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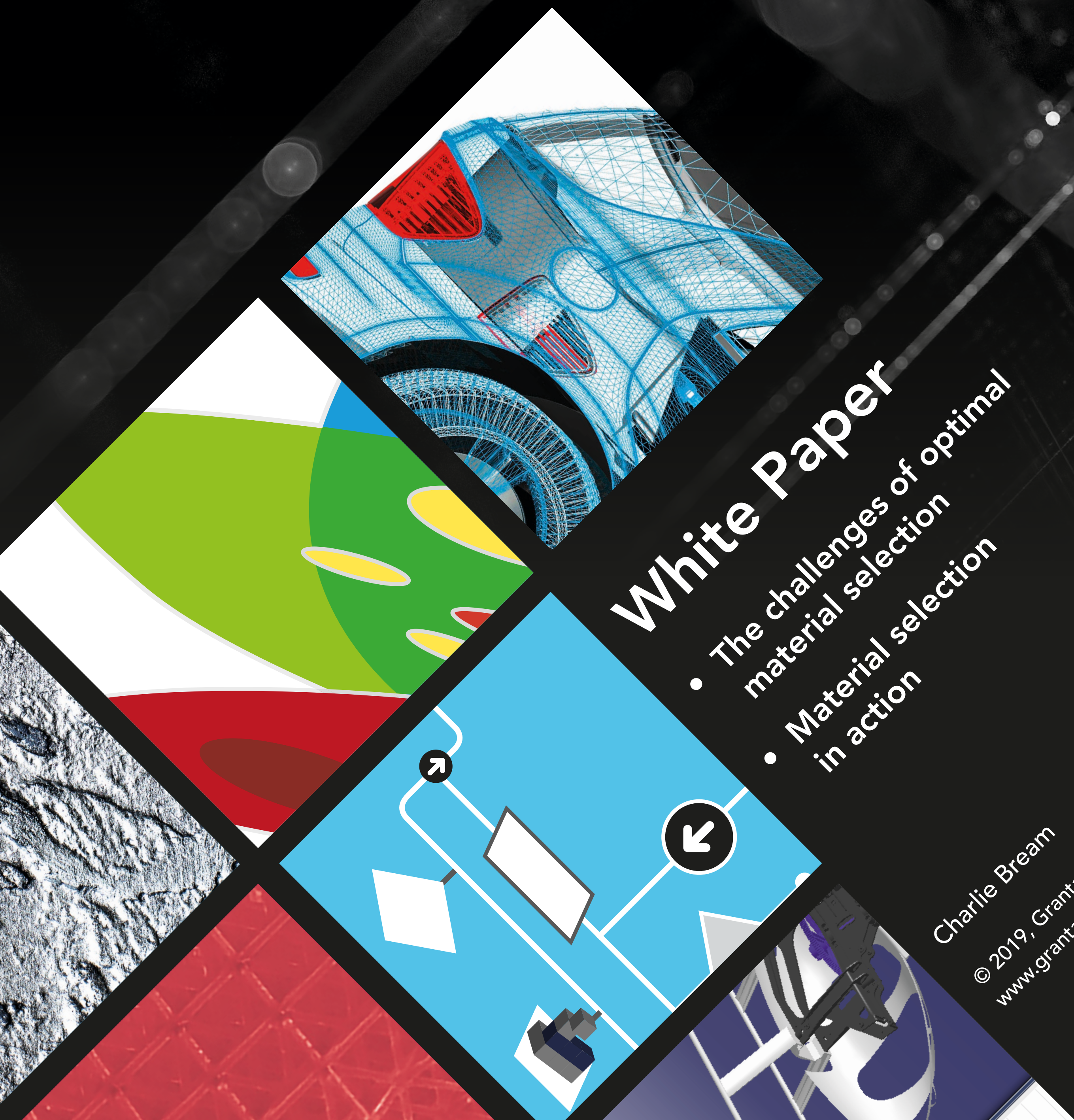
CES Selector

The Missing Link for Optimal Product Design



White Paper

- The challenges of optimal material selection
- Material selection in action

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CES Selector White Paper

CES Selector - The Missing Link for Optimal Product Design

Introduction

Your business success is intimately linked with the success of your products. As a result, you invest huge amounts of time and money in optimizing your product development processes. You optimize your product design by providing your product designers with the latest CAD tools. You optimize your product performance by giving your analysts the latest simulation tools. But what do you do to optimize your choice of materials?

