthetic experience and finally, a 'verdict' was asked to put results into perspective.

The findings suggest that the EBM walls are predominantly perceived as being trustworthy: a majority indicate experiencing the walls as being sturdy, reliable, robust, and able to last a long time. This is underlined by 71% of respondents who indicate a positive attitude towards potential implementation. It can be concluded that from a technical point of view, EBM for interior applications is considered by the respondents to be a worthy alternative to conventional bricks. However, even though EBM is perceived as technically adequate, the walls call into mind associations with 'old fashioned' building materials: experiential attributes like artisanal, traditional and primitive all score high. A possible cause could be the blandness of colours, the porousness, and the rough texture of some of the walls, which were often indicated as unattractive. The name of the blocks, namely 'earth-blocks', might also contribute to this image. An important point that must be made here is that this does not imply that the walls are being experienced as unattractive; a large share of the respondents indicate the EBM walls as an attractive building material, and only a few indicate the contrary. But it could mean that the appearance is often not experienced as contemporary.

The discrepancy between technical adequateness and associations with traditionalism might explain the readiness to potentially implement the material but only when covered with a plaster. Important to note is that this study solely concerns interior walls which are customarily plastered.

Associations with traditionalism and primitivism are more often mentioned in research on both EBs [6] and earth construction materials in general [8, 10, 21]. Remarkable in this study is that this association does not negatively affect the perception of the technical adequateness of the EBM walls. This might have to do with the fact that the EBs used in the walls have a similar appearance to conventional fired bricks (or concrete blocks in the case of wall no. 4), thereby possibly 'reassuring' respondents.

Looking at differences between individual walls provides a further understanding of why they are evaluated as they are; the walls most often perceived as porous and irregular in texture (walls no. 2 and 5) are also most often experienced as primitive and artisanal. Likewise, wall no. 4, constructed using cement-stabilised compressed earth blocks, is experienced as the most industrial of the walls and evokes associations with concrete and cheapness. But on the other hand, it is also experienced as sturdy and reliable. Both examples show that objective material attributes, like manufacturing techniques and raw materials used, influence the evaluation of subjective material attributes. By coupling these subjective evaluations with the objective material attributes, an understanding is gained of how the two are related; this understanding might contribute to predicting how EBs will be perceived by the general public based on the objective material attributes.

5.1. Limitations

The findings of this study need to be seen in the context in which the survey is conducted. As noted in the theoretical framework, subjective material evaluation is influenced by both the physical context in which the material is presented and the respondent's personal and cultural background. This study was conducted through small EBM walls in a decontextualised setting; this way of presenting undoubtedly affects material evaluation and, therefore, only gives an indication of which aspects play a role in material evaluation. To gain a thorough understanding of the subject, it will be necessary for future research to be conducted in a real-world context (i.e. buildings in which EBM is used). Moreover, because virtually all respondents were Belgian, and the research was conducted in a Belgian context, the presented results are foremost relevant in Belgium. This is relevant because building cultures and traditions vary substantially from country to country.

To reach a large number of respondents, this study chose to address the potential (end-) user in the most general terms; this results in a large group of people who are not specifically invested in the material and most likely are not in the situation in which the consideration of building materials is a meaningful undertaking. This choice was made on purpose to gain insights into general topics that play a role in evaluating EBM. To get more in-depth insights into the perspective of parties that actually might consider adopting EBs and, therefore, increase the relevancy of the results, future research should invest itself more with the decision-maker during the implementation process. People involved in this process will have more knowledge about the material and will consequently have more to share on the subject.

To conclude, this study's results are foremostly meant to map which aspects play a substantial role and which aspects do not in the material evaluation of EBM. Therefore, before we can generalise the findings of this study, it will be necessary to conduct more in-depth, qualitative research in a real-world context.

6. Conclusion

This study aimed to map how potential (end-) users evaluate EBM and identify which factors are important during this material evaluation. Seven material attributes for material evaluation, ranging from objective to subjective, were extracted from the literature. Through a survey, the subjective material attributes were mapped: the sensory attributes (reporting of the senses), aesthetic experience (attractiveness of sensory attributes) and the experiential attributes (perceptions, associations, emotions). Questions related to these attributes were supplemented by a final set of questions to ask the respondents about a ‘verdict’ concerning the implementation of EBM.

Through this survey, five EBM mock-up walls were evaluated by potential (end-) users, which revealed that the most mentioned sensory characteristics are the colour and roughness of the material. From an experiential point of view, respondents indicate the walls as being (technically) trustworthy but often experience the walls as traditional or unstylish. Finally, most respondents indicate a positive attitude towards potential implementation, even though plastering of the walls is preferred.

