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Virtuhab portal: Materioteca with focus on analysis of sustainability in design – focused on residential units[1]

Portal Virtuhab: materioteca com enfoque na análise da sustentabilidade no projeto – foco habitação

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Abstract

At present, the design of new products requires the union of technical, aesthetic, economic and environmental factors. In this context, the choice of materials and constructive processes becomes integrated into the design, planned throughout the product life cycle. The effectiveness of this choice depends on the efficiency of the correlated factors mentioned above. Finding such information is a hard task and often disappointing. The inclusion of sustainability adds in another variable to the already complex equation. As a consequence, studies on the sustainability of materials need to be made available for designers. This paper presents a proposal to fill this gap, using a materioteca with a new concept: in addition to samples of materials and technical information, it features a full description of the economic, social and environmental sustainability impact of each material. The results obtained so far show that it is possible to empower designers with an assessment of the sustainability of each material compared to other similar ones, allowing for a relevant set of projective information.

Keywords: sustainability, design, prototypes, materials, materioteca.

Resumo

Na abordagem atual, a concepção de novos produtos exige a união de fatores técnicos, estéticos, econômicos e ambientais. Nesse contexto, a escolha dos materiais e dos processos construtivos passa a ser integrada ao projeto, planejada durante todo o ciclo de vida do produto. A eficácia dessa escolha depende da eficiência correlacionada dos fatores anteriormente citados. Encontrar esse conjunto de informações é tarefa árdua e muitas vezes decepcionante. A inclusão da sustentabilidade traz mais uma variável à já complexa equação, de modo que o projetista necessita ter disponíveis estudos sobre a sustentabilidade dos diversos materiais existentes. Este artigo apresenta uma proposta de suprir essa lacuna, mediante a utilização de uma materioteca com um novo conceito, no qual, além de amostras de materiais e informações técnicas, apresenta um relatório completo sobre a sustentabilidade econômica, social e ambiental de cada material. Os resultados obtidos até o momento da pesquisa aqui relatada demonstraram ser possível fornecer aos projetistas uma análise da sustentabilidade relativa de cada material em comparação com outros similares, proporcionando um conjunto relevante de informações projetuais.

Palavras-chave: sustentabilidade, design, protótipos, materiais, materioteca.

[1] Materioteca: a "library" (either virtual or physical) containing a collection of samples of different materials with specifications about their structure, composition, origin, physical and chemical properties and usage.

Introduction

Ensuring sustainability in product design involves a balance between three dimensions: economic, social and environmental. We should look for profit that meets the interests of all parties involved in the process: investors should have the financial return; the local community should enjoy the benefits of the activity carried out; employees should have their return in quality of life and social equity. And all that should not harm the environment, in which we all need to survive. Kubota *et al.* (2014) emphasize the role of such balance, stating that "environmental issues must now be considered as part of the overall process of product development."

Sustainability is one of the most discussed issues today, and is no longer a novelty. It involves many different areas of knowledge: social sciences applied to engineering, interconnecting with human sciences, exact sciences, etc. From the professional point of view, to be receptive and updated on this topic has become increasingly important. It is currently expected that each person must be able to recognize its share of responsibility, of what they can do to help, regardless of the professional activity exercised. Sustainability acts as a social link, in which each individual action has an effect shared by all.

Hansen *et al.* (2010) explain that the awareness of society for sustainable development is connected to the search for increased environmental performance of organizations. This attitude stimulated the development of a line of thought that tries to assess the environmental impact of goods and services through a comprehensive approach of the interconnections between the systems and the environment. This became known as Life Cycle Assessment (LCA).

Both in academy and in industry, the theme "sustainability" has been inserted gradually. It is hard to find in the market any event (certification, training, graduate programs, master classes, lectures, symposia, fairs, etc.) that do not include the issue of sustainability as a focus of debate. Another finding that proves the increase of interest in this subject is the amount of papers sent to conferences, events and journals, where the area of sustainability had considerable increase in publications. However, despite this increase, the necessary understanding of this issue still faces difficulty in two related aspects: the complexity of the factors involved, and the lack of interconnected variables and constraints. As stressed by Kubota *et al.* (2014), most of the papers (63%) are of theoretical character, which propose methods and conceptual models of product development, considering aspects of technical design aligned with aspects of eco-design, sometimes called sustainable design. This theory-oriented approach is followed by case studies for the evaluation of the proposed models. Therefore, there is a lack of practical approaches and applications, especially in the form of university study extension, strengthening the bond between research, teaching and extension.

This paper shows joint actions carried out at the university, involving engineering, architecture and design courses, which aim to contribute to solving the abovementioned problem. It shows results regarding the construction of a sustainability-oriented materioteca, available physically and virtually.

Review

"The management of materials has become vital for engineering bussines. One of the main reasons is the growing number of regulatory and environmental commitments that specify the declaration and often complete omission of some materials and substances". (Eureka Magazine, 2014). This affirmation resumes the importance of the materials today.

