Sustainable footwear solutions for the scrap tyre sector

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Abstract

The increasing demand for resources is raising several concerns on the society, and the scarcity of these resources demands for innovative ideas/products to tackle the current consumption patterns. Circular Economy has emerged with the aim of closing the loop of constant extraction of resources and creating a circular path on how the resources are consumed and disposed. On this scope the current dissertation focusses on implementing circular economy measures in the tyre market, in Portugal, to create a sustainable sandal that thrives social inclusion and the use of recycled and environmentally friendly alternatives. To achieve this, it is necessary to foster an understanding over the concept of circular economy and its practices as well as understanding the role of design in the conception of a product. Based upon the literature review on circular economy, product design and eco-design a methodology is elaborated to guide the development of a sustainable sandal prioritizing sustainability and social inclusion in the process of creating and developing the product.

This dissertation accomplishes three major goals: extensive literature review, methodology with guidelines for the product development and, results and further recommendations. The literature review is a baseline for the methods proposed in the methodology and the results comprise the outputs obtained from the application of those methods.

Key words: Circular Economy, Sustainable Sandal, Eco-Design, Scrap Tyre, product development

1. Introduction

With the Industrial Revolution companies and consumers have adopted a linear model of value creation that initiates with resource extraction, goes through the processing phase, use by consumers and then disposal. On this scope, the global plastic economy does not fall behind the tendency and relies heavily on non-renewable feedstocks thus consigning overwhelming amounts of plastic to the trash (*Mckinsey&Company*, 2016). The unanimous global trend of plastic consumption increase seems to lack a foreseen end, with amounts of plastic waste reaching millions of tonnes every year

(*European Commission*, 2018; Ritchie & Roser, 2018). Following this trend of consumption, looking at the automobile industry, the ownership of vehicles worldwide has been growing faster than the global population, and in 2010 it surpassed 1 billion units. Consequently, the tyre industry grows along, and in the year of 2017, it was manufacturing over a billion tyres, meaning almost 12 billion tonnes of natural rubber was being extracted from the environment. To follow the tendency of linear model, dumping and stockpiling of tyres is the most common practice of disposal, loosing significant resources to industries and posing serious hazards to the environment (*Mckinsey&Company*, 2016; Chaturvedi & Handa, 2017). Circular Economy emerges to tackle the linear consumption and to explore the full potential of every asset. On this scope, this paper aims at further studying and exploring the potential of scrap tyres in the development of a marketable product based upon the circular economy strategies and product design metrics.

This paper is organized in five sections. This section gathers the introduction and purpose of the paper. Section 2 summarizes the literature review elaborated to study the thematic of circular economy and product design. Section 3 the methodology proposed is explained in detail. Section 4 describes the results and discussion obtained from the application of the methodology described. Finally, section 5, gathers the main conclusions drawn.

2. Literature Review

2.1 Circular Economy

The *Ellen MacArthur Foundation* (2013) describes a CE as a regenerative industrial system which replaces the "end-of-life" of the products by a regeneration of these. It focusses on a shift *"towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models"*. According to a study by the *Ellen MacArthur Foundation* (2015) there are three main principles by which a Circular Economy is believed to be based on. These principles are: (1) *Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows:* it is necessary to choose the right resources, processes and technologies that allow an environmentally friendly performance by using better resources. Plus, it is also necessary to replace the activities that compromise natural resources by others more sustainable. (2) *Optimize resource yields by circulating products, components and materials at the highest utility at all times in both technical and biological cycles:* an extension in products life cycle is necessary in a Circular Economy (Sauvé et al., 2016). To assure this it is necessary to implement techniques of remanufacturing, reuse and recycle to close the flow of materials (Geissdoerfer et al., 2018). (3) *Foster system effectiveness by revealing and designing out negative externalities:* a CE focusses on reducing the effect of negative externalities in the society, i.e., diminishing the side effects of an activity. These externalities are typically air, water or noise pollution, health effects and climate changes

(*Ellen MacArthur Foundation, 2015)*. To achieve a CE some strategies must be applied in a value chain to promote competitiveness and prosperity. The most important and relevant in the development of this product are: (1) *Eco-Design:* Defined by many authors as the characteristics of a product that guarantee the sustainability of the product until the end of its useful life (Plouffe et al., 2011; Dewulf, 2013; Lindahl & Ekermann, 2013; Su et al., 2013; Ghisellini et al., 2016); (2) Green *Procurement:* is the search for goods, services and works that provide a minimized environmental impact throughout their life (Sönnichsen & Clement, 2020); and (3) *Sustained Lifespan*: possible through reuse, repair, refurbish, remanufacture and repurpose (Potting et al., 2017).

2.2 Product Design

Design is a global element of culture and extremely important in creating and differentiating a product (Burdek, 2005). A good design expresses the individuality of a product, is easy to understand and takes into consideration the product ecology, energy conservation, recyclability, durability and ergonomics (Burdek, 2005; Maiocchi, 2015). Product design is related to the physical image of a product aimed at exceeding the customers' expectations. According to Slack et al. (2007) there are five necessary stages to obtain a product with the desired features: 1) *Concept generation*, (2) *Concept Screening*, (3) *Preliminary Design*, (4) *Evaluation and Improvement Design* and (5) *Prototyping and final design. Concept Generation* stands for the transformation of the main idea into a physical product without losing its nature and necessary specifications. According to Unleash by Deloitte (2019) at this phase it is crucial to well-define and create a statement that properly indicates the user, the need and the insight thus increasing the specificity of the problem. *Concept Screening* is the examination of this preliminary phase of the product in terms of feasibility, acceptability and vulnerability to define whether this is a worth product in a company (Slack et al., 2007). Concept screening is a multi-criteria decision-making problem that is hindered by the complexity of problem solving. One of the methods used in this phase is the Pugh chart, a methodology proved to help and facilitate the evaluation of an alternate design route (Thakker et al., 2009). This method introduced in Unleash by Deloitte (2019) is a decision-making tool that allows the comparison among different alternatives, all against an existing baseline based on range of design criteria. A Pugh chart can comprise multiple alternatives and highlight the advantages and disadvantages of each of them. *Preliminary Design* uses flow charts or component structures to understand and identify, which components build up the product and how these interact (Slack et al., 2007). *Design Evaluation and Improvement* is highly linked with the previous since it focuses evaluating the necessity of improving the latter design before the prototype is made or tested. According to Unleash by Deloitte (2019) a survey is a relevant tool to gather relevant information related to demographic group of the potential customer, requirements of the customer, the range of prices the customer is willing to pay and also how willing the general population is to switching from the use of previous non-sustainable versions of the product to a sustainable one. This information is necessary to better match the users' wants and needs to the product developed. *Prototyping* provides the final details of the product through a range of specifications referring to the package and the process necessary to deliver the product to the customer (Slack et al., 2007). According to several authors (Moe et al., 2004; Yang, 2005; de Beer et al., 2009; Viswanathan & Linsey, 2009) it is essential to prototype when developing a product to allow designers to specify problems related to the design, facilitate the accomplishment of user needs and engineering requirements.

Circular Economy and Design must be connected, yet, this connection is complex and begs for a transformation in the way designers think and develop products (Cura, 2016). Circular design must come up with products or services, which are as functional as before, with the same optimum quality materials, and providing a performance as good as otherwise, yet minimizing the negative impact throughout its useful life. The challenge rests at reducing the use of primary raw materials, keeping the products inside the closed loop (Medkova & Fifield, 2016). This challenge is overcome by a redesign of products to ease the incorporation of these again in the processing cycle. Thus, the new era' designers must consider durability, compatibility, modularity or multitasking functions (Cura, 2016; RSA, 2016). All in all, a circular product always keeps its integrity and should avoid imposing costs to the environment when it is being restored to keep the economic value (Lieder & Rashid, 2016; Hollander et al., 2017).

To take advantage of scrap tyres and implementing the strategies of Circular Economy combined with product design, a marketable product is going to be developed following the methodology proposed in the next chapter.

3. Methodology

The basis of the methodology is adapted from the one proposed by Slack et al. (2007), which was further extended to a multi-methodology approach. The application of different methods allows a better model validation, theory testing and a better gathering of important information to consider. Hence, in each step of the methodology proposed by Slack et al. (2007) different methodologies will be applied, following directives of different authors. **Figure 1**, represented below, shows the methodology to be followed throughout the master dissertation. Each step is further explained.

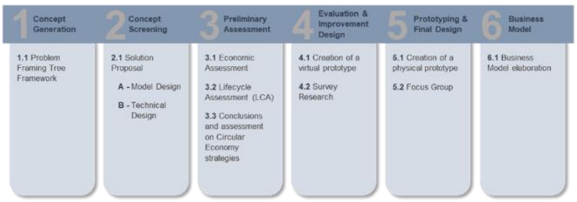

Figure 1 - Proposed Methodology

Step 1 – Concept Generation

The goal of the first phase is to clearly define and understand the problem. In this step the Problem Framing Tree Framework is applied. To develop the problem tree, based on the research developed and presented by Vesely (2008) and Ammani et al. (2010), Zimmerman (2014) and Unleash by Deloitte (2019), several steps will be followed. The development of the tree begins with the definition of the purpose of the problem tree, followed by the identification of major problems that are inherent to the problem identified. With this settled, the causes of those problems must be identified and, finally, an evaluation to the overall tree must be made to validate the coherence of the problems and causes identified. Then, it is possible to identify the core problem and what is causing it in a pragmatic way.

Step 2 – Concept Generation

Concept Screening is the phase to conceptualize a solution to tackle the previous problems found. To initiate the solution proposal, Step 2.1 is crucial to create a baseline for a proper solution based on the problem identified in the previous phase. To provide an elaborated and concrete solution, an assessment over the solution characteristics must be carried out. This analysis is divided into two sub sections – A and B. In section A the selection of the best design typology is made. The tool Pugh Chart proposed by Thakker et al. (2009) and Deloitte (2019) will be used since it aids in evaluating design solutions against a baseline – status quo - similar product. According to the authors, to perform the Pugh Chart five steps must be followed: first it is necessary to select the evaluation criteria followed by an attribution of different weights for each criteria. Having this set, a group of different design alternatives must be selected along with a baseline option to work as a status quo for the analysis. Then, each alternative must be compared to the status quo, attributing plus (+) signs and minus (-) signs is done if the alternative is better or worst that the baseline, respectively. Finally, the weights must be summed or deduced depending on the rating given.

Despite the effectiveness of the Pugh Chart, to increase its validity a weighting method must be conjugated in step 2, in the Pugh Chart, to better attribute and decide on the weights to measure. The Swing Method was the method selected due to its quantitative-based analysis. For this analysis, each criterion is compared and ranked from the most important to the least and each criterion is attributed with a weight under 100 points. Each criterion must weigh less than the criterion above. Finally, a normalization is done with the application of the following formula: [1] $w_i = \frac{s_i}{\sum_{i=1}^{n} s_i}, \forall i = 1,2,3,4,5.$ The sum of the normalizations for each criterion must equal to 1, and each value must be included in the interval [0,1]. Subsection B is meant to elaborate on the products' parts and composition. The technical design refers to all the features of the product that are not related to the design itself, such has the materials, components and the properties of each.

Step 3 – Preliminary Assessment

For step 3.1, an economic assessment must be done on the selected materials. This economic assessment will provide another decision variable in the selection of the materials. In the light of the ultimate goal of this dissertation it is important to address the economic strand in this analysis. To perform step 3.2 a Life Cycle Assessment (LCA) will be applied. The LCA follows four phases introduced by ISO (2006): first, it is necessary to define the goal and scope. The system boundaries must be defined as well as any assumptions made to perform the analysis. The second phase is the lifecycle inventory analysis (LCI) in which the functional unit is described and all the data relevant is collected (Street et al., 2005). This step is critical to obtain a quantification of the impacts in the following phases and will be aided with the *Ecoinvent* data base, provided by *SimaPro* software. In the third phase, the impact assessment is made. This stage classifies, characterizes, normalizes and attributes weights to the effects of the environmental discharges inherent in the system, to understand its environmental relevance and estimate further environmental impacts. For this step, the *ReCipe* method will be used. According to Carvalho et al. (2014), the *ReCiPe* the most recommended approach because it is one of the most flexible methods since it includes three levels of outputs' aggregation. Finally, the final phase is the interpretation where the information from the previous phases is analysed and evaluated.

Step 4 – Evaluation & Improvement Design

Step 4.1 aims at creating a virtual prototype. Step 4.2 aims at further investigating any need for improvement. this evaluation shall be performed through a survey concerning potential users. As introduced by Deloitte (2019), the use of surveys allows the collection of standardized information from a large group of participants, proving to be a very cost-effective methodology. The survey will be used to gather relevant information related to demographic group of the potential customer, requirements of the customer, the range of prices the customer is willing to pay and also how willing the general population is to switch from the use of previous non-sustainable versions of the product to the sustainable developed one.

Step 5 & 6 – Prototyping and Final Design & Business Model Elaboration

The final phase of the methodology is the creation of a physical prototype that incorporates all the considerations and decisions made throughout the four previous phases. Step 5.1 is completed once the physical prototype is ready and able to be experienced by a future possible user. In step 5.2 a group interview will be conducted to gather relevant opinions from the users about the product developed. Based on the research by Wilson (2013), the focus group should be composed of three to twelve people who might actively contribute to the enhancement of the product. Afterwards, the creation of a business model, is crucial for the launch of the product in the market, and one of the goals of the present paper is to develop a product able to be commercialized, thus, step 6 will guide through the steps necessary to perform in the elaboration of the business model focussed on the launching of a sustainable product. The model used is the Tripled Layer Business Model Canvas, presented by Joyce & Paquin, (2016). This model has three main steps that correspond to the three layers of the model: economical, environmental and social layer.

4. Results and Discussion

4.1 Concept Generation

In this section the problem tree is presented along with relevant considerations and the information obtained from the compilation of the tree branches.

The process of development of the tree branches was obtained from inputs from different experts and knowledge obtained from the literature. **Figure 2** shows a representation of the problem tree developed from the insights gathered.

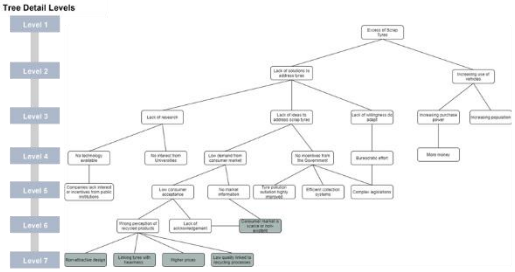

Figure 2 – Problem Tree

The tree is composed of seven levels of detail, in which the first level – level 1 – corresponds to the Excess of Scrap Tyres issue. The problem at hand concerns the inexistence of solutions to address scrap tyres, which is inherent to a lack of supply in the consumers' market and is supported by the lack of incentives from public institutions. To achieve the Level 1 issue on the tree, each bottom level must be addressed first. Therefore, by tackling the bottom causes in the tree – Level 7 -, it is easier to reach the upper causes. Hence, the solution should be a product that addresses all these bottom problems in the problem tree.

4.2 Concept Screening

A solution must be developed to tackle each of the branches selected before. The solution proposed is a sandal composed of three components made, preferentially, from different materials provided by companies based in Portugal and delivered to national penal institutions to be manufactured by prisoners. The sandal is composed, partially, by scrap tyres. Scrap tyres will be used to extract the outer sole of this sandal. Yet, to avoid the direct contact between the foot and the tyre, an extra midsole is necessary. This midsole will assure the necessary thickness to provide the best comfort and safety on the sandal. All in all, three components are necessary to create the sandal. The mid sole and upper fabric will be made of materials selected according to their sustainability.

Model Design

In the light of the Eco-Design practices, *Incorporate Modularity* was addressed in the design process. This practice was a guideline in the selection of the design to be carried through the development of the sandal. The design selection was aided with the development of a Pugh Chart in which four designs were evaluated based on five design criteria: Low Material Content, Adaptability, Cost, Attractiveness and Ease of manufacture, presented by Pigosso et al., (2013). The design selected is presented next.

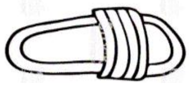

Figure 3 – Sandal design

Technical Design

The three components of the sandal will be composed of different materials. The outer sole will be made of scrap tyres, and for the remaining components a deeper investigation must be made.

<u>Mid-sole:</u> The potential materials to incorporate in the mid-sole should be sustainable, resistant and comfortable. The resistance and flexibility provided by rubber soles are highly pointed out as the differentiating factor in these types of soles. Besides rubber soles are also durable, and the low conductivity of this material makes it a safe option to be in contact with the foot surface (*Sustainable materials and components for footwear, 2016)*. Rubber

soles can be divided into three different types: natural rubber, synthetic rubber and recycled rubber. Cork was also selected since it is a typical Portuguese material used for soles production and with great comfort on the foot and resistance (*Leaf*, 2020). Fabric Strap: cotton is a fibre with great strength properties due to the long cellulose chains in its composition making it highly versatile. Hemp fibre is harsher than cotton making it stiffer and granting strength, durability and more UV resistant. Jute does not require fertilizers, easing the cultivation process and making it economically viable. It is used in footwear items due to its strength and low extensibility (*Sustainable materials and components for footwear, 2016)*.

4.3 Preliminary Assessment

4.3.1 Economic Analysis

Table 1 shows the cost of acquisition obtained per each material along with the supplier and supplier location. The materials displayed first in the table are the possible materials to use in the fabric strap. All the prices obtained were in Euros and the materials were all sold in m2.

Table 1 – Price and supplier location per material

Material	Cost	Supplier	Supplier Location
Jute	5,90 € / m2	Mundo dos Tecidos (consulted in September 2020)	Portugal
Organic Cotton	7,90 € / m2	Mundo dos Tecidos (consulted in September 2020)	Portugal
Hemp	7,63 € / m2	Hemp Fabric Lab (consulted in September 2020)	India
Natural Rubber	4,41 € / m2	Thames Supplies Valley (consulted in September 2020)	United Kingdom
Synthetic Rubber (TR)	3,20 € / sole	Bolflex (consulted in September 2020)	Portugal
Cork	5,36 € / m2	BricoButikk (consulted in September 2020)	Portugal
Recycled rubber	3,45 € / sole	Bolflex (consulted in September 2020)	Portugal

Jute seems to be the fairest option to use so far, yet, an environmental analysis still must be done to have a better selection basis. For the mid sole materials all the materials are sold with 4mm thickness. Natural rubber was only found in a English brand sold by 19,69£ per 5 m2. Cork slabs were also sold in a 15 square meter wide slab (80,17€/15 square meter) which translates into 5,36€/m2. Translating these values into a price per sole, it is obtained that a natural rubber sole would be obtained by 0,22€ per sole and a cork sole per 0,27€. Natural rubber proves to be the cheapest material, yet, being supplied by an English supplier implies transportation costs (economic and environmental) higher therefore cork would be a better option. However, both natural rubber and cork are being sold in slabs, whereas synthetic and recycled rubber are being sold in transformed soles.

4.3.1 Life Cycle Assessment

The goal of this analysis is to select different materials under the LCA scope. The scope of this study is to design a product; thus, the current lifecycle analysis will only emphasize the preliminary data of each material to be discussed. The geographical boundary is Portugal – since we are producing the sandal in Portugal and the materials should be obtained by Portuguese suppliers - and the temporal boundary is subject to the product's useful life – which will highly depend on the use of each consumer, yet the average flipflop lifespan is 2 years (Yasukawa & Page, 2020). The physical boundary is the *Cradle-to-Gate,* which only covers the production and extraction of each material. he software to used was *SimaPro* and the correspondent data base used was *EcoInvent Database.* The FU selected was 1kg of material. To proceed with a fair comparison, only the fibre production of the different fabric materials was considered due to the *Ecoinvent* limitations regarding some types of textiles. From the analysis to the fabric strap materials, it was obtained that Jute Jute was also the material with the lowest single score, even though in a few categories' hemp proved to be less pollutant. For these reasons, jute is the selected material to be used in the fabric strap in the sandal. Being a typical Portuguese material, used for many applications in the past, it makes it a good option to highlight the Portuguese nature on the essence of the sandal. In the mid sole materials analysis, the material with the lowest single score was both recycled and natural rubber. For the midsole, the most sustainable material is recycled rubber and the worst is synthetic rubber. Despite having the lowest environmental impact, recycled rubber's price was relatively higher than the natural rubber one (recycled rubber sole sold by 3,45€ whilst one square meter of natural rubber was sold by 4,41€ - about 0,22€ per sole). considering, the Eco-design practices mentioned before and also *Incorporating modularity* and promoting an *environmentally friendly assembly* the use of recycled rubber soles will ease the process of assembly with the promotion of the use of an environmentally friendly material.

4.4 Evaluation & Improvement Design

The software used to develop the virtual design was *Rhinocerus 3D*, a software that provided 3D modelling tools for design.

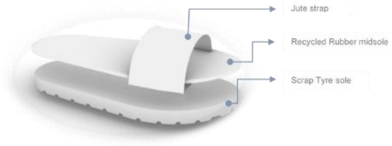

Figure 4 – Virtual Prototype

The preparation and assembly of the three components should be made through a few independent activities pointed in a process flow chart.

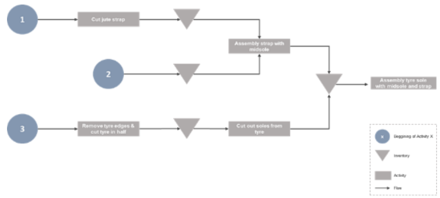

Figure 5 – Process Flow Chart

Having the basic design set, the parts idealized, and the processing flow explained, an upgrade on the design shall be made to correctly represent how the product should look like after the assembly if the parts. As decided before, the materials to incorporate are scrap tyres, recycled rubber and jute fabric.

Figure 6 – Assembled sandal

With the prototype ready, a survey was designed and presented to several potential consumers obtaining 127 responses. From the survey, it was registered that the women market is larger than men's enhancing the need for a more diverse offer for female buyers; most men revealed to pay from 10€ to 15€ while for women are willing to pay between 15 to 20€; men claimed to concern more about the recycled content while women worry more about the environmentally friendly material when buying sustainable footwear; to better satisfy the female market demand, in the long term, focus should be placed in creating a wider range of different sandals (with different color or design variations) focused on this market; for men, there is no need for creating different models even because this market seems to have a lower purchasing frequency, yet, focus should be placed in communicating and proving the durability of the product since this aspect is more important for men when buying footwear. To summarize, the market is receptive to the product, justifying the intention of creating it.

4.5 Prototyping and Final Design

For the physical prototype, the process initiated with the preparation of the tyre, which it was necessary to cut with a saw to extract the soles. The jute straps were cut in slabs and an ink spray was used to give the strap more stability and comfort.

Figure 7 – Physical Prototypes

Having the prototype ready, a focus group was elaborated, and the most significant highlights were pointed out: need for reducing the product weight, preference for the design with the open strap and a need to eliminate the aluminum threads in the sole.

4.6 Business Model Elaboration

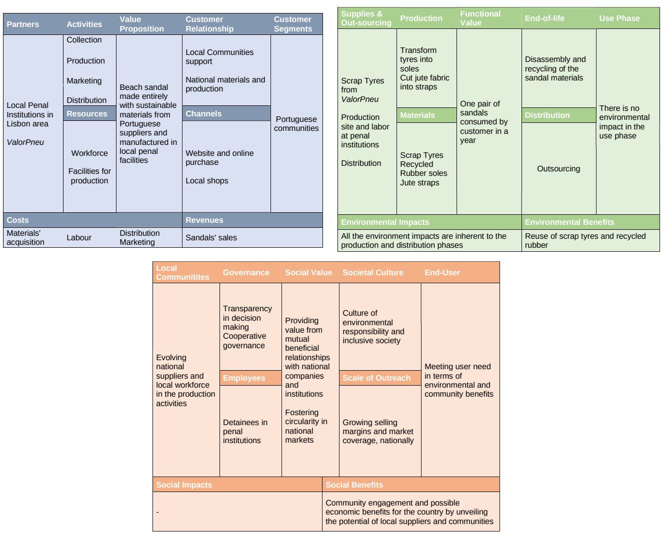

Figure 8 – Triple Layer Business Model Canvas

The triple layer business model canvas, in Figure 8, was the model chosen to create the sandal's business model.

5. Conclusion

One of the main objectives of this paper was to develop a sustainable and environmentally friendly design that would promote circular economy practices and combine these with eco-design strategies. This dissertations' goal was accomplished and all the necessary guidelines to make further research were outlined. To provide a marketable product the pain points gathered in the focus group must be addressed.

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