

PARAMETRICAL DESIGN TOOL AND THE PRODUCTION OF TECHNICAL DATA FOR SUPERADOBE DOMES

ARTIGO

Ferramenta de desenho paramétrico e a produção de dados técnicos para domos de superadobe

Deborah Macêdo dos Santos¹, José Nuno Beirão²

RESUMO: O interesse em construir domos de superadobe (também conhecido como sacos de terra compactada) tem aumentado desde que se tem desenvolvido uma consciência mundial em prol de uma sobrevivência sustentável para o equilíbrio do planeta. O objetivo principal desta pesquisa é desenvolver uma ferramenta paramétrica que ajude os arquitetos a criar modelos virtuais de domos de superadobe, na fase de estudos de criação e construção. Este desafio foi abordado pela adoção de uma metodologia experimental que explora o desenho gerativo paramétrico, com o uso de uma linguagem de programação visual (VPL). Neste artigo apresentamos o desenvolvimento de uma ferramenta para a fase de idealização que é capaz de antecipar os quantitativos da obra. Embora a ferramenta não funcione em ambiente BIM, o modelo gerativo produz informações técnicas de saída destinadas a informar a obra relativamente a condições técnicas e quantidades de material. A usabilidade da ferramenta foi validada com uma amostra aleatória internacional de especialistas.

PALAVRAS-CHAVE: Construção em terra; Modelagem geométrica; Building Information Modelling (BIM); Linguagem de programação visual (VPL); Arquitetura sustentável.

¹ Universidade Federal do Cariri, IISCA. Juazeiro do Norte, Ceará, Brasil.

² Universidade de Lisboa, Faculdade de Arquitetura, CIAUD. Lisboa, Portugal.

ABSTRACT: The interest in earthbag dome construction (also known as earthbag or superadobe) has been increasing as world consciousness develops to achieve the planet's equilibrium for sustainable living. The main objective of this research is to develop a parametric tool to help architects modeling virtual earthbag domes from ideation to construction phase. This challenge has been addressed by adopting an experimental methodology that explores parametric generative design with the use of a visual programming language (VPL). In this paper we present the development of a tool for the ideation level including features that allow for the calculation of material quantification. Even though the tool does not work in a Building Information Modeling environment, the generative model outputs technical information to support construction, namely material quantities. The usability of the tool was validated by a random international sample of experts.

KEYWORDS: Earth construction; 3D modelling; Building Information Modelling (BIM); Visual programming language (VPL); Sustainable Architecture.

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INTRODUCTION

This research aims at facilitating the virtual modeling of superadobe domes by architects and also the calculation of the quantitative resources to build up the dome. It is also an indirect way to encourage the adoption of ecological materials used in ancient construction techniques into our current construction practices

In face of the finitude of natural resources and accelerated environmental degradation, recently many researchers (SALGUEIRO; FERRIES, 2015; FATHI; SALEH; HEGAZY, 2016; KENSEK; DING; LONGCORE, 2016; RAHIMIAN; IULO; DUARTE, 2018) have explored the use of digital technologies in various phases of design and planning to improve the development of resilient, sustainable, and environmental-friendly architecture.

Some other researchers have also published work regarding the combination of earth architecture and digital technologies (FUJII et al., 2009; DI MASCIO, 2013; VARELA; PAIO; RATO, 2013; MUÑOZ; JOVE, 2014). It is pertinent to associate the use of digital technologies with the development of these kind of projects because they cause less damage to the environment and should therefore be facilitated. Inside the universe of earth architecture, research merging digital technologies and earthbag techniques is hardly found.

Superadobe is also known as earthbag, sandbag or superblock. It is the construction technique where the walls are built out of stacked bags filled with earth, interspersed with barbed wire to improve clamping between layers (HUNTER; KIFFMEYER, 2004; MINKE, 2006; HART, 2015; SANTOS; BEIRÃO, 2016). These constructions are durable, strong, climatically efficient, and formally flexible (HUNTER; KIFFMEYER, 2004). They are low cost and quick to build. They are composed with renewable and reusable resources, hence promoting sustainable development (BARNES; KANG; CAO, 2006).

Regarding formal composition, the superadobe buildings assume shapes like domes, arches or conventional linear designs (SANTOS; BEIRÃO, 2016). Only with dome composition, the construction can be build up almost exclusively with superadobe, including roofing and foundations.

Because of all those advantages, the earthbag dome have been widely applied for different purposes. One of them is answer to social housing crisis, like the temporary village to receive Iraqi refugees made in 1995 by The United Nations Refugee Agency - UNHCR (ALBADRA; COLEY; HART, 2018). Besides the social housing solution, the earthbag dome has also been adopted in contemporary constructions, like “casa Vergara” (VALLEJO, 2011), built in Bogotá in 2011, a project that integrates the earthbag dome in a contemporary design, creating an innovative project. Many eco-communities and ecovillages have also adopted de earthbag dome because of its ecological potential of resilient design. During the year 2017 we have cataloged a generous amount of earthbag dome figures in social media (Instagram) with the hashtags #earthbag and #superadobe, there were more than 6.000 figures of each descriptor. Some of them have their location identified by the authors, which refers to different locations of the world, such as: Japan, Russia, Venezuela, United States, Australia, India, Brazil, and others.

Although earth construction is recognized as a low environmental impact solution, the existing software tools are still limiting factors in this specific type of project and especially for dome composition which requires to follow more specific design rules. Considering this, we formulated the hypothesis that the virtual modeling of the domes could be aided by a parametric tool specifically developed for the purpose.

This paper offers an overview of the superadobe dome constructive rules and a practical contribution through an application in a computational tool named “CICERO” (Creative Interface for Constructing Earthbag Resource Objects). It is a parametric generative dome design tool developed with the use of a visual programming language (VPL) that generates earthbag designs considering the geometric limitations of the construction

technology guiding the designers towards consistent solutions. It also presents some BIM (Building information modeling) characteristics, since it provides automatically technical data while the model is being generated parametrically.

METHODS

The research adopted an experimental methodology exploring the advantages of parametric generative design with the use of a visual programming language (VPL systems), through a computational thinking approach.

