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"An intuitive system to evaluate the sustainability of evolving projects"

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ABSTRACT (English)

There is an increasing awareness of and desire for sustainability in product design, which translates into an increasing workload for those designers with projecting duties. New information, new methods to analyse data and new green certifications are among many variables that require an up-to-date know-how.

While other disciplines benefit from tools or databases that can be used to evaluate sustainability, no such tool yet exists in industrial design. Such a tool should be easy and dynamic and able to evaluate every aspect of a project.

Assigning a quantitative sustainability evaluation to a product requires the consideration and calculation of many parameters for every decision in the design process. The sheer quantity of data to be considered often means that attempts at such an evaluation are inaccurate. The most vulnerable kind of designers are those with little experience or academic training, those who work independently, and those who lack experience in the specific area in which they are working.

Against this background, this thesis proposes and elaborates a framework to assess and evaluate the environmental, economic and social sustainability of products and provide a final sustainability score. The framework works on a holistic analysis of multiple stages of the design process and makes use of readily available and up-to-date data.

ABSTRACT (Spanish)

En el área de diseño de productos, la creciente consciencia sustentable genera una constante fuente de conflicto para quien está a cargo de proyectar. Nueva información, nuevas maneras de interpretar los datos, o nuevas certificaciones ecológicas son, entre otras, variables que requieren de una actualización en el know-how.

Así como en otras disciplinas existen bases de datos que sirven de material de consulta, en el diseño de productos no hay nada que ofrezca de modo fácil y dinámico la capacidad de analizar la sustentabilidad de cada aspecto de su proyecto.

La cantidad de variables o parámetros involucrados en cada toma de decisión complejiza dicha capacidad de análisis, y en muchos casos resulta en diseños que desestiman las consecuencias que generan. Los proyectistas que sufren en mayor medida la falta de información son aquellos con poca experiencia o formación académica, aquellos que trabajan independientemente, y aquellos que incursionan en ámbitos previamente desconocidos.

Respondiendo al contexto, esta tesis propone y ejecuta la elaboración de una plataforma de consulta para las situaciones mencionadas, que pueda ser usada de modo intuitivo, y que funcione a partir de la interpretación holística de datos fácilmente hallables y actualizables.

0 / Introduction

0.1_ A clear trend

The growing awareness of potentially harmful parameters is often desestimated. Since the beginning of sustainability awareness, there has been a constant rise in further and deeper revisions. Building up environment care is good news for the planet, because things that three years ago were unknown, now might be requisites in certain markets. But designers have to cope with this increasingly critical judgements, and probably some tool is missing to let them delegate some time consuming duties and focus on the rest -and always important- aspects of design.

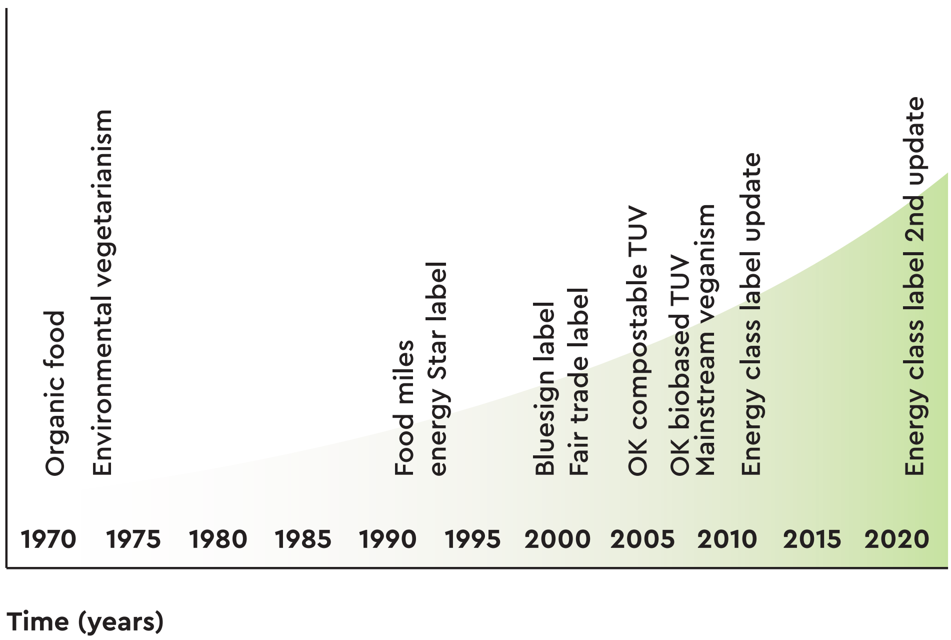

Figure 1: New sustainable concepts over time

And this trend has been on both ends of the market system: not only more green tools, labels and habits are available for producers (supply) but also a greater share of market is willing to pay for sustainability (demand). Depending one on other as they grow relevance, the result is an exponential importance, and thinking that the current situation might be getting even, or slowing down would be not understanding the promising future of it. The growth of sustainability-marketed products grows not only in absolute values, but also in share, and with higher values than what NYU Stern School of Business calls "conventional"[1] (fig. 1b).