Optimal material + Optimal design = Optimal product

Most businesses rely on simple 'rules of thumb' to choose materials, or just choose materials that have "worked well enough" before. This is not good enough in today's competitive markets, where the choice of the right materials for a product is often the biggest component of its cost and can often make the difference between a me-too product and a ground-breaking new product category, as the adoption of Gorilla Glass did for the iPhone. The missing link for optimal product design today is a tool your engineers can use for optimal material selection.

The challenges of optimal material selection

How do product development teams typically select materials today?

1. They use what they are familiar with or have used before. There is good reason for this, as they will have built up experience of in-service performance and processing, and can have confidence in the supply chain.

2. They are mandated to use the company's preferred materials. Here, the aim is often to restrict proliferation of materials and suppliers, enabling the company to reduce material prices with volume purchases.

These approaches have been used for years and can work well, particularly in 'stable' environments. However, they have two fundamental flaws. First, you cannot be confident that you are using the very best material option for your application. Second, you need to be able to respond to a whole series of scenarios where it becomes necessary to consider new materials. One key cause is material shortages – recent examples have been caused by factory fires or natural disasters, prompting a 'force majeure'. Others include new regulations restricting the use of certain chemicals; a new product requiring a new set of material characteristics; or material failures, perhaps due to evolution in the use of a product demanding higher operating speeds, pressures, or temperatures. In these cases, companies are forced to widen the net and consider 'new' (for the company) materials. Product development teams tend to:

3. Reach out to suppliers/consultants for advice.

4. Search the web!

These are unsatisfactory approaches. Which materials/suppliers should you be considering? Is there a better material out there? How do you assess where to focus your limited development resources? Although many suppliers are happy to work with you to find the best solution for your application, they are not impartial, and often formulate custom grades that meet your specific needs – tying you into their grades, charging a premium, and not always providing full details of what the grade is, making it difficult to find an alternative in the future.

But how do find data fast at this stage, when you want to iterate quickly? And how do you compare different materials when the design is not fixed, and will most likely vary depending on the materials chosen? For example, you can lightweight a steel beam by replacing it with aluminium – however, to achieve the same load

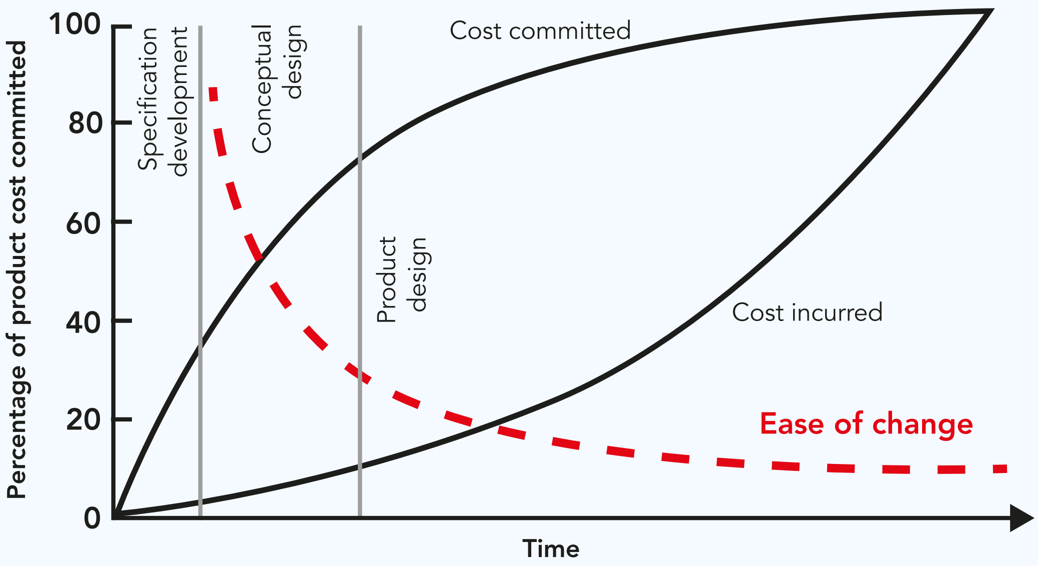

Figure 1: *Manufacturing cost commitment during design*
(ref: Ullman, D. G. (2003). The mechanical design process, McGraw-Hill. Boston/London)

You also face the challenge of finding data on the properties/characteristics that are important for your design. This means not just technical data, but also economic, regulatory, and environmental information. Depending on your target application, there will be a host of requirements not covered by a typical Technical Data Sheet (TDS). To get these, you often need to contact suppliers and get into an in-depth discussion about your application, your requirements, and what volume of material you are likely to need, before you will get even 'ball park' figures. This takes time and effort and can't be done for many materials. So how do you get around this? How can you be comprehensive in your search for materials without investing too many resources?

