



# SYSTEMATIC REVIEW OF LITERATURE ON SUSTAINABLE ROOF-TILES FOR PRODUCT DEVELOPMENT

## REVISÃO SISTEMÁTICA DA LITERATURA SOBRE TELHAS SUSTENTÁVEIS VISANDO O DESENVOLVIMENTO DO PRODUTO

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### ARTICLE INFO

Article history:

Received 2020-07-31

Accepted 2020-10-20

Available online 2020-10-20

#### keywords

Ecological Roof-Tiles

Recycling

Tetra-Pak

PET

Composites

#### palavras-chave

Telhas ecológicas

Reciclagem

Tetra-Pak

PET

Compósitos

### ABSTRACT

*This article is based on the Product Development Process (PDP), with the study of alternative materials, both solid waste and possible composites, for tile production. The aim of this research was to perform a Systematic Review of Literature in order to find a low cost, durable and ecologically interesting solution for use in popular dwellings. The research method used was the search for articles, making a systematic review allied to a bibliometric analysis. Four electronic databases were accessed and articles in Portuguese and English were selected to collect important information using the 5W2H tool. Also, a general survey was carried out on prices and weights of tiles in the market. The compilation of data provided sufficient material for proposal development, which was mainly based on the use of Tetra-Pak® packaging for the development of tiles PET bottles also had a strong potential of use, since they are lightweight and ecologically sustainable. On the other hand, the price was still high when compared to what is on the market. Alternatively, tiles produced with Tetra-Pak® packaging were the most appropriate tiles for projects due to their quality, low cost and efficiency for use in popular houses, also presenting environmental benefits.*

### RESUMO

*O presente artigo se fundamenta no Processo de Desenvolvimento de Produto (PDP), com o estudo dos materiais alternativos, tanto dos resíduos sólidos como de possíveis compósitos, para a fabricação de telhas. O objetivo do trabalho foi a realização de uma Revisão Sistemática da Literatura, com intuito de encontrar uma solução de baixo custo, durável e ecologicamente interessante, para a utilização em habitações populares. O método aplicado foi a busca de artigos já existentes, fazendo uma revisão sistemática aliada a uma análise bibliométrica. Foram acessadas quatro plataformas eletrônicas, coletando artigos em português e em inglês, passando a compilar informações importantes a partir da ferramenta 5W2H. Também, foi realizada uma pesquisa geral em preços e pesos de telhas no mercado. A compilação de dados forneceu material suficiente para elaboração de propostas, que se basearam, principalmente, na utilização das embalagens Tetra-Pak® para o desenvolvimento das telhas. As garrafas PET, que têm, também, um elevado potencial de aplicação, mostraram-se leves e ecologicamente sustentáveis, porém o preço ainda se apresentou alto, comparado com o que há no mercado. As telhas produzidas com embalagens Tetra-Pak® se mostraram as mais apropriadas para o foco do projeto, pois têm qualidade, baixo custo e são eficientes para o uso em casas populares, além dos benefícios ambientais.*

## 1. INTRODUCTION

The world population produces an average of 1.2 kg per day of solid urban waste (MSW). This amount corresponds to 1.4 billion tons per year, which, according to the United Nations (UN), will become 2.2 billion tons in 10 years. According to an investigation carried out by the UN and the World Bank, in the last 30 years, the increase in the volume of garbage in the world was three times higher than the rise in population (Araújo et al., 2014).

In Brazil, in 2016, 78.3 million tons of garbage were discarded. Based on this amount, 91% was collected, but almost half of the percentage (about 45%) went to controlled and uncontrolled landfills. The Brazilian Association of Public Cleaning Companies and Special Waste (ABRELPE) reported that 29.7 million tons of solid waste were generated with improper disposal, directly reflecting on the safety and health of the population. From the perspective of the high generation of waste, waste becomes a problem for society that must be managed appropriately. However, the effort to reuse the discarded material as a way to solve the large volumes of garbage has been highly encouraged (ABRELPE, 2016).

Reuse, in a global context, is widespread, especially with sustainable development in mind. The available natural resources are finite and, mainly, in the civil construction sector, they are used in very high quantities. Thus, the use of waste is an opportunity for innovation for product development, as well as contribute to the preservation of the environment (MMA, 2012). Fortunately, there are already several materials that are manufactured from waste, such as bricks produced with rubble, ISOPET blocks (from Styrofoam and PET bottles), concrete with tire rubber or bricks and concretes with the addition of PET or PET fibers. Thus, it is essential that the recycling and reuse of discarded materials is strongly encouraged, aiming at sustainability (Santos, 2018).

At the Federal University of Paraná (UFPR), in Brazil, sustainable development is also very widespread. The Technological Innovation Study Group (GESIT) - which was founded by the Production Engineering course - is currently developing a project of a sustainable popular home, using alternative materials. With this focus, the group is investigating approaches to recycle and reuse solid waste to build houses for the low-income population in Brazil. The main idea of the project is to perform the production in joint efforts, involving the families that will benefit from the project, with the aim of helping the population and the environment at the same time. Currently, alternatives are sought for application on roofs of houses, emphasizing the search for possible tile options.

The roof tiles on the market are often manufactured using new materials, some of which contain toxic substances for the population. The variety has been growing, always in search of lower prices and variety of colors and shapes. The types normally used in popular housing are ceramic tiles and fiber cement tiles. Widely used in Brazil, ceramics built from the drying and cooking of clay materials are excellent in terms of thermal comfort. On the other hand, they require a resistant structure that supports the higher weight of the roof formed by

the tiles (Cardoso, 2000). In contrast, fiber-cement tiles, widely used because of their lightness, are being prohibited from being manufactured and applied in the country, due to the asbestos in the composition. There is already an option without asbestos, but even so, tiles with low thermal insulation and aesthetically devalued (Beraldo, 2013).

In order to produce low-cost housing, it is necessary to identify low-cost materials to contribute to the viability of the enterprise. In Brazil, according to the Brazilian Institute of Geography and Statistics - IBGE, in 2017, 50% of people lived on a salary lower than the minimum wage (Domingues, 2017). Therefore, the market for the production of popular houses is wide, since half of the Brazilian population has a low-income socioeconomic profile.

Therefore, the study presented in this article was motivated by the reuse of solid waste applied to popular housing, focusing on the manufacture of roof tiles. Based on this, the main objective was to carry out a Systematic Literature Review in order to identify tiles produced from solid waste that can be used in popular housing roofs.

## 2. LITERATURE REVIEW

The concept of sustainability is constituted by three main pillars: economic, environmental and social sustainability. According to Ayres (1996), sustainability can be defined as a way of acting in relation to nature, since we are responsible not only with the present, but with future generations. The objective is to promote development without scarcity of resources to guarantee survival in a few years.

The sustainability proposal within companies brings economic growth and financial success combined with benefits for society in general. It is seen as a way of relating environmental preservation to impacts within the company's business and profits (Savitz, 2016). Companies work with products, which go through a series of processes before, during and after reaching the consumer.

Based on this context, the Product Development Process (PDP) appears, being divided into three basic phases: pre-development, development and post-development. The first phase of the project consists of market research, in search of the first ideas for creating a product. It is during this phase that economic and potential risk assessments are performed for the development of business plans. The second phase, known as development, consists of 4 different projects. The first is the Informational Project, combining the client's needs with the interpretation of what is presented. The second is the Conceptual Project, proposing a concept to the product and summarizing the functions to be performed by it. The last two, the Preliminary Project and the Detailed Project, respectively, determine the materials, design, components, and dimensions of the product, in order to allow the launch of the input on the market. Finally, the post-development is limited to monitoring the product launched on the market until its disposal in the environment. In this phase, measures are taken to repair possible defects and establish goals to remove the product from the market (Rosenfeld et al., 2006).

The initial stages of the process (pre-development) are extremely important since products with a good specification and consensus among all decision-makers are three times more likely to succeed in the market. Besides that, it is a stage when costs are low and products are being designed and could assist in reducing costs in the following phases (Bakster, 2003).

In civil construction, the development of new products must be carried out based on the same steps of the PDP. Alternatives that aim to reduce the consumption of materials, energy and waste generated must be found, to preserve and improve the built environment. As a consequence, the change in conventional projects must be applied in civil construction, to reduce the environmental impact based on the adoption of renewable, non-toxic materials, conducive to self-construction and potentially recyclable (Shelb, 2016).

According to Cardoso (2000), the roof is defined as: "Discontinuous covering made of materials capable of providing rainwater tightness, rested or fixed on a light structure." This consists of four main elements: roofing; weft; support structure and rainwater catchment system. The roofing is formed by the tiles, which in turn have the main function of sealing. The weft is the support system of the tiles, being constituted of the roof battens, rafters, and purlins. The system is supported on the structure with the function of distributing loads in the building. Finally, the catchment system has the function of draining rain.

In conventional housing, mainly single-family homes, the roof structure is made of wood. Figure 1 shows an example of a roof and its wooden structure.

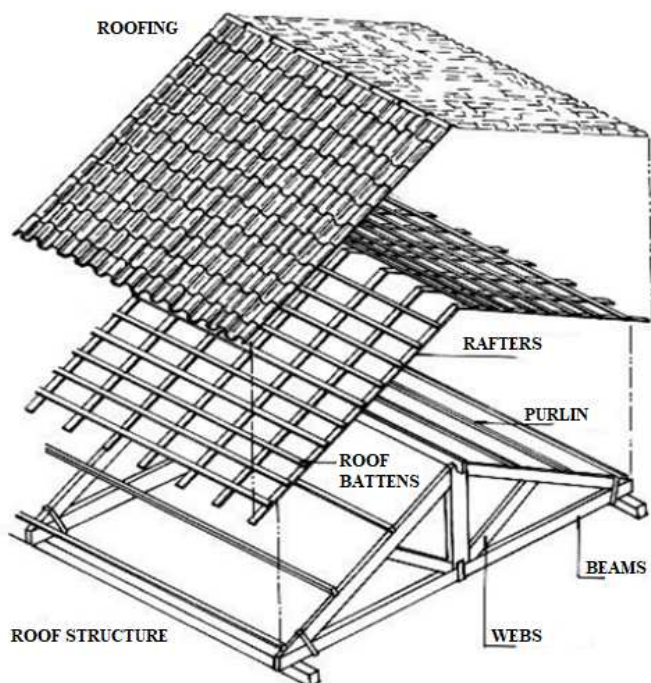


Figure 1 - Roof framing elements. Source: Rodrigues (2006).

### 3. METHODOLOGY

The method used for this article was the Systematic Literature

Review, which, according to Sampaio et al. (2006), works as a method of critical evaluation of all scientific studies within the area of interest, locating and working on a synthesis of evidence. It is an overarching and impartial method, that a general and reliable view of the subject is obtained.

The Systematic Review of this article was carried out looking for articles and studies related to tiles made of solid waste. For the review, references were searched, limited to articles that were written in Portuguese or English on four electronic platforms: Google Scholar; Scielo; Capes Portal and Science Direct. According to Dresch et al. (2015) the first stage of the Systematic Review is the definition of the keywords, which are presented in Table 1.

Table 1 – Keywords.

Keywords	
Portuguese	English
Telhas	Roof-tile
Telhas ecológicas	Ecological Roof-Tiles
Reciclagem AND telhas	Recycle AND tiles
Compósitos	Composites
Resíduos para telhas	Waste for roof-tiles
PET	Composite roof-tile
Telhas de PET	Tiles AND PET
Tetra-Pak®	

From the keywords presented, we moved to the second phase of RSL according to Dresch et al. (2015), when the gathering of articles occurred. These, totaled 45, arranged between the databases illustrated in Figure 2. The search for more recent articles was used as a filter, aiming at the emphasis on the most up-to-date research, all above the year 2000. Greater attention was paid to articles between 2008 and 2018, but some were found a little before this interval, that were also relevant to the research. Additionally, studies were selected without considering duplicate (repeated) articles and bringing only what referred to the topic addressed.

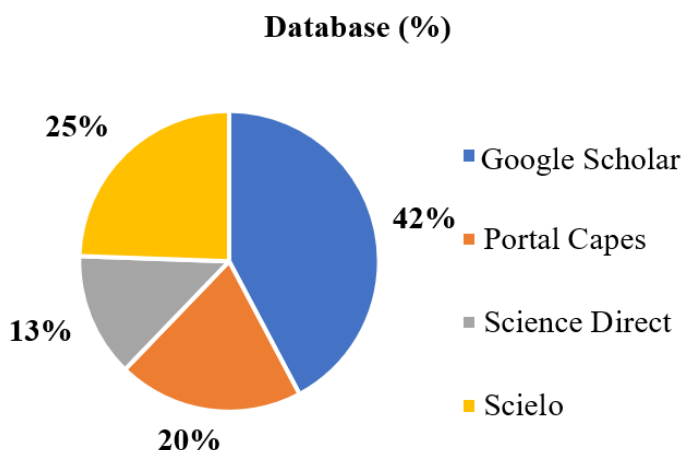


Figure 2 - Percentage of articles per database.

The first filtering has already served as a way of extracting the most relevant articles from what was on the platforms, since there are several aspects to the subject of tiles and recycling in which the chosen keywords are mentioned. Then, the abstracts of these articles were read, removing what still did not fit the research, leaving only 26. To continue the work, all those who did not fit the study were also eliminated because they did not

bring enough information to evaluate the product correctly. At the end, 11 articles were analyzed. Figure 3 represents a basic outline of how the articles were chosen.

The tool applied to the method for the compilation of data is known as 5W2H, that serves mainly to extract the most important information within the articles, helping in the organization of relevant data (LEITNER, 2017). This tool is based on seven basic questions in English, which were brought to the method according to Table 2. Seven questions were asked and all of them were answered with information extracted directly from the articles.

Based on the 11 articles chosen, a bibliometric analysis was carried out comparing the results between the years and places of publication, facilitating the process of discussing the

results. Thus, once the method was developed, the Product Development Process for a possible coverage could be most effective and a sure way of achieving good results.

To complement the analysis and bring it in line with current market data, a search was carried out within the main tile sales sites, looking for updated prices on what already exists. Price / m<sup>2</sup> and mass / m<sup>2</sup> data were passed on a table comparing conventional tiles (ceramic; fiber cement) with those of Tetra-Pak®, vegetable fibers and PET bottles. The survey was carried out on the websites of “Leroy Merlin”, “Marchio”, “Telhas and CIA” and “Ecopreserve” stores, limiting itself to one tile among each type, choosing those with the lowest price / m<sup>2</sup>.

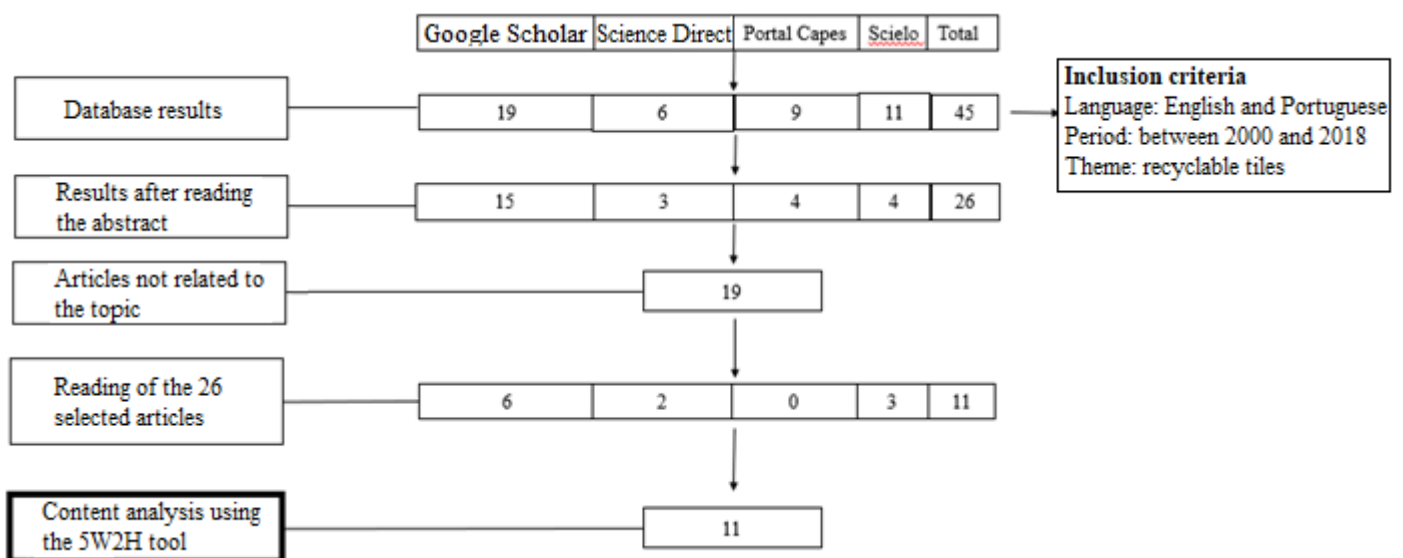


Figure 3 - Research steps for the selection of articles.

Table 2 – 5W2H.

5W2H	Questions	Answers to questions
WHAT	What was the aim of the study?	Main goal
WHERE	Where was the research done?	Place of publication
WHEN	What year was the research conducted?	Year of publication
WHO	Who developed the study?	Authors
WHY	Why was the study conducted?	Reason
HOW	How was the study/experiment done	Method
HOW MUCH	How much does it cost to build the tile?	Tile cost

## 4. RESULTS

Through the bibliometric analysis of the chosen articles, it was possible to categorize them by their region of origin. The studies found were mostly Brazilian, being divided according to the States of Brazil, given by Figure 4. A greater number of articles is found in the State of São Paulo.

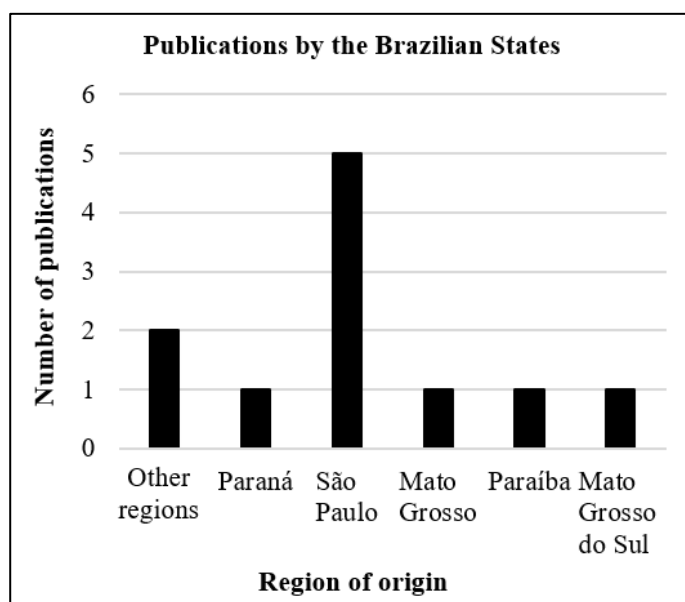


Figure 4 - Publications by the Brazilian States.

The publications were also analyzed according to the number of articles published per year, according to the Figure 5. The years 2015 and 2010 were those with the highest number of results, with a period without articles between the years 2004 to 2007.

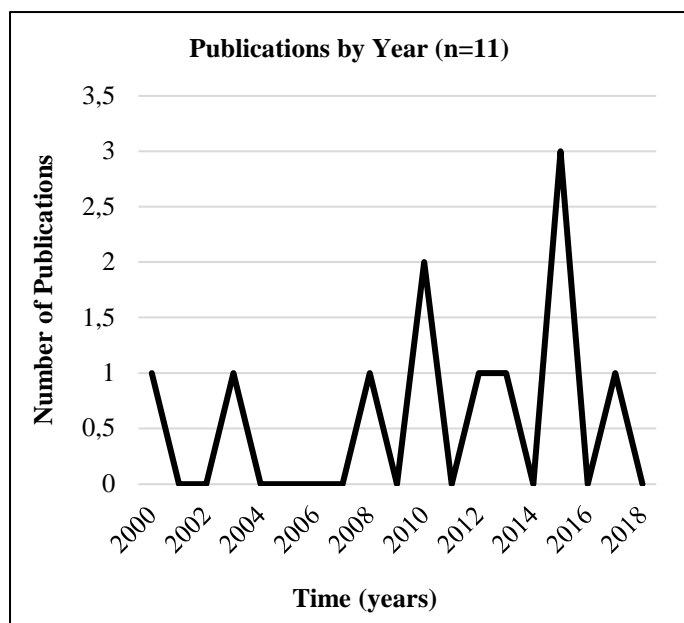


Figure 5 - Publications of articles throughout the years.

Regarding the bibliographic analysis, based on the 5W2H Table (Table 3), it was possible even more comprehensive discussion of data. In the cost column of the Table, the acronym N / I means that the amounts have not been inserted. The study can be divided into 3 large blocks: the first is composed of the first 3 articles in the table, which worked with a focus on plastic materials, being Teske et al. (2015) and Silva et al. (2010) on roof-tiles in PET bottles; the second block consists of the next 3 articles in the order of the table, which focus on the use of Tetra-Pak® packaging (Carton packaging or Long life packaging) as raw material; finally, the third is composed of the last 5 articles of the order, which deals with more differentiated raw materials, having for example the use of bamboo or the use of civil construction waste in the development of roof-tiles

For articles that focused on plastic, we can highlight the similarity in the motivations of the authors Seguiri et al. (2017), Teske et al. (2015), and Silva et al. (2010), in which everyone seeks a reduction / reuse of waste. On the other hand, it is important to analyze the prices of the last two, which are even higher when adding plaster to the roof-tile composition.

The reuse of Tetra-Pak® packaging was what motivated Araújo et al. (2008), Silva et al. (2015), and Cerqueira (2003). Araújo et al. (2008) made a comparison between conventional roof-tiles and those of ecological material, while Silva et al. (2015) and Cerqueira (2003) evaluated only roof-tiles with Tetra-Pak® packaging in relation to the indexes that the roof-tiles must support. Unfortunately, it was not possible to compare prices between items.

Beraldo et al. (2013), Darsana et al. (2015), and Savastano et al. (2000) used vegetable fibers as raw material. Firstly, it can be noted that the first two authors focused on cost reduction and they did not emphasize more sustainable production. However, Savastano et al. (2000) aimed to reduce waste, but only in agricultural production. Among these three, only Darsana et al. (2015) has information on price. Yoshimura et al. (2012) and Mendonça et al. (2010) seek sustainability, in a more indirect way in their work, in which the first article seeks to reuse/recycle paper and the second seeks to maintain the environmental cycle by reusing construction and demolition waste. Neither provides prices, but both aim to evaluate the roof-tiles in general.

It is also possible to highlight, among all articles, one similar step-by-step, since most of them evaluated the capacity of roof-tiles for various tests, mainly the mechanical resistance (bending), water absorption, resistance to temperatures, and measurements of density and impermeability.

The results of the survey in the Brazilian market are shown in Table 4. It should be noted that there are no types of roof-tiles that were worked on in the articles since they have not yet been produced for trade in Brazil. In the table, N/I means that the values were not informed.

**Table 3 – Results of the 5W2H**

Number	Reference	Region	Objective	Motivation	Step-by-step	Final cost
1	Seghiri et al., 2017	ARG- Ouargla	Develop a composite from recycled plastic to manufacture roof-tiles	RW/RRW	A	N/A
2	Teske et al., 2015	Brazil - Curitiba-PR	Analyze the technical feasibility of using plaster and PET waste on roof-tiles	RRW	D	R\$720.00/m <sup>2</sup>
3	Silva et al., 2010	Brazil - Campinas-SP	Present economic and ecological advantages of PET roof-tiles	RW	B	R\$77.40/m <sup>2</sup>
4	Araújo et al., 2008	Brazil - Campina grande-PB	Compare roof-tiles made of ecological material (those with long life packaging) with conventional roof-tiles	RW	A	N/A
5	Silva et al., 2015	Brazil - Lavras-MG	Evaluate the use of recycled roof-tiles based on Tetra-Pak® packaging in thermal comfort.	RRW	C	N/A
6	Cerqueira, 2003	Brazil -São Carlos-SP	Evaluate roof-tiles of Tetra-Pak®	RRW	A	N/A
7	Beraldo, 2013	Brazil - Campinas-SP	Analyze corrugated roof-tiles made from bamboo, cement, and sand particles	RC/ RD	A	N/A
8	Darsana et al., 2015	India- Chennai	Produce profitable roof-tiles using coconut fiber	RC	A	Rs 38,74
9	Yoshimura et al., 2012	Brazil - São Paulo-SP	Improve the environmental performance of roof-tiles from post-consumer paper waste	RW/RRW	D	N/A
10	Savastano et al., 2000	Brazil - Campina Grande-SP	Select waste and vegetable fibers for roof-tile production	RRW	A	N/A
11	Mendonça et al., 2010	Brazil - Mato Grosso do Sul-MS	Evaluate the thermal performance of construction and demolition waste roof-tiles	BA	C	N/A

Note: N/A – not available;  
Motivation: RW- to Reduce solid Waste;  
RRW- to Reuse/Recycle solid Waste;  
RC- to Reduce costs;  
BA- to Balance the environment changing due to urban growth and the maintenance of the more scarce resources;  
RD- to Reduce problems with durability by using fibers in roof-tiles.  
Step-by-step: A- Physical testing (density, flexural/tensile strength, permeability, water absorption);  
B- Comparison among roof-tile models;  
C- Temperature and Humidity testing;  
D- Measurement of dimensions, mass, source of raw material, production, installation, maintenance and durability, destination after useful lifetime, albedo, insulation, and Life Cycle Assessment of the roof-tile.

**Table 4 – Information of the Brazilian market.**

Name	Store	Relation kg/m <sup>2</sup>	Roof-tiles/m <sup>2</sup>	Price/m <sup>2</sup>
Fiber cement roof-tile Econoflex	Leroy Merlin	10.656	0,41	R\$ 18.84
Ecologic roof-tile Tetra-Pak®	Ecopreserve	5.981	0,6	R\$ 21.90
Roof-tile Romana	Leroy Merlin	25.577	17	R\$ 23.80
Roof-tile Portuguesa	Leroy Merlin	25.770	17	R\$ 23.63
Roof-tile Americana	Marchio	27.840	12	R\$ 21.60
Roof-tile Portuguesa PET Injection (transparent) - Primalux	Telhas e Cia	N/I	16	R\$ 176.00
Roof-tile Pet Eurotop Classic translucent	Leroy Merlin	2.193	7	R\$ 130.52

## 5. DISCUSSION

The articles referring to PET tiles, allied to what was researched in the market, showed that they are an expensive form of coverage, being unfeasible for use within the defined objective, even them being light tiles. According to Silva et al. (2010), the fact that they have a smaller mass per m<sup>2</sup> leads to a need for a lighter roof support structure that does not need to support high loads, which would result in a good decrease on the final price, but further analysis would be necessary seeking for more information.

According to Araújo et al. (2008), the long-life packaging tiles have better results than fiber cement tiles, mechanically and in physical-chemical characterization, also showing excellent durability. There is still a great environmental contribution in the recycling of long-life packaging, reducing the quantities of solid urban waste.

Vegetable fibers among the articles studied (Beraldo et al. (2013), Darsana et al. (2015) and Savastano et al. (2000)), these being bamboo, coconut fibers and fibers from agroindustrial waste, respectively, presented positive results for standard requirements (absorption, permeability, resistance), but without prices, the evaluation of this type of tile should be further developed to reduce construction costs. Although, Savastano et al. (2000), further states that studies with fibers presented for mechanical characteristics should be continued, because they still do not show satisfactory results.

Regarding recycled paper tiles, the results are satisfactory for reducing environmental impacts, however there is not enough information to classify the tile properties (YOSHIMURA et al., 2013). The tiles from construction and demolition waste (MENDONÇA et al., 2010) were also not specified about fundamental properties, only the thermal insulation part, which also makes these tiles disposables as the best option under the conditions worked.

## 6. CONCLUSION

Through the results obtained, focusing on the research objective of finding tiles for popular housing, three factors were analyzed mainly: price (both found in the articles and in the current market survey), response to tile durability and density-related to weight / m<sup>2</sup>.

Tetra-Pak® tiles were considered the best alternative, being relatively inexpensive within market prices, in addition to having low density, which also means less need for a reinforced structure for placing the tiles.

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