Computational thinking

Computational thinking is an analytical way of thinking that can solve any solvable problem (WING, 2008). The use of computational thinking has to follow three key aspects: abstraction, automation and analysis (WING, 2008; LEE et al., 2011). This paper is structured according to this approach and the methodological procedures are:

a) Abstraction: After collecting from existing literature an extensive set of earthbag building technical characteristics, the task is generalized, and the unnecessary details are removed to design a general problem comprehension in the form of a generic diagram. It presents the main parameters for the generation of earthbag domes;

b) Automation: This action corresponds to the design of the code. In this case, to the development of a parametric model able to generate the earthbag domes and associations of various apses. For better formatting purpose, we present the pertinent data collection, together with the automation section, in this paper.

c) Analysis: Checking if the results match the expectations. This was done via online testing with a sample of specialists from different parts of the world.

Research validation

Visual programming languages may be argued to have begun in the sixties, when a computer graphic experiment named GRAIL (Graphical input language) was presented as computer programming via flowcharts (ELLIS; HEAFNER; SIBLEY, 1969a)(ELLIS; HEAFNER; SIBLEY, 1969b). Nowadays, the most successful VPLs work as plug-ins in a CAD or BIM modeling system, such as Dynamo for Revit and Grasshopper for Rhinoceros (Grasshopper also connect to Archicad and VisualArq). In this research, the adopted set is the second one.

The methodological procedures used to validate CICERO were:

- a) Insert CICERO in a web-based platform to implement tests online.
- b) Submit the tool to architects with experience in earthbag construction to experiment the tool and request answer to an inquiry.
- c) Evaluate the survey and their results. Conclude regarding tool validation.

Abstraction

Aiming to solve the challenge of designing a parametric system for earthbag domes, a generic code diagram was designed (Figure 1) identifying the changing variables, the kind of shapes that can be generated and the expected associated technical data outputs.

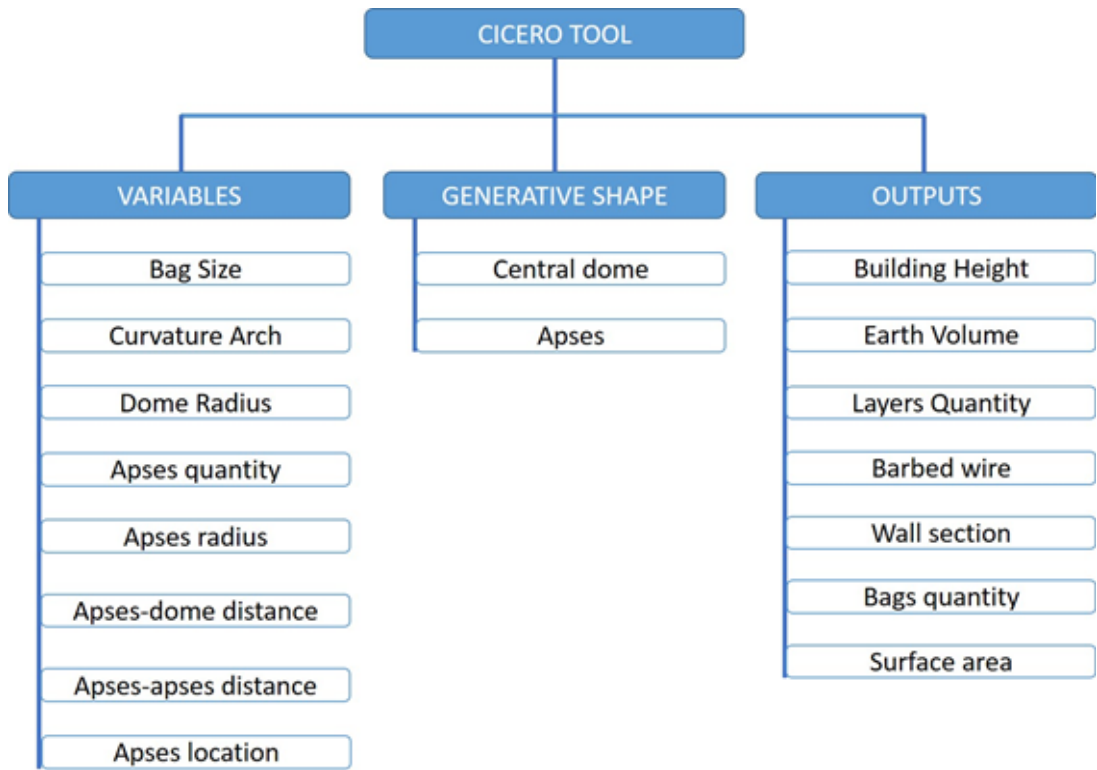


Figure 1: Generic code diagram.

Source: Authors.

Data collection and code implementation (Automation)

Finding the data collection needed as input is one of the main problems of computer architectural design when used for graphic output (RYBNIKAR, 1985). To develop the VPL code for the earthbag dome construction, two general steps were necessary.

Firstly, an overview of research on earthbag construction was done to identify technical rules, constructive constraints and general characteristics of earthbag domes.

Secondly, we devised a way to insert all technical variables into the code parameters. The goal was to provide a tool where the user could provide inputs and receive an interactive response from the model. The identified inputs refer to: bag size, curvature arch, radius of the dome, quantity of apses (smaller domes) to assemble around the first one, distance of the apses to the center, the angle to locate the apses and finally their radius (Figure 2).

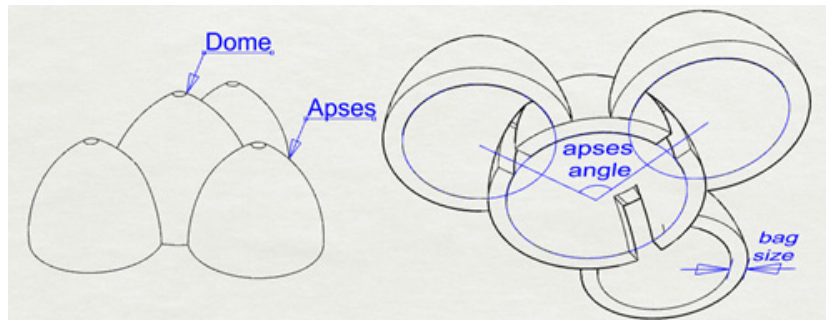


Figure 2: Schematic design of dome and apses.

Source: Authors.

Variable Inputs and their relations

The tool inputs are inserted resorting to number slider interfaces (Figure 3). These sliders were predefined, constrained to specific limitations resulting from the survey on the structural constraints of the constructive technique.