Timing is everything

It is also critical to make material choices at the right point in the development process. As shown in Figure 1, around 80% of a product's manufacturing cost is locked-in at the end of the conceptual design stage. Once a design concept is 'fixed' it becomes increasingly difficult to change any aspects of the design. Changing just one component not only impacts that component itself but can have a knock-on effect on other components. So, you must find optimal materials as early as possible.

-bearing capability you'll need to increase its cross-sectional area (i.e., change the design).

A systematic approach

CES Selector is a software tool for optimal material selection, developed and refined over 25 years by world-leading experts, originally at Cambridge University, and then at spin-out company Granta Design. It turns the systematic materials selection methodology developed by Professor Mike Ashby into a powerful tool for use by engineers and designers. To do this it combines world-leading materials reference data with powerful searching, comparison, and visualization software, making complex material selection from thousands of possible choices into a quick and simple process.

Optimal material selection requires you to be able to consider every possible type of material using a practical method to 'down-select' the material with the right properties that ensure you create a market-leading product. Often, this will involve complex trade-offs between performance, cost, manufacturability, regulatory performance, and technical aspects such as material stiffness, durability and strength. Choosing an optimal material given this complexity is only possible with the right combination of systematic approach,

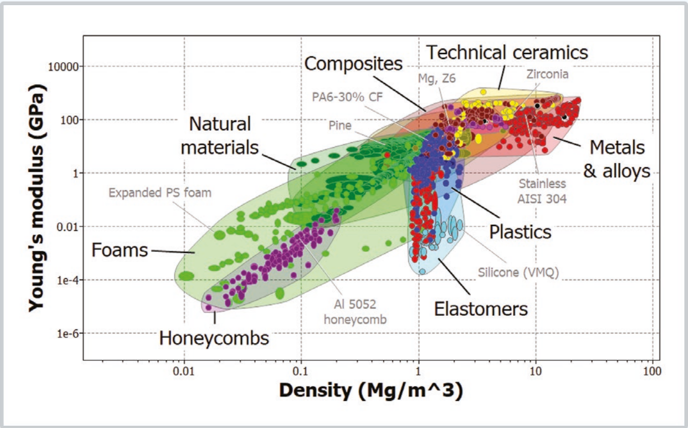

Figure 2. *Plotting properties for the full MaterialUniverse dataset in CES Selector. Each small 'bubble' shows the possible range of properties for a generic grade of material.*

software tools, and a complete set of the right materials reference data. CES Selector is the only tool available today that does this in a software package designed for use by engineers.

The right data

At the heart of CES Selector is the MaterialUniverse screening dataset, compiled and collated by materials experts at Granta. This covers all classes of engineering materials and has several characteristics that are essential for effective solution. Firstly, every datasheet provides a **standard set** of properties, including price and environmental impact, and these properties are described in a way that makes them **comparable** across material classes. Secondly, rather than providing data on specific grades, each datasheet represents a **generic grade of material**. For example, if we consider a 30% glass-filled polyamide, there are hundreds of grades on the market from a number of suppliers, each exhibiting slightly different performance. In MaterialUniverse, these are represented on one datasheet and for each property we have a range of values, as shown in *Figure 2*. This represents the range in performance you can expect from the material. Finally, there are **no gaps in the data** provided – every property is populated, even if this requires that property to be estimated. This means that potential materials are not missed during a screening exercise due to absent data.

The MaterialUniverse dataset is supported by specialist datasets, which contain more in-depth information on specific grades of materials. The datasheets in these specialist datasets are linked to the generic grade in the MaterialUniverse. Thus, you can complete an initial screening exercise with MaterialUniverse, then 'drill into' more detailed data to find specific purchasable examples of a generic material grade.

The right tools

Data is only useful if you can apply it, and that is where the right tools are needed. CES Selector provides a range of such tools to search, filter, plot, compare, and

	Aluminum, 357.0, sand cast, T6	Magnesium, AZ91C, cast, T6	PA66 (50% glass fiber)
Computed Properties			
Mass per unit of strength	0.0572 - 0.0612	+19 % ⇧	-26 % ⇩
Cost per unit of strength	0.0991 - 0.116	+35 % ⇧	0 %
General information			
Price			
Price (GBP/kg)	1.69 - 1.94	+9 % ⇧	+29 % ⇧
Price per unit volume (GBP/m^3)	4530 - 5320	-13 % ⇩	0 %
Physical properties			
Density (Mg/m^3)	2.69 - 2.74	-33 % ⇩	-41 % ⇩
Mechanical properties			
Young's modulus (GPa)	70.6 - 73.4	-33 % ⇩	-81 % ⇩
Specific stiffness (MN.m/kg)	26 - 27.1	0 %	-67 % ⇩
Yield strength (elastic limit) (MPa)	281 - 311	-41 % ⇩	-31 % ⇩
Tensile strength (MPa)	345 - 380	-15 % ⇩	-44 % ⇩
Specific strength (kN.m/kg)	104 - 115	-12 % ⇩	0 %
Elongation (% strain)	2 - 2.4	+108 % ⇧	+9 % ⇧
Elongation at yield (% strain)			
Compressive modulus (GPa)			
Compressive strength (MPa)	109 - 121	0 %	+67 % ⇧
Flexural modulus (GPa)	70.6 - 73.4	-33 % ⇩	-85 % ⇩