These results have limitations and are foremostly meant to pinpoint which EBM aspects respondents emphasise but lack a real-world context and actual decision-makers. These factors should, therefore, be included in future research and will help to effectively indicate where extra attention is needed in terms of further development, commercialisation and communication with regard to EBM.

7. Acknowledgements

This research was supported by the Living Lab Circular Economy “Application of Earth Blocks in Practice”, funded by VLAIO, the Flemish Agency for Innovation and Entrepreneurship, and the NextGenerationEU fund of the European Commission.

8. CRediT author statement

N de Vries[1] (1st author, corresponding author): Conceptualisation, Methodology, Formal analysis, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization.

E Knapen[1], R Novais Passarelli[1] (2nd and 3th author): Supervision, Conceptualisation, Methodology, Investigation, Writing - Review & Editing.

E Nuyts[1,2] (4th author): Methodology, Formal analysis, Data Curation

References

[1] Fabbri A, Morel J-C, Aubert J-E, Bui Q-B, Gallipoli D and Venkatarama Reddy B V 2022 *Testing and Characterisation of Earth-based Building Materials and Elements, State-of-the-Art Report of the RILEM TC 274-TCE* (Cham: Springer)
[2] Williams C, Goodhew S, Griffiths R and Watson L 2010 The feasibility of earth block masonry for building sustainable walling in the United Kingdom *J. Build. Apprais.* **6** 99-108
[3] E Pelicaen et al 2023 IOP Conf. Ser.: Earth Environ. Sci. **1196** 012062
[4] Dorado P, Cabrera S and Rolón G 2022 Contemporary difficulties and challenges for the implementation and development of compressed earth block building technology in Argentina *J. Build. Eng.* **46** 103748
[5] Schroeder H 2012 Modern earth building codes, standards and normative development *Modern Earth Buildings* ed MR Hall *et al* (Sawston: Woodhead Publishing) p 72-109
[6] Hughes E, Valdes-Vasquez R and Elliott J 2017 Perceptions of compressed earth block among residential contractors in North Carolina: An exploratory evaluation *J. Green Build.* **12** 89-107
[7] Ben-Alon L, Loftness V, Harries K A and Cochran Hameen E 2022 Overcoming the Perceptual Gap: Worldwide Perceived Comfort Survey of Earthen Building Experts and Homeowners. *4th International Conference on Bio-Based Building Materials*.
[8] Morel J-C, Charef R, Hamard E, Fabbri A, Beckett C and Bui Q-B 2021 Earth as construction material in the circular economy context: practitioner perspectives on barriers to overcome *Phil. Trans. R. Soc. B* **376** 20200182
[9] Pelé-Peltier A, Charef R and Morel J-C 2023 Factors affecting the use of earth material in mainstream construction: a critical review *Build. Res. Inf.* **51** 119-37
[10] Ben-Alon L, Loftness V, Harries K A, Hameen E C and Bridges M 2020 Integrating earthen building materials and methods into mainstream construction *J. Green Build.* **15** 87-106
[11] Ashby M and Johnson K 2002 *Materials and Design: The Art and Science of Material Selection in Product Design* (Oxford: Butterworth Heinemann)
[12] Wastiels L 2010 Mapping material experience in architecture, characterization of material warmth *PhD Thesis* Vrije Universiteit Brussel, Brussels
[13] Hegger M, Drexler, H., & Zeumer, M. 2007 *Basics: Materials* (Basel: Birkhäuser)
[14] Karana E 2009 Meanings of materials *PhD Thesis* Technische universiteit Delft, Delft
[15] Bejder A K 2012 Aesthetic Qualities of Cross Laminated Timber *PhD Thesis* Department of Civil Engineering, Aalborg University, Aalborg
[16] Rauch M, Kapfinger O and Sauer M 2015 *Refined earth construction & design with rammed earth* (Munich: DETAIL)
[17] Veelaert L, Moons I and Du Bois E 2021 Formulating guidelines for the systematic set-up of experiential material characterization studies: a case of plastic demonstrators. *Proceedings of the Design Society* p 1587-96.
[18] Veelaert L, Moons I, Rohaert S and Du Bois E 2019 A Neutral Form for Experiential Material Characterisation. *Proceedings of the Design Society: International Conference on Engineering Design* p 1743-52.
[19] Schifferstein H N J and Wastiels L 2014 Chapter 2 - Sensing Materials: Exploring the Building Blocks for Experiential Design *Materials Experience* ed E Karana *et al* (Boston: Butterworth-Heinemann) p 15-26
[20] Schifferstein R and Cleiren M 2005 Capturing product experiences: A split-modality approach *Acta Psychol.* **118** 293-318

[21] Zami M S 2021 Barriers hindering acceptance of earth construction in the urban context of the United Kingdom *Archit. Eng. Des. Manag.* **18** 941-58