Civil Engineering is one of the sectors that most contributed to the formation of national GDP, directly and indirectly (economic impact). The sector is notably responsible for guiding public policies to reduce the housing deficit (social impact) and is a decisive element in the preservation of the environment (environmental impact). Given the percentage of waste disposed in municipal landfills, including even sanitation deficit issues and illegal occupation of green areas, construction is an industrial sector that lacks the evaluation of positioning of companies on sustainability (Librelotto *et al.*, 2012). As a result, this sector was chosen as a starting point for the implementation of the proposal presented here.

The design stage can be considered a complex activity. This is nothing new as it involves knowledge and expertise in various areas. And, in essence, it is a multidisciplinary process. It is characterized by the need for integration and correlation of aesthetic, marketing, financial, ecological, productive and ergonomic factors.

The design of new products, according to Manzini and Vezzoli (2008) should, in an ideal situation, incorporate the product-service system, not limited to the physical product only (defined by material, form and function). Thus the result of a design would be an integrated set of product, service and communication.

Within this line of thought, the authors point out that the design should "bind" the technically possible with the ecologically necessary, acting within four levels of interference: environmental redesign of existing products; design of new products to replace the current ones; design of new products – services that are intrinsically sustainable; and proposal of new scenarios for a new sustainable lifestyle.

Again, according to Manzini and Vezolli (2008), considering the current state of design activity, the professional performance is in almost all cases limited to the first two levels mentioned. Although useful, these levels are insufficient to achieve environmental sustainability (guaranteed only by including the other two levels – Design for Sustainability).

An analysis of the most recent publications shows that there is a consensus among authors in the field, showing that sustainability needs to be incorporated into the design activity. It is also highlighted in the literature that in order to yield a permanent effect and not just a sporadic or a f materialsltionne,ect and not just sporadic ty of materials need to be made available for the designers.superficial one, it must be based on the union of the three basic dimensions: economic, social and environmental.

Under this approach, the design that incorporates the principles of sustainability becomes, if not the only possible solution, at least the most relevant one to the occurrence of the union of philosophy of continuous improvement with the increasing need for conservation of natural resources, quality of human life and the prevailing economic model.

The design performed following the sustainable concept requires the management of a considerable amount of information. On the other hand, the market demands faster and faster solutions. Therefore, the use of categorized and classified data has become important.

As commented by Ashby and Johnson (2011), classification is the first step to bring order to any scientific research; it sorts out an initially disordered population into groups which somehow have significant similarities. Due to the design of products to be essentially a multidisciplinary activity, classification plays an important role. "Design involves choice, and a choice is made from a wide range of ideas and data – including the choice of materials and processes" (Ashby and Johnson, 2001, p. 123).

It is essential, in the field of materials and processes that the classification would occur through the mediation of a materioteca. This becomes the starting point for further analysis, for example, of the performance of materials at the level of comparative sustainability.

In accordance with Duarte and Pazmino (2010), a materioteca can be defined as a kind of library of materials and aims to provide the tactile and visual contact of the user with the materials, and provide technical information and facilitate the conscious choice of a material for the development of a product.

Hauenstein and Kindlein Jr. (2014) reported more than 90,000 materials and processes available for the manufacturing of industrial products. Therefore, to define the manufacturing materials and processes best suited to a product is a hard task – for which the availability of information is one of the most important factors. The selection of materials is directly related to the quantity and quality of available data. It is the designer's task to transform these data into useful information for the design.

The inclusion of the variable "sustainability" in a materioteca conveys the main innovation of the design reported in this paper. Its objective is to provide the researcher with useful and recent information on the technical requirements of each material, accompanied by extensive study of the variables related to sustainability: economic, environmental and social. Consequently, by using the materioteca, in addition to data on the properties, characteristics, strengths and limitations of each material, the professional designer will have at their disposal a complete analysis of the environmental implications of each choice.

There are some references for choice materials: softwares, information systems or websites. One of them is Granta Design. Founded in 1994 as a spin-out from the University of Cambridge, Granta helps engineering enterprises to manage information on the materials (metals, plastics, composites, and more). The software helps to develop and apply material intelligence, making better material decisions and reducing risk as they optimize their products. Granta provides supporting resources to thousands of university educators worldwide as they teach the next generation of engineers, scientists, and industrial designers about materials, processes, and sustainability (Granta, 2014).

Life Cicle Assessmet (LCA) is an important tool to analyse the enviromenntal impact of materials. According to EPA – Environmental Protection Agency (2014) –, LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by: compiling an inventory of relevant energy and material inputs and environmental releases; evaluating the potential environmental impacts associated with identified inputs and releases and interpreting the results to help you make a more informed decision.

Other analyses must be done about materials, like: cost, properties, environmental impact, preferred materials, restricted substances, manufactoring process, information for design, recycling and disposal.

Materials, sustainability and adapted ESA model

The present project was based on the ESA model, found in Librelotto (2009), which was initially used for analysing sustainability in the construction industry. In the referred model, through the joint analysis of market pressures, and considering company performance and conduct, companies were classified according to predetermined terms: defeated, deprived, indifferent, responsible, opportunistic and pioneer. In addition to the direct application by the author, the model was used in two dissertations, both focused on construction as well, and two undergraduate researches in the furniture area, totalling five case studies.

Supported by the results obtained by analyzing the potential demonstrated in the case studies, the ESA model was applied to the analysis of the sustainability of the materials used in the manufacture of physical products for design, architecture and civil engineering (volumetric models and prototypes). The method was adapted according to the specific area. Therefore, the performance axis assessed the economic criterion of sustainability; the conduct axis evaluated the environmental criteria of sustainability and the pressures axis evaluated the social criteria of sustainability. The position occupied by the material used in the model or prototype in the cube determined the degree of "sustainability" on a broader approach, looking at the three sustainability variables.

Magnado *et al.* (2012) highlight the importance of including sustainability in architectural design analysis and consequently in the choice of materials. For these authors, the eco-design and the Design for Environment (DfE) are related approaches, and the latter belongs to a family of design guidelines known as Design for X (DfX). Its inclusion in the methodological design procedures is related to the environment and to the health and safety of the human being. These two factors must be considered throughout the entire product life cycle. The DfE presents design guidelines related to the ecological factor, which can be used as a checklist by the product development team.

Table 1 shows the changes made to the ESA model with a view to specific application in volumetric models and prototypes. The results of this initial survey were instrumental in assembling the research methodology used to compose the data of the materioteca. It can be observed by the images shown in Figure 1 that the economic and environmental axes were divided into three parts and the social axis into two. The positioning is done by the composition (x, y, z), with scales from 0 to 10.0.

To perform the present study, an adaptation of the terminology used in the original ESA model (applied to the construction industry) was carried out:

- The term "pioneer" was replaced by "suitable": it represents a model and/or prototype built out of modern principles of sustainability, considering the economic and environmental criteria, but the social question is not necessarily very strong.
- The term "opportunistic" was replaced by "effective": it represents a model and/or prototype built within the expected economic and environmental point of view, in a social environment that does not have too much pressure.
- The term "indifferent" was kept: it represents a model and/or prototype built in an environment with little or no pressure from the social point of view, and in it materials considered "normal" are used, without the occurrence of too much concern of environmental or economic aspects. However, both from an economic and environmental point of view, too expensive or hazardous materials have not been used, i.e., the model is not innovative, but also does not require too much commitment.
- The term "defeated" was replaced by "inappropriate": it represents a model and/or prototype poorly designed and implemented, with very high cost and harmful materials to the environment.
- The term "poorly" was replaced by "average": it represents a model and/or prototype that partially meets the environmental and economic issue, in an environment where social pressures are high. That is, a model built, for example, with materials that are expensive and difficult to recycle and/or reuse.
- The term "responsible" was replaced by "innovative": it represents an opposite concept to inadequate. It is a prototype built with pre-selected materials, representing a good innovation, responsibly complying with the requirements of the design.

The classification of the prototype according to the ESA model considers as x-axis, the environmental; y-axis, the social, and z-axis, the economic dimension. The first step of classification was the position according to social pressure, as follows:

Y-axis: marks from 0.0 to 4.9 with the possibility of suitable, indifferent and effective models.

Y-axis: marks from 5.0 to 10.0 with the possibility of inappropriate, average and innovative models.

The second step of the classification was the definition of the positioning of the property on the y axis (weak or strong social issue), with the other averages acting as ordered pairs (x, z). The classification is then as follows:

- Indifferent: economic factor from 0.00 to 6.66 associated with an environmental factor from 0.00 to 6.66;
- Effective: one of the factors (economic and environmental) should have an index between 6.67 to 10.0 or both at least between 3.33 to 6.66;
- Suitable: both factors must have a minimum score of 6.67;
- Inappropriate: same numerical situation as Indifferent, but, in this case, the social pressure is high;
- Average: same numerical situation as Effective, but with high social pressure;
- Innovative: same situation as Appropriate, but with high social pressure.

One of the main considerations in the research was the attempt to provide smaller companies with cheaper solutions, in terms of analysis of sustainability, without the need to purchase imported software or measurements of difficult access. After conducting a literature and field research, the values stipulated in the rating sheets were divided into three main groups (originated from the ESA model) and each divided again into two basic subjects:

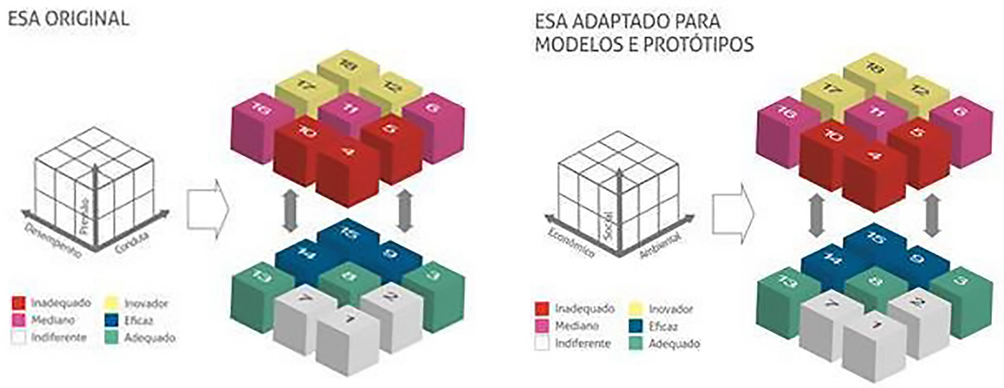
• Group 1 – Economic Factors:

(i) Model making material: material purchase price (R$); amount of material used (kg); and percentage of use of the material considering commercial dimensions available on the market (%);

(ii) Manufacturing process: amount of necessary tools (units); cost of electricity (kwh x cost of kwh in R$); and model making time (minutes);

• Group 2 – Social factors:

(i) Model making material: number of suppliers in the region (unit); availability of material, i.e., waiting time for making the purchase (days); and existence of alternative materials (approximately equal cost) in the area unable to use the material of choice (yes or no).



(a) (b)

Figure 1. Adapted ESA for analysis of prototypes in product design.

(ii) manufacturing process: the possibility of generating income for the region, that is, if the raw material used in the model is manufactured in the region (yes or no); number of companies able to manufacture the raw material used in the model in the region (quantity); and training of workforce of the region specialized in the production of the raw material used in manufacturing the prototype (qualitative observation measure).

• Group 3 – Environmental Factors:

(i) Model manufacturing material: the possibility of recycling the material used in the prototype (% of material that can be recycled); possibility of reuse of the material used in the prototype (% of material that can be recycled); and origin of the raw material (virgin, recycled or mixed).

(ii) manufacturing process: total energy expenditure in manufacturing prototype (R$); amount of useless by-products generated in the manufacturing process (kg); and the amount of by-products that can be sold for recycling or reuse generated in the manufacturing process (kg).

In implementing the ESA, the scores were assigned through quantitative and qualitative comparisons with other possible materials that could have been used to build the prototype, observing the technical and aesthetic requirements. Using the proposed methodology, the volumetric model or prototype developed with the use of a given material was compared with two other materials. It is limited to two materials only for the purposes of this research, emphasizing, however, that there are no limits for a practical application.

The present proposal has been tested in several projects. The pictures in Figure 2 show, for illustrative purposes, two of these projects. The first is a functional small-scale model used to study a proposal of housing that can be implemented in cases of relocations of communities that have suffered environmental disasters. The second is a model developed to test an alternative material for the construction of walls.

Based on these preliminary results, the methodological procedures for the application of ESA model, with reference to the materials available in the materioteca, were initiated and placed in the Virtuhab website.

Creating the materioteca and virtuhab website: Methodological procedures

As a starting point, in implementing the project reported in this article, literature search was used to determine the state of the art of the debated issue, followed by field research (use of techniques for data collection and determination of a possible sample). It then followed the standard procedures of synthesis of information, composition variables of sustainability, preparation of requirements for materials classification as a function of sustainability, choice of groups of materials in which to perform the analysis, testing and validation procedures.

In the initial stage of the research, the determination of the variables to be considered was performed together with their possible effects, followed by the possible measurement techniques. Because of the topic discussed, it was necessary to work with qualitative and quantitative variables.

According to Severino (2007), the correct procedure in these cases is to refer to research as a qualitative approach or quantitative approach, because with these designations it is possible to refer to various methodological sets, with an emphasis on one or the other approach. This is because one can hardly conclude a purely qualitative or purely quantitative research, especially in the area of applied social sciences (industrial design).

The methodological procedures and strategies for this research were:

(i) Definition of the material content, manufacturing processes and sustainability required for the initial assembly of the materioteca. Considering the large volume of materials and manufacturing process related to them, we used the classification shown in Figure 3, structured according to Lesko (2004) and Ashby and Johnson (2011). The proposed classification in Figure 3 may change as new materials are incorporated into the materioteca.

As for the manufacturing processes, we tried to simplify, following the suggestions proposed by Hudson (2008) and Lesko (2004):

- Group 1: Casting;
- Group 2: Forming Processes (liquid, plastic and solid);

(a) (b)

Figure 2. Demonstration of application in scaled models.

- Group 3: Machining Processes;
- Group 4: Junction processes (welding, rivets, and others);
- Group 5: Heat and surface treatments;
- Group 6: Other manufacturing processes.

(ii) Construction of the conceptual map of the basic materials content, manufacturing and sustainability processes.

The conceptual map was formed by the interconnection of data obtained from the literature with those obtained from field research. The field research involved visits to existing materiotecas, questionnaires and interviews with students and teachers that use materiotecas (both physical and virtual) and practical observations in product design disciplines. The selected design phase was the detailing of the chosen alternative, when groups of students must define the materials and manufacturing processes of their creations. Through the conceptual map, it was possible to establish some important relationships between the fundamental concepts of materials, manufacturing processes and sustainability applied to product design, properties and applicability under the ESA model approach.

(iii) Select the model to be used for making the demonstration spreadsheets.

Due to the amount of information available from different materials, it was necessary to draw up a standard spreadsheet, without which it would be very difficult for the designer to make the comparison of social, economic and environmental dimensions, preventing the implementation of the ESA model. Although some proposals for the model might have already been set, the great diversity of materials is hampering this step.

Figure 4 shows the model currently used. Figure 4 describes each material exposed in the materioteca. For example, considering the stainless steel basic material, we have:

- Material: Stainless steel (C – Fe – Ni – Cr)
- Group: austenitic
- Type: Normal
- Technical specification: AISI 304
- Trade name: stainless steel

Within the area of mechanical properties, data are made available, such as ductility, hardness and toughness (among others); in electrical properties, the designer will find data, for example, on resistivity; physical and thermal properties include density, specific heat and conductivity, among others, while the organoleptic (sensory) properties are more applicable for the systemic analysis of the design and provide information concerning colour, taste, odour and brightness.

As examples of usage and typical applications, photos of the material applied in different environments, with various finishing and surface treatments are shown.

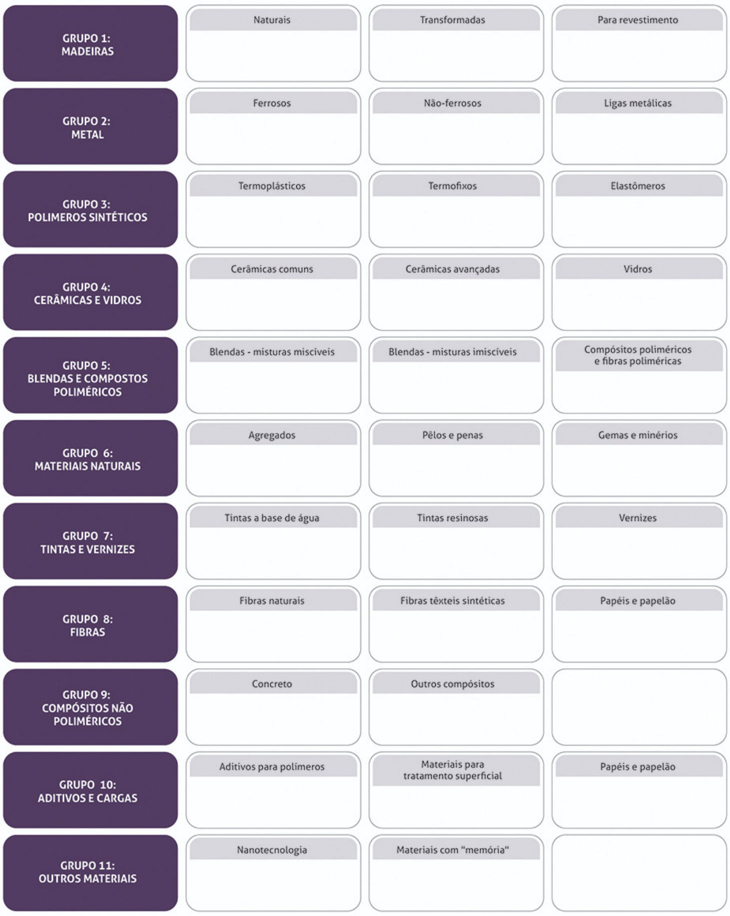


Figure 3. Classification of materials exposed in the materioteca.

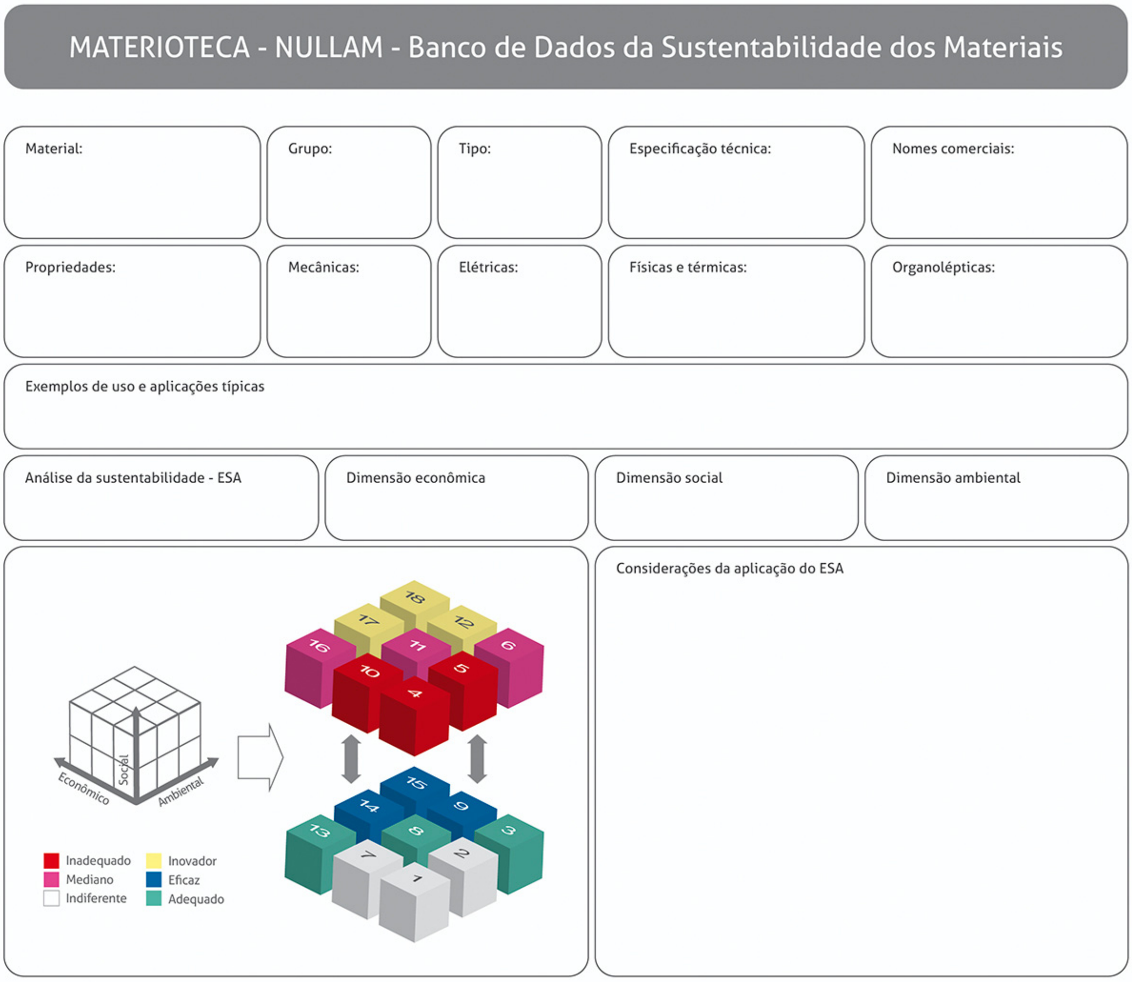


Figure 4. Model currently used in the materioteca.

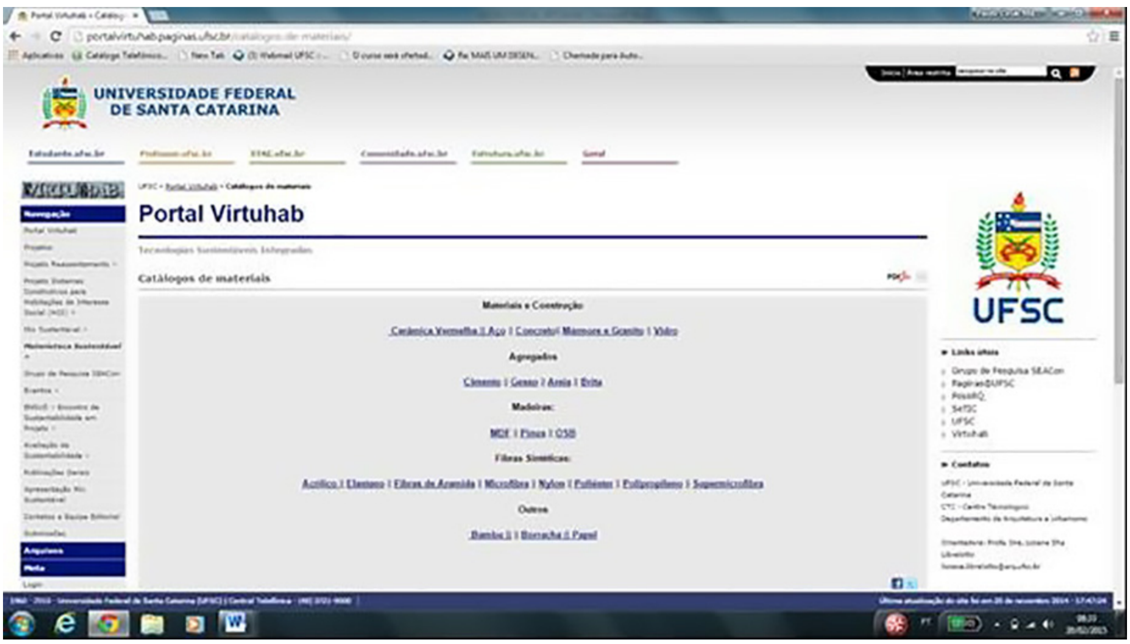


Figure 5. Digital materioteca available on the website.

In the sustainability analysis area there are all relevant data related to each dimension. The ESA graph is shown comparing two similar materials, one of the same group and one of another group (only for exemplification). For example, stainless steel AISI 304 ESA shows a comparison graph with SAE 1020 phosphatised and painted carbon steel and with nylon, PA 6.6. If the users want to get the comparison chart with another material, they will need to input the data of the required materials through the website, which will generate the chart. Note that this stage of the project is still under implementation. Figure 5 illustrates a part of the website.