Figure 3. *Access and compare complete and comparable data*

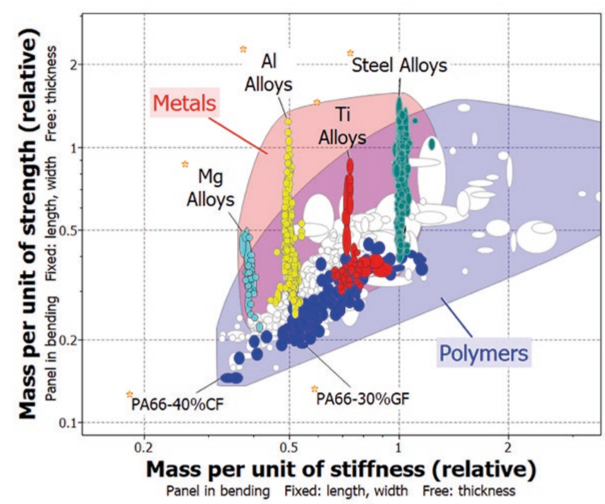

Figure 4. *Selection result for a panel in bending. Colored materials meet the 'must have' material requirement. Those in the bottom-left of the chart can minimize the mass of the part while providing a good combination of both stiffness and strength.*

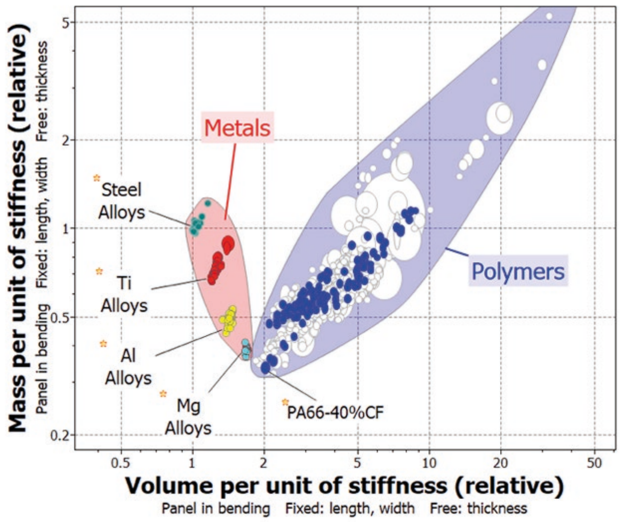

Figure 5. *Selection result for a panel in bending showing how the free variable, panel thickness, needs to change with material choice to achieve optimal performance. For example, replacing a steel alloy with a 40% carbon fiber filled PA66, can lead to a weight saving of 65%, but the panel thickness will need to increase by a factor of two to achieve the same stiffness.*

rank materials data as you narrow down your material options. A number of these are combined in the systematic materials selection methodology [1]. CES Selector offers a simple 'wizard' user interface enabling the user to move through the stages of this process. Key elements of this approach are:

- **Filter** based on 'must have' requirements for your material; the software allows you to quickly narrow down the choice from the 4,000 materials in MaterialUniverse
- Identify the **function** to fulfil – in a simple graphical user interface, you choose your engineering application: e.g., are you interested in a flat panel and how it performs in bending? Or the likely failure point of a pressure vessel? Or thermal shock resistance?
- Specify **constraints** and **objectives** – e.g., for the example of a panel, are you concerned about its stiffness, its strength, or both? Is the geometry fixed, or do you have freedom to change the thickness? Do you want to minimize cost, or mass, or find a trade-off between these factors?

Based on these choices, CES Selector will propose so-called **performance indices**: mathematical formulae showing the combination of material properties that you need to optimize in order to best meet your objectives. Plots such as Figures 3 and 4 enable you to trade-off between these objectives and understand how the free variable (e.g. panel thickness) needs to change with material choice to achieve optimal performance.

In addition to the systematic selection tools, CES Selector provides capabilities including: a fast method for identifying materials that have a similar property profile to a reference material; a method to estimate the environmental impact of your product; and tools to model part cost and the properties of potential hybrid material systems.

Optimal material selection in action

Refrigeration company Tecumseh provide a good case study in the use of CES Selector. Their reputation is built on good design and material expertise. In an increasingly competitive global market, they wanted to ensure that their material selection processes were rigorous and reproduceable - and to produce high quality products at an optimal price, while also considering environmental factors. The use of CES Selector on just two projects led to a three-fold reduction in production time for one component, and generated millions of euros of cost savings from making the right materials decisions.

One of these projects looked to reduce the weight of an electrical box cover, while ensuring it continued to meet UL fire-resistance legislation. Changes in regulations had led use of a different plastic, but Tecumseh had problems with the solutions that suppliers offered. After several months and design iterations, where all new suggestions came at a higher price, the team gained access to CES Selector and were able to apply it as part of a rationalized decision-making process. They were then able to constrain the material properties, quickly and objectivity, and to search exhaustively across a wide range of supplier datasheets. Constraints included the right impact test properties, Charpy test value, flammability, and thermal insulation (CEI). Their search yielded 29 families of polymers which met all the criteria including ABS + PC, PC, PPO + PS, and ABS "Polylac". Using CES Selector comparison tools, the engineers quickly identified Noryl (PPO + PS) as the ideal solution, because it not only met legislative and weight requirements, but also had significant advantages in terms of the cost/density ratio of the material.

A few weeks' work led to saving of 0.5€ per product which has already saved 2 million €

A second project set out to reduce both the cost and

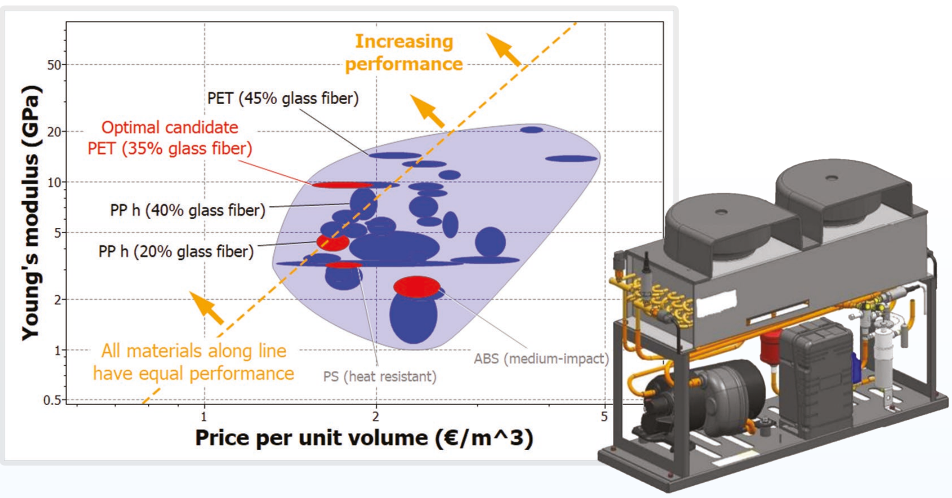

Figure 6. *Identification of optimal polymer for the replacement of a metal ventilation unit component (Tecumseh)*

weight of a ventilation unit (pictured). The fan mounting bracket (the topmost component) had been of metal construction. While plastics are often discounted due to lower rigidity, Tecumseh were aware that switching to a lighter thermoforming plastic could significantly reduce manufacturing time (by avoiding the multi-stage processing required for the metal), and thus the cost. They were happy to redesign the component if it would lead to the predicted threefold reduction in production time. They used CES Selector systematic selection and in just a few weeks were able to research and model a suitable replacement part. The result is a cheaper, lighter product, made from easy-to-source materials. When making more than 2 million of these units per year, this soon leads to significant cost savings.

Conclusion – Your materials selection checklist

CES Selector enables you to make the missing link in optimal product design, by making possible optimal materials selection. Whether or not you adopt the CES Selector technology, here are some key requirements for making that link:

- ✓ Reference data to support screening across the full range of generic materials types, with in-depth data to then identify specific materials grades.
- ✓ The screening data must be comparable across materials classes and complete (no 'holes' in the data).
- ✓ You need tools to filter and systematically 'down select' from the full range of materials possibilities.
- ✓ You need help to apply your conclusions at the next step in the development process – e.g., by exporting property data for the chosen material to support simulation and design work, and by generating plots and comparison data to present your conclusions to stakeholders.

If you can meet these criteria, you'll make smart materials choices.

References

[1] M.F. Ashby, Materials Selection in Mechanical Design, 5th edition, Butterworth-Heinemann, 2016

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