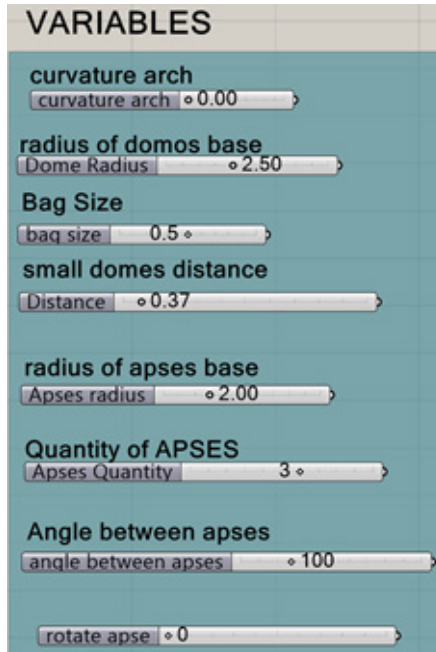


Figure 3: CICERO inputs.
Source: Authors.

Dome design

BAGS

The purpose of the bag is to retain the earth during the construction process. They can be acquired in tubes as continuous bags or individual bags. Polypropylene bags are more recurrently used; however other kinds can be used like burlap which has the advantage of being made also of natural and environment friendly material. Polypropylene is the cheaper alternative and is not as environmentally toxic as the polyvinyl chloride (PVC) (WOJCIECHOWSKA, 2001); besides, it can be recycled. For construction, the disadvantages are related with fragility resulting from direct ultraviolet sunlight. There are some polypropylene bags with ultra violet protection, but it only delays the degradation process a few weeks, in case the bags are left exposed to sunlight. The indication then is that they must be protected as much as possible, for instance by plastering. However, after plastering, the polypropylene bags are the stronger option and do not deteriorate (HART, 2015).

The wall width is the variable with greatest influence on structural safety (CANADELL; BLANCO; CAVALARO, 2016), then the bags chosen must be bigger than 12 inches (30,48cm) wide, when flattened in each layer (HUNTER; KIFFMEYER, 2004; HART, 2015). Khalili suggests a roll of 14 to 16 inches (35,56 to 40,64cm) wide Superadobe tubing (KHALILI, 2008). For individual bags, Hart suggests bags around 18 inches (45,72cm) wide when flat and 32 inches (81,28cm) long (HART, 2015). After the survey about available bag sizes we considered the sizes that match the structural constraints: 40, 50 and 60 centimeters wide bags after compaction.

RADIUS

For a self-supporting single dome, the ideal interior diameter suggested by Khalili is: 2,5 to 3,5 meters (KHALILI, 2008). However, new studies simulated a diameter of 6,0 meters (HUNTER; KIFFMEYER, 2004; CANADELL; BLANCO; CAVALARO, 2016).

ARCH CURVATURE

Earthbag domes are supposed to work with the force of gravity, rather than against it; they are structurally made by the revolution of the most stable design: the dome. The design of self-supporting dome section was created by the observation studies of a hanging chain under tension, once it is reversed is under maximum compression (WOJCIECHOWSKA, 2001; KHALILI, 2008) and becomes a catenary arch (KHALILI, 1986). Even though the catenary arch is the strongest and most stable arch in gravity, it is hard to reproduce it on site in real scale. Because of the structure and method of building a self-supporting earthbag dome has a taller “Lancet” or “Ogival” profile design (GONZÁLEZ, 2006; KHALILI, 2008).

Two kinds of arches were already studied and validated by theoretical studies as the better structural designs for earthbag domes: The pointed arch, originally proposed by Khalili, and the variable arch, proposed by recent structural studies, see figure 4 (CANADELL; BLANCO; CAVALARO, 2016). The variable arch is more steepen aiding extra stability to structure (HUNTER; KIFFMEYER, 2004).

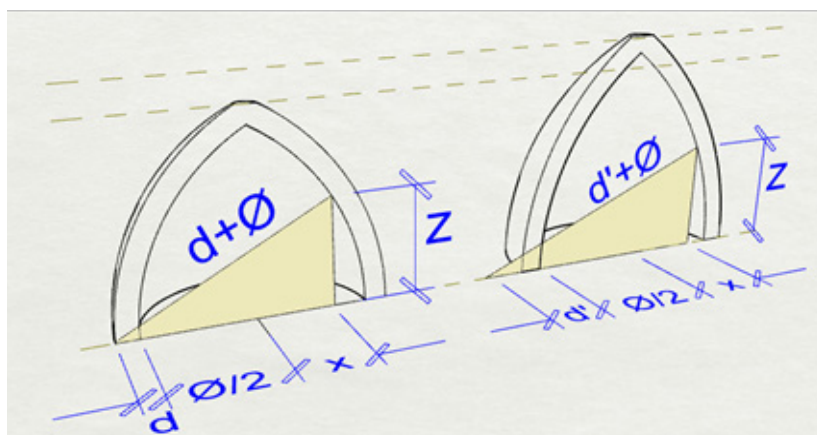


Figure 4: relations for dome design. Pointed arch and variable arch.

Source: Adapted from Canadell et al., 2016.

During the construction, it is required the use of two cords as a compass to define the geometry, the center compass to adjust each layer and the height compass to design the arch curvature.

For the pointed arch, the compass must be stacked touching the entrance door covering a cord equivalent to the internal diameter plus bag size. For the variable arch (Figure 4), according to literature, the distance (d') to stack the cord to the dome entrance can be increased up to 1,50m (CANADELL; BLANCO; CAVALARO, 2016).

Based on the arches’ curvature equations, it is possible to find the dome height and design the dome section.

DOMES CODE DESIGN

Based on the previous collected data, the volumetric dome geometry was codified in grasshopper (Figure 5).

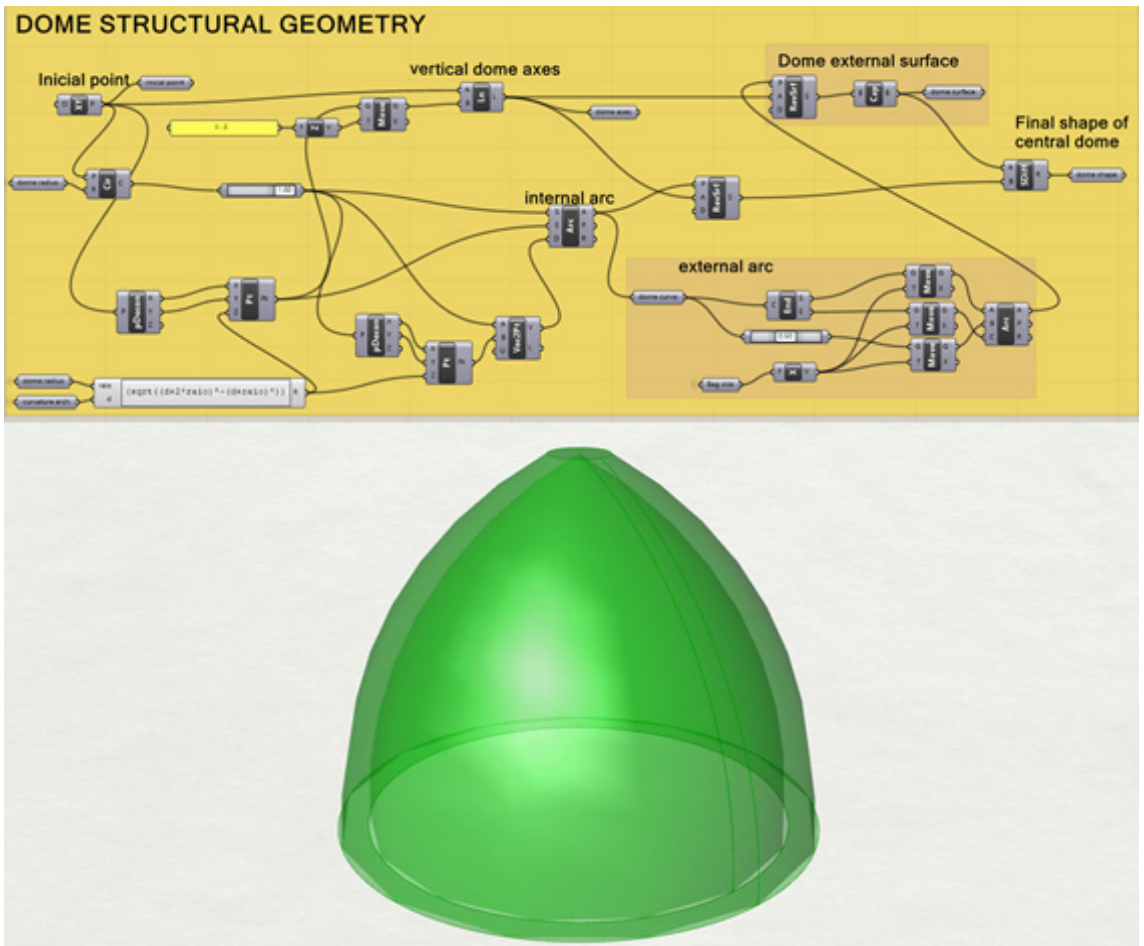


Figure 5: Parametric dome design.
Source: Authors.

Apses design (Clustering)

To achieve designs with a bigger living area, it is recommended to build several interconnected domes instead of a bigger one (HUNTER; KIFFMEYER, 2004).

It is also a good structural strategy, building additional semi-domes (apses), assembled around a big central one acting as buttresses, like in the historical Byzantine constructions (COWAN, 1977).

These associations are build interlocking bags by overlapping alternate rows. The apses will work as a buttress, for the larger dome adding stability to the overall design (COWAN, 1977; KHALILI, 1986). Together they will counterbalance each other permanently.

It is a praxis recommendation to insert at least one third of the apses projection inside the cluster to work as a buttress.

Based on the previous collected data, the volumetric apses geometry was codified in grasshopper (Figure 6).

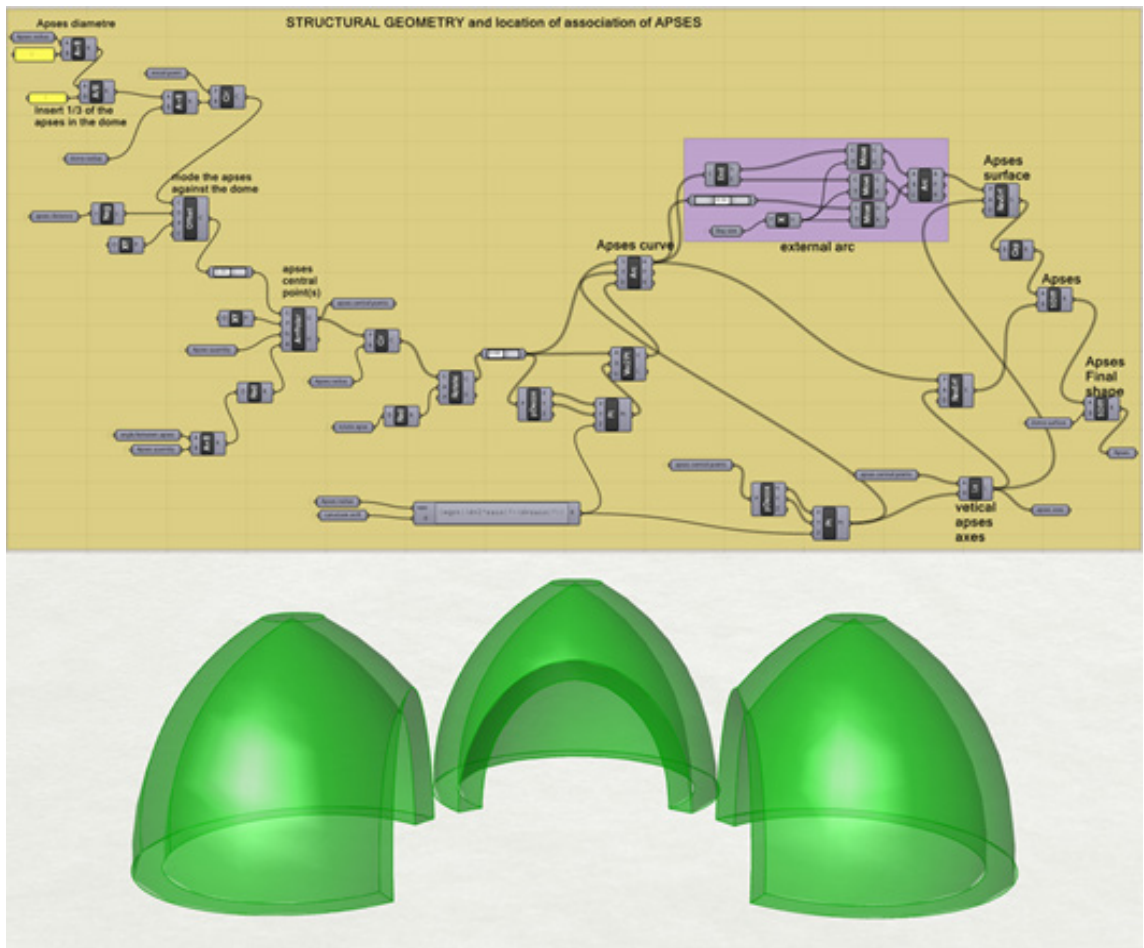


Figure 6: Parametric apses design.

Source: Authors.

Summary Inputs Board

Table 1 shows a summary of all inputs needed for the generation of the central dome and apses.

Variables	Numerical values	Unity
Bag Size (compacted)	0.4 - 0.5 - 0.6	Meters
Curvature Arch	1 to 1.5	Meters
Dome Radius	0.75 to 5.00	Meters
Quantity of apses	0 to 5	Integers
Radius of apses	0.75 to 5.00	Meters
Distance (apses to center)	≥0	Meters
Angle location (apses)	0 to 360	Degrees
Rotate apses	0 to 360	Degrees

Table 1: Summary Inputs Board.

Source: Authors.

Outputs

BUILDING HEIGHT

If the radius is known, the height of the building can be extracted by resorting to basic trigonometry, with rectangle triangle proportions (Figure 7). Then the height is given by the equation $height = \sqrt{(bag + 2 * radius)^2 - (bag + radius)^2}$.

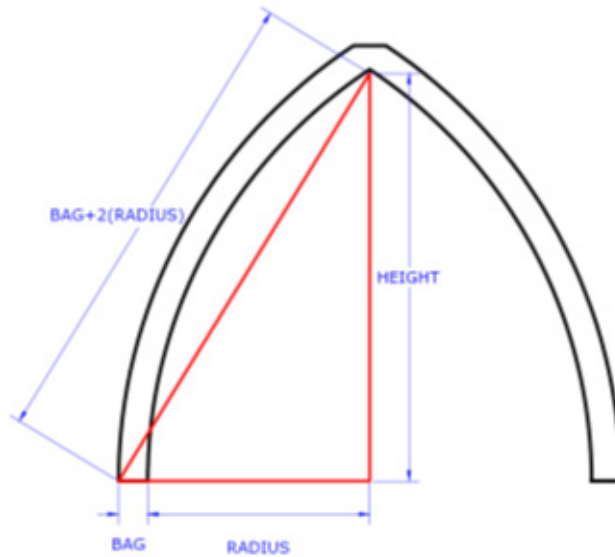


Figure 7: Diagram of equation to find building height.

Source: Authors.

VOLUME OF EARTH

The volume of earth consumed in the construction is extracted from the 3D model. However, it is necessary to calculate two variables: the relation between the compacted and uncompact soil and the composition plus percentage of soil mixture. As the conditions can change according to each site, the final user has to do this calculus.

The volume extracted from the model refers to the compacted mixture when the soil particles are pressed together. Therefore, for calculating the earth amount needed in the construction process it is necessary to calculate the uncompact mixture quantity when the soil is loose and mixed with air.

The trivial praxis in quantification engineering calculus is to add 40% to discover the uncompact soil volume V_e . So, we developed the equation that multiplies the earth compacted volume (V_c) per a compression factor (f) to obtain the needed earth volume (V_e). $V_e = V_c + (V_c \times f)$. When the factor (f) is unknown one adopts the 40% addition as standard value, $V_e = 1,4V_c$.

As bags contain soil, any soil type can be used, except highly organic soil, increasing the chance to use on-site material (CALKINS, 2009). However the ideal mix for earthbag construction is approximately 30% of clayed soil and 70% sandy soil (HUNTER; KIFFMEYER, 2004; CALKINS, 2009; GEIGER, 2011; HART, 2015). Most of the world's oldest remaining earth constructions were built with this soil mix ratio. Sometimes it is not possible to achieve the ideal ratio depending on the site soil; in such a case the builder needs to insert different proportions of natural hydraulic lime.

LAYERS QUANTITY

After the tamping process, the layers lose height up to 12 cm (GEIGER, 2011). After the conclusion of higher layers, the underlying rows can flatten down also. They can variate a little between themselves.

For empirical studies, it was defined that, considering representations

necessities, the height of each earthbag layer must represent by the rate of ten centimeters (HUNTER; KIFFMEYER, 2004). Then, to identify the number of layers the equation is given by dividing the total height by 0,10 meters.

BARBED WIRE

Ideally two threads of 4-point barbed wire are applied, parallel to each other, between the layers along the entire length of the wall to increase bag to bag friction and overall stability (WOJCIECHOWSKA, 2001; HUNTER; KIFFMEYER, 2004; GEIGER, 2011; HART, 2015). The wire combined with the woven polypropylene fabric add a high tensile strength to the structure. Therefore, the total length of barbed wire is twice the length of all bag layers, except the last one.

BAGS QUANTITY

The bags quantity is extracted from the model. The total of bags in linear meters is the length of all bag layers, plus at least 20cm of loose material, for each cut, to tie off the ends (HUNTER; KIFFMEYER, 2004; HART, 2018).

WALL SECTION

The wall section is derived from calculating the bag width plus inner and outer covering material (2,5cm thick plastering). When the bags are full and tamped, the wall presents layers of 10 cm of height. A 2,5cm thick layer of plaster regularizes the wall surface, both inside and outside. The mathematical expression for the wall section is presented in Figure 8. The bag diameter corresponds to twice the bag size.

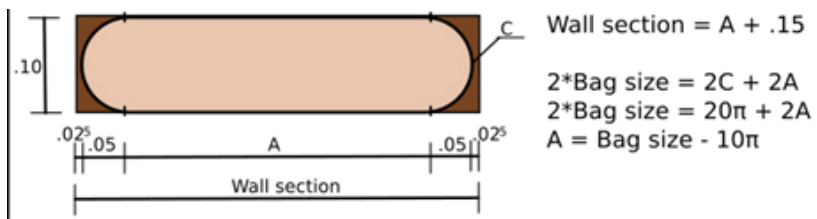


Figure 8: Wall section expression.

Source: Authors.

SURFACE AREA

The quantity of external surface is extracted directly from the model. Knowing the total external surface is important to calculate the quantities of coating material to protect the structure. The covering materials can variate according to each project. However, it is often used chicken wire or synthetic mesh to wrap the entire dome surface providing adhesion more adherent surface for usual covering materials, including stucco and earthen plaster (HUNTER; KIFFMEYER, 2004; HART, 2015, 2018).

The chicken wire or synthetic mesh quantity is calculated depending on the way selected to attach it into a bag wall. One way to do it is install lengths of tie wires into the barbed wire between layers, to project beyond the wall more than 5 cm, during the construction (HUNTER; KIFFMEYER, 2004). When the walls are built, the chicken wire is stretched over the walls, including doors and windows, then it is cinched tight and tacked down. The chicken wire consolidates the plaster coating and its surface corresponds the 1,1 times the wall surface (inside surface plus outside surface). This values considers chicken wire overlaps needed to guarantee a continuous consolidation of the plaster coating.

Outdoor plasters need stabilization to avoid erosion or degradation by weather. Some examples that can be added to the mixture are Portland cement, lime, flour, and cactus juice (HART, 2018). The ratio of lime mixture is 1 part of hydrate lime to 3 parts of sand.

The quantity of plaster used to cover inside and outside wall surfaces is taken from the geometric model (inside plus outside surfaces) and multiplied by the 2,5cm thickness. The additional grooves generated by the bag layers correspond to four times ($r^2 - \pi r^2/4$) multiplied by the sum of all layers' perimeters. In this equation r corresponds to half the bag layer thickness, in other words to 5cm.

Therefore, the geometric model outputs an accurate list of all material parts and their quantities, including bags, barbed wire, earth divided in its constituent parts, chicken wire and plaster. Any additional outside surface finishing like painting or lime whitewash can be also taken directly from the geometric model.

RESULTS AND DISCUSSIONS (ANALYSIS)

The code structure provides a generative design interface, based on changing the input variables bounded by the known structural constraints and generate a volumetric model together with the necessary constructive information outputs, namely those informing material quantities which enable the calculation of construction costs.

The CICERO tool was designed after some preliminary code prototypes based on a systematic literature review process and several trial implementations until an idealized usability was eventually achieved. There is a rectangle box interface on the right side of the interface providing the variables, or the inputs to be changed per project by the user. On the left side, there is the generated simplified 3D model providing the constructive information as outputs. They are given in real time to help decision making while the creative process is under development.

At first, we tried to design the model revealing the detailed design of walls, including the layers, barbed wire and covering, but the algorithm became slow and the tool used to crash depending on the computer. Then we decided to provide a schematic visualization to have the benefit of an algorithm that runs faster. However, the tool still informs the number of layers as output. Only geometry is simplified. This method of simplification and high simplification - the use of only primitive forms - of buildings representation, to the detriment of better user experience by algorithmic design, have been indicated and adopted by well-known researchers (SHAVIV; GAVISH; AMIR, 1990).

We had the same crash problem when applying windows and doors parametrically, then we decided to include fixed internal doors between rooms. Windows and doors can be added later on when a design is fixed, in the algorithm, and then the calculations of material quantities are updated.

VALIDATION

Later on, an evaluation was made resorting to online users, using the 'shapediver' (www.shapediver.com) platform to host the tool (Figure. 9). In this way, the users did not need to download anything, and they could do the entire procedure online.

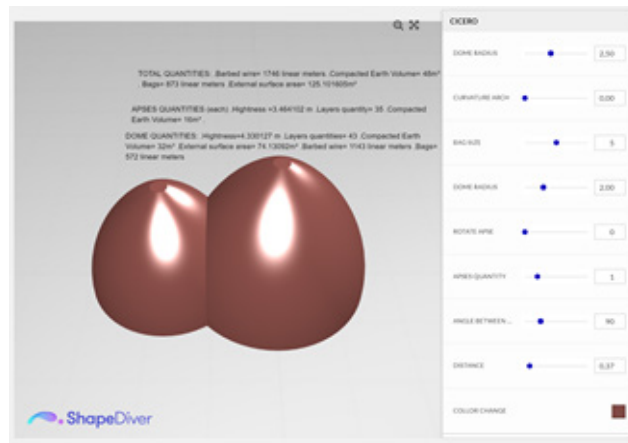


Figure 9: CICERO tool.
Source: Authors.

The tool was embedded in a website (www.cicero.earth) with a video-tutorial and an inquiry to answer after its use. The inquiry was available in English and Portuguese and was divided into three larger categories: user characterization, user interaction and subjective suggestions for improvements.

The website was disclosed aiming at experts in earthbag construction and planning for validating the technical data, the tool usage and establish a general profile of the target audience for the final tool.

It was also necessary to collect data from lay people (not just from experts) to evaluate the tool user experience.

User Characterization

There were seventeen people, with different working nationalities (Brazil, United States, Guatemala, Turkey, Portugal and Italy), recruited for the research sample. The age variations were: 47% between 26 to 35 years, 35% between 36 to 45 years, 6% between 46 to 55 years and 12% over 66 years old.

Five of them were specialists in planning, had constructive experience in earthbag buildings and still work in this field. One works in Europe, two in Brazil, and two in the United States. One with less than five years of experience, two with five to seven years, and two with more than ten years. Two usually plan by hand, and three use CAD software. When it was asked how much time they usually need to design a virtual volumetric model, most of them answered differently: two never did, one needs minutes, one needs hours and one needs days.

There was one retired (did not specified the career), and only one student in the sample, all the other persons were architects, designers or professors in these fields. Two of them did not know about earthbag construction before this research, the others learned it in University, books, workshops, conferences, websites, video programs and manuals.

User Interaction

There were three exercises to evaluate the tool performance for time and comprehension of the tool, and ten objective questions based on the 10 Nielsen's heuristics (NIELSEN, 1995).

The exercises were designed to recreate three different known volumetric dome models, extracted from the literature (Figure. 10). Technical images and respective information to feed the tool were given. After finishing the experiment, users were requested to sign how much time they took to design the virtual model.

The exercises were given in an ascendant difficulty scale, where they needed to change progressively more variables to generate more complex dome clusters. Eighty-eight percent, did the exercises in less than ten minutes using CICERO. Only two people took more time to do them. The first because he was doing other things during the exercise, the second was a Brazilian and said that he had difficulties to understand the parameters in English and had to check their translation first.

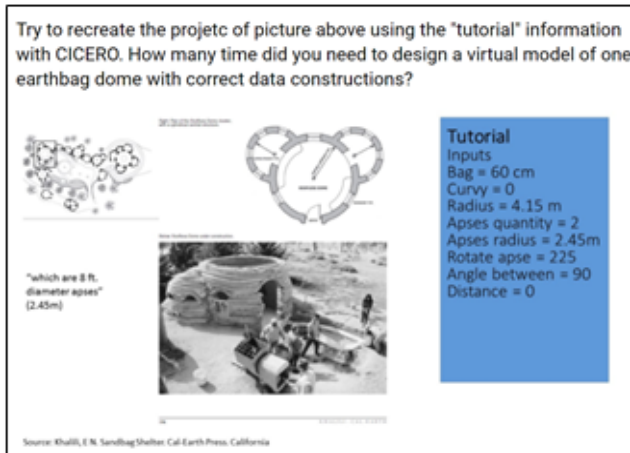


Figure 10: Example of the exercise given to validate the tool.

Source: Authors.

The questions are based on Nielsen’s heuristics; these are guidelines to evaluate the user interaction. They regard: visibility of system status; match between system and real world; user control and freedom; consistency and standards; error prevention; recognition rather than recall; flexibility and efficiency of use; aesthetic and minimalist design; help users and documentation.

All fourteen people answered this part. All heuristics parameters were well ranked in evaluation (more than 85%). The only parameter that took less was about the help documentation, where just 71% said it was enough for their CICERO understanding.

Suggestions

The last comments and suggestions given by the participants were: insert in Cicero additional data regarding buttressing (besides the included apses), openings and safety factors; improve the explanation on the parameters with auxiliary documentation; insert the measurement units in the parameters and finally translate the tool for other idioms.

IS CICERO A BIM TOOL?

During presentations in conferences and research groups, it was discussed that CICERO could be seen as a BIM tool, due to the technical outputs that it gives. That statement makes sense considering that Building Information Modeling (BIM) are not an exclusive set of software programs, it is a process. To be specific, a modeling technology and a set of processes associated to produce, communicate and analyze constructive models (EASTMAN et al., 2011) and we would add, whilst providing associated technical data.

After a deep review of the meaning of acronyms BIM, Gaspar and Ruschel understood as a first reference that to be a BIM, this technological process must fill three items: a) object-based design; b) parametric manipulation; c) relational database (GASPAR; RUSCHEL, 2017). To put in another way, the Building Information Model is a three dimensional geometric and

parametric model with embedded data (KENSEK, 2014; TURK, 2016; LIMA et al., 2017).

As CICERO offers an object-based design, with parametric manipulation and some relational database, their utilities match with the presented definitions of BIM (Figure 11). However, CICERO can still be improved with additional technical documentation for construction management.

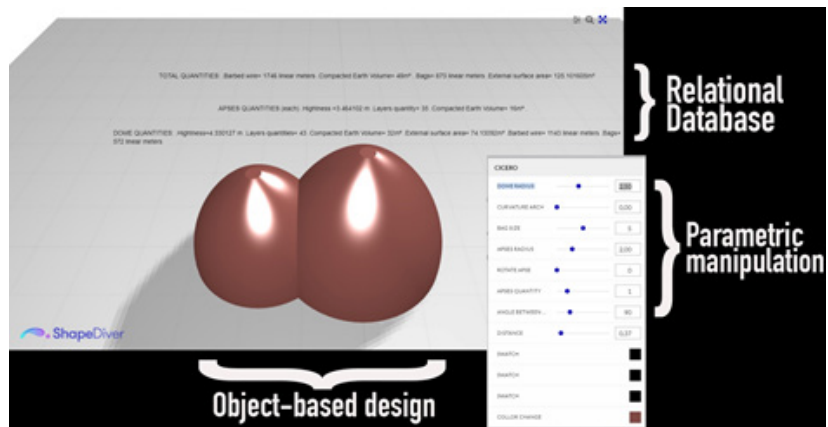


Figure 11: Correlations between CICERO and BIM
Source: Authors.

CONCLUSION

The results of the validation process confirmed the hypothesis that the use of a parametric modeling tool can improve and aid the design of earthbag domes providing new useful tools to designers. The user can create complex models, with one or more domes associated by just changing a few numeric variables, receiving the construction specification outputs, in a short period, with high efficiency. As a practical contribution, this tool is expected to help architects to design earthbag building domes, in an easier and faster way while generating automatically the necessary documentation for construction. Additionally, the generated model provides also 3D models that can be used together with digital fabrication tools to fabricate 3D scaled models that are otherwise difficult to fabricate. Finally, we also expect that the use of this tool may increase the promotion of this form of sustainable building. Future work includes improving the tool by embedding it in a BIM environment and combining dome solutions with other constructive techniques creating hybrid architectural solutions.

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REFERENCES

- ALBADRA, D.; COLEY, D.; HART, J. Toward healthy housing for the displaced. **Journal of Architecture**, v. 23, n. 1, p. 115–136, 2018.
- BARNES, B.; KANG, M.; CAO, H. Sustainable characteristics of earthbag housing. **Housing and Society**, v. 33, n. 2, p. 21–32, 2006. Disponível em: <<http://dx.doi.org/10.1080/08882746.2006.11430534>>. Acesso em: 20 jul. 2018.
- CALKINS, M. **Materials for Sustainable Sites Defined**. New Jersey: John Wiley and Sons, 2009.
- CANADELL, S.; BLANCO, A.; CAVALARO, S. H. P. Comprehensive design method for earthbag and superadobe structures. **Materials and Design**, v. 96, p. 270–282, 2016. Disponível em: <<http://dx.doi.org/10.1016/j.matdes.2016.02.028>>. Acesso em: 12 jul. 2018.
- COWAN, H. J. A history of masonry and concrete domes in building construction. **Building and Environment**, v. 12, n. 1, p. 1–24, 1977.
- DI MASCIO, D. Understanding and Managing the Constructive Characteristics of Vernacular Architecture Two raw earth dwellings. **eCAADe 2013: Computation and Performance – Proceedings of the 31st International Conference on Education and research in Computer Aided Architectural Design in Europe**, v. 2, p. 435–444, 2013.
- EASTMAN, C.; TEICHOLZ, P.; SACKS, R.; LISTON, K. **BIM Handbook: A Guide to Building Information Modelling For Owners, Managers, Designers, Engineers, Contractors and Facility Managers**. 3. ed. New Jersey: Wiley, 2011. v. 1
- ELLIS, T. O.; HEAFNER, J. F.; SIBLEY, W. L. **The Grail Project: An experiment in Man-machine communications**. Santa Monica: Rand corporation, 1969a.
- ELLIS, T. O.; HEAFNER, J. F.; SIBLEY, W. L. **The Grail Project: An experiment in Man-machine communications**. Santa Monica: Rand corporation, 1969b.
- FATHI, A.; SALEH, A.; HEGAZY, M. Computational Design as an Approach to Sustainable Regional Architecture in the Arab World. In: *Procedia - Social and Behavioral Sciences*, **Anais...** Elsevier, 2016. Disponível em: <<http://linkinghub.elsevier.com/retrieve/pii/S1877042816307030>>. Acesso em: 12 jul. 2018.
- FUJII, Y.; FODDE, E.; WATANABE, K.; MURAKAMI, K. Digital photogrammetry for the documentation of structural damage in earthen archaeological sites: The case of Ajina Tapa, Tajikistan. **Engineering Geology**, v. 105, n. 1–2, p. 124–133, 2009. Disponível em: <<http://dx.doi.org/10.1016/j.enggeo.2008.11.012>>. Acesso em: 12 jul. 2018.
- GASPAR, J. A. da M.; RUSCHEL, R. C. A evolução do significado atribuído ao acrônimo BIM: Uma perspectiva no tempo. **Blucher Design Proceedings**, p. 423–430, 2017. Disponível em: <<http://www.proceedings.blucher.com.br/article-details/27662>>. Acesso em: 12 fev. 2018.
- GEIGER, O. **Earthbag building guide**. [s.l.] Excellence in natural building series, 2011.
- GONZÁLEZ, F. D. **Geometrias da arquitetura de terra: A sustentabilidade geométrica da terra crua**. Lisbon: Universidade Lusíada, 2006. v. 1
- HART, K. **Earthbag architecture**. Lexington: Hartworks, 2015.
- HART, K. **EARTHBAG the complete step-by-step guide**. 1. ed. Canada: New society publishers, 2018.
- HUNTER, K.; KIFFMEYER, D. **Earthbag Building: The Tools, Tricks and Techniques**. Gabriola Island, Canada: New society publishers, 2004.
- KENSEK, K.; DING, Y.; LONGCORE, T. Green building and biodiversity: Facilitating bird friendly design with building information models. **Journal of Green Building**, v. 11, n. 2, p. 116–130, 2016.
- KENSEK, K. M. **Building information modeling**. New York: Routledge, 2014.
- KHALILI, E. N. **Ceramic houses and earth architecture**. 7. ed. California: Cal-Earth Press, 1986.
- KHALILI, E. N. **Emergency sandbag shelter and eco-village**. Hesperia, CA: Cal-Earth Press, 2008.
- LEE, I.; MARTIN, F.; DENNER, J.; COULTER, B.; ALLAN, W.; ERICKSON, J.; MALYN-SMITH, J.; WERNER, L. Computational thinking for youth in

practice. **ACM Inroads**, v. 2, n. 1, p. 32, 2011. Disponível em: <<http://dl.acm.org/citation.cfm?doid=1929887.1929902>>.

LIMA, R. H. F.; ARAÚJO, B. G.; PAZ, G.; OLIVEIRA, I. M. Mapa de danos de edificações históricas utilizando a metodologia BIM. (S. Scheer, E. T. Santos, M. M. X. Lima, Eds.) In: Anais do 1o Simpósio Brasileiro de Tecnologia de Informação e Comunicação na Construção, Fortaleza. **Anais... Fortaleza: Marketing aumentado**, 2017. Disponível em: <http://marketingaumentado.com.br/sbtic/sbtic2017_artigos.html>. Acesso em: 15 mar. 2018.

MINKE, G. **Building with Earth**. Basel, Switzerland: Birkhäuser, 2006.

MUÑOZ, M. del R.; JOVÉ, F. From refined to popular architecture. Mixed rammed earth walls with adobe reinforcements. (C. Mileto, F. Vegas, L. Gracia, V. Cristina, Eds.) In: proceedings of the international conference on vernacular heritage, sustainability and earth architecture, Valencia, Spain. **Anais... Valencia, Spain: CRC press**, 2014.

NIELSEN, J. 10 Heuristics for User Interface Design: Article by Jakob Nielsen. **Jakob Nielsen's Alertbox**, p. 1-2, 1995. Disponível em: <<http://www.nngroup.com/articles/ten-usability-heuristics/>>. Acesso em: 10 fev. 2018.

RAHIMIAN, M.; IULO, L. D.; DUARTE, J. M. P. A Review of Predictive Software for the Design of Community Microgrids. **Journal of Engineering (United States)**, v. 2018, 2018.

RYBNIKAR, O. Computer-Aided Architectural Design. **Batiment International, Building Research and Practice**, v. 13, n. 1, p. 31-36, 6 jan. 1985. Disponível em: <<http://www.tandfonline.com/doi/abs/10.1080/09613218508551239>>. Acesso em: 17 maio. 2018.

SALGUEIRO, I. B.; FERRIES, B. An "environmental BIM" approach for the architectural schematic design stage. **International Journal of Architectural Computing**, v. 13, n. 3-4, p. 299-312, 2015. Disponível em: <<http://www.scopus.com/inward/record.url?eid=2-s2.0-84957658646&partnerID=tZOtx3y1>>.

SANTOS, D. M.; BEIRÃO, J. N. D. C. Data collection and constructive classification of superadobe buildings. **Revista Ciência e Sustentabilidade**, v. 2, n. 2, p. 208-226, 2016.

SHAVIV, E.; GAVISH, O.; AMIR, U. Implementation of Solid Modeling in High Hierarchy Architectural Language. **Environment and Planning B: Planning and Design**, v. 17, n. 2, p. 205-220, 1990. Disponível em: <<http://www.envplan.com/abstract.cgi?id=b170205%0Ahttp://epb.sagepub.com/lookup/doi/10.1068/b170205>>.

TURK, Z. Ten questions concerning building information modelling. **Building and Environment**, v. 107, p. 1-11, 2016.

VALLEJO, J. A. Casa Vergara: Un proyecto de exploración de materiales. **Exkema**, v. 3, n. 3, p. 38-41, 2011.

VARELA, B.; PAIO, A.; RATO, V. Digital tectonic: Rethinking building with earth in architecture. In: CORREIA, M.; CARLOS, G.; ROCHA, S. (Ed.). **Vernacular Heritage and Earthen Architecture**. The Netherlands: CRC press, 2013. p. 809-813.

WING, J. M. Computational thinking and thinking about computing. **Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences**, v. 366, n. 1881, p. 3717-3725, 2008. Disponível em: <<http://rsta.royalsocietypublishing.org/cgi/doi/10.1098/rsta.2008.0118>>.

WOJCIECHOWSKA, P. **Building with earth: a guide to flexible-form earthbag construction**. White River Junction, United States: Chelsea Green Publishing Co, 2001.

Deborah Macêdo dos Santos
deborah.santos@ufca.edu.br

José Nuno Beirão
jnb@fa.ulisboa.pt