(iv) Application of the ESA model

This step refers to the actual application of the ESA model for each of the materials of the materioteca. Here, each material, previously classified, is analyzed using spreadsheets already filled in with the previous steps. The description is represented by the sample (or sample set) itself, individual report about the material and demonstrative graph. Due to physical limitations, it is not viable to submit the demonstrative graph of all possible combinations, so the virtual part of the materioteca is needed in order for the designer to make the necessary simulations, comparing each generated graphs. The individual report on each material is the direct result of the previous steps, while the demonstrative graphs produced serve only for orientation of the procedure.

The graph shows, at the end, an "index of sustainability" achieved by a particular material, which allows the designer to obtain a quantitative measure of comparison; this gives them the possibility to compare a material with others in the same group or in a different group from the sustainability point of view. The section *Case study – application of the ESA model: Results* presents a case study showing how the index of sustainability of materials used in the construction of a model was obtained.

Initial steps of the project

The materioteca currently under construction already has more than 700 samples, with updated information in the demonstrative spreadsheets. The project entitled Nullam – Database of Materials Sustainability, currently underway, will fill the gap regarding the virtual part of the materioteca, resulting, in addition to the completion of the website, in the software that will allow more simplified drawing of the ESA graph. At this time, the graphs are still prepared using Excel. Figure 6 shows photos of the materioteca (physical part).

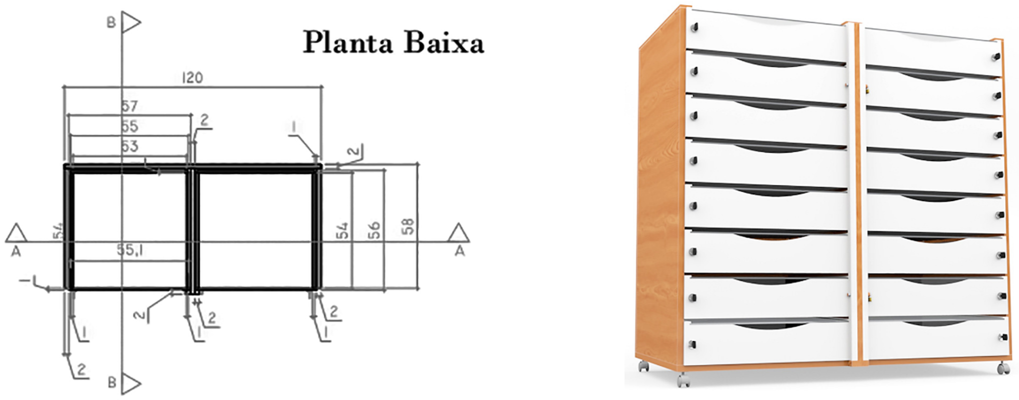
All activities are carried out by undergraduate students (with scientific initiation scholarships), extension and master students, guided by two senior lecturers (PhDs). Communication takes place via Dropbox and weekly meetings are held to check the preset goals.

During the first two years of the project (2013-2014), the scientific initiation scholarship students were also responsible, in addition to activities related to the ongoing research, for the design of the furniture needed in the physical space and patents linked to the project: Virtuhab (website that houses projects of the group), Sustainable Materioteca and Sustainable Mix (forthcoming journal). The pictures in Figure 7 show one of the furnitures designed for the physical part of the materioteca. This furniture appears in the second photo of Figure 6. The images in Figure 8 show the patents developed by scholarship students.

Further, this paper will report a comparison case study using the ESA model for three different materials used to make a volumetric model for ergonomic study.

(a) (b) (c) (d)

Figure 6. Photos of the materioteca (physical part).



(a) (b)

Figure 7. Furniture designed by students for the materioteca.

(a) (b) (c)

Figure 8. Patents associated to the project and developed by students.

Case study – application of the ESA model: Results

The ESA model was tested in a range of simulations in the materioteca. This item shows the test in the construction of foundation blocks used in the first model shown in Figure 2 of this article. For this, it was necessary to separate it into two analyses: the first referring to the material of construction of moulds, for which the options were plywood, cardboard leather type and natural Pine wood. In the second analysis, we considered the material to fill the foundation blocks, testing concrete, plaster and polyester resin. Figure 9 shows a step in the building of the models of this part.

Considerations on the data collected for analysis:

- E1 factor refers only to the purchase price of the material. The prices from three suppliers were considered. The value placed in the table considers the average of the suppliers and the percentage relative to the weight of the material actually used. The possibility of reuse of the surplus is analyzed in another topic.
- E2 factor refers only to the weight of material used, which was measured after preparation of the model.
- E3 factor refers to the use of the material with respect to commercial dimensions.
- E4 factor relates only to the number of tools used in the making of each model, and it was a simple list.
- E5 factor relates to the cost of energy measured according to the production time of each part of the model.
- E6 factor closes this first group and refers to the time spent in the manufacture of each model. The time spent in making the mould in this case was recorded for all models.
- S1 factor accounts for the suppliers in the region. The Greater Florianópolis area was considered, including the cities of São José, Palhoça and Biguaçu.
- S2 factor is the waiting time.
- S3 factor verifies whether the replacement of the material with a similar one is available in the region.
- S4 factor examines whether there is the possibility of generating income for the region.
- The S5 factor analyzes the existence, or not, of qualified companies to manufacture the raw material used in the region.
- The S6 factor refers to the existence and labour capacity for the considered material. The analysis of this factor, in this case, was qualitative.
- A1 factor analyzes the recyclability of the material.
- A2 factor refers to the possibility of reuse.
- A3 factor analyzes the origin of the raw material.
- A4 factor calculates the total energy consumption in the processing of raw materials. As the models were built on a small scale, this factor had a very small impact.
- A5 factor analyzes the generated amount of useless by-products.
- The A6 factor analyzes the possibility of sale of by-products generated.

Tables 1 and 2 show the application of the ESA model.

Figure 9. Models built to test the ESA model.

Table 1. Application of ESA model to determine the sustainability of the material of the moulds.

ESA model application														
	Economic criteria					Social criteria					Environmental criteria			
	Paperboard stone	Plywood	Pinus	Grade		Paperboard stone	Plywood	Pinus	Grade		Paperboard stone	Plywood	Pinus	Grade
E1	R$ 25,00	R$ 12,00	R$ 14,00	5,00	**S1**	5	6	15	9,00	**A1**	100%	80%	100%	9,00
E2	180 g	335g	322g	7,00	**S2**	1	1	1	8,00	**A2**	0%	0%	30%	3,00
E3	66%	75%	89%	9,00	**S3**	many	many	many	8,00	**A3**	recycled	mixed	virgin	2,00
E4	6	5	5	8,00	**S4**	no	yes	yes	8,00	**A4**	R$ 4,46	R$ 4,39	R$ 3,82	8,00
E5	R$ 0,35	R$ 0,44	R$ 0,23	4,00	**S5**	0	3	8	8,00	**A5**	10%	20%	10%	8,00
E6	56 min	46 min	37 min	8,00	**S6**	does not exist	little	little	6,00	**A6**	0%	0%	20%	4,00
Average				**6,83**					**7,83**					**5,67**

Table 2. Application of ESA model to determine the sustainability of the filling material.

ESA model application														
	Economic criteria					Social criteria					Environmental criteria			
	Concrete	Plaster	Polyester resin	Grade		Concrete	Plaster	Polyester resin	Grade		Concrete	Plaster	Polyester resin	Grade
E1	R$ 17,00	R$ 15,00	R$ 45,00	7,00	**S1**	28	26	2	10,00	**A1**	100%	100%	0%	9,00
E2	560g	430g	280g	5,00	**S2**	1	1	4	8,00	**A2**	100%	100%	0%	9,00
E3	100%	100%	67%	9,00	**S3**	many	many	none	9,00	**A3**	virgin	virgin	virgin	5,00
E4	3	3	8	8,00	**S4**	does not exist	no	no	8,00	**A4**	R$ 2,46	R$ 3,45	R$ 18,33	10,00
E5	R$ 0,23	R$ 0,65	R$ 1,25	8,00	**S5**	0	0	0	8,00	**A5**	0%	0%	0%	8,00
E6	32 min	34 min	456 min	10,00	**S6**	does not exist	no	no	6,00	**A6**	100%	80%	0%	9,00
Average				**7,83**					**8,17**					**8,33**

Final considerations

The choice of materials in product design is more than simply the consideration of technical and productive attributes. A good product must meet the needs of all user groups, involving productive, economic, ergonomic, social, environmental and aesthetic aspects, and the materials used in the product must comply with these aspects.

The ESA model, originally designed for use in construction, could be adapted in order to provide designers a quantitative/qualitative way of assessing sustainability in economic, social and environmental dimensions.

For the realization of practical experiments, we used the work developed by engineering, design and architecture students, of students with scientific initiation scholarship and of masters and doctoral students. Some selected volumetric models were randomly chosen for testing and validation of the original ESA model adaptation, only one of which is shown in this paper.

We opted for the use of volumetric models because they use less material, which facilitated the subsequent application in the materioteca. According to this kind of application, one can enumerate the following considerations:

- The adaptation of the ESA model developed by Librelotto (2009) was satisfactory for the analysis of materials, allowing a comprehensive approach to sustainability;
- The correct completion of the model spreadsheets is very important. Due to the nature of the variables, small oscillations can change the position in the rating cube and could lead to hasty and incorrect conclusions;
- There is the need of new studies proposing measurement of variables in the form of weights, testing the GUT (Gravity – Urgency – Trend) tool so that the characteristics of each material can be analyzed in each case.

As recommendations for future work, it should be noted that the ESA model was built aiming at application in the construction sector. The authors of this paper detected in ESA the potential to analyze the sustainability of any product. One has to consider, however, the characteristics of each sector. Because of this, the ESA model adapted for use in material analysis to a materioteca still needs to be tested further. It is also necessary to draw up a set of guidelines that can guide the designer (or design team) to better positioning of the economic, social and environmental variables in the ESA graphic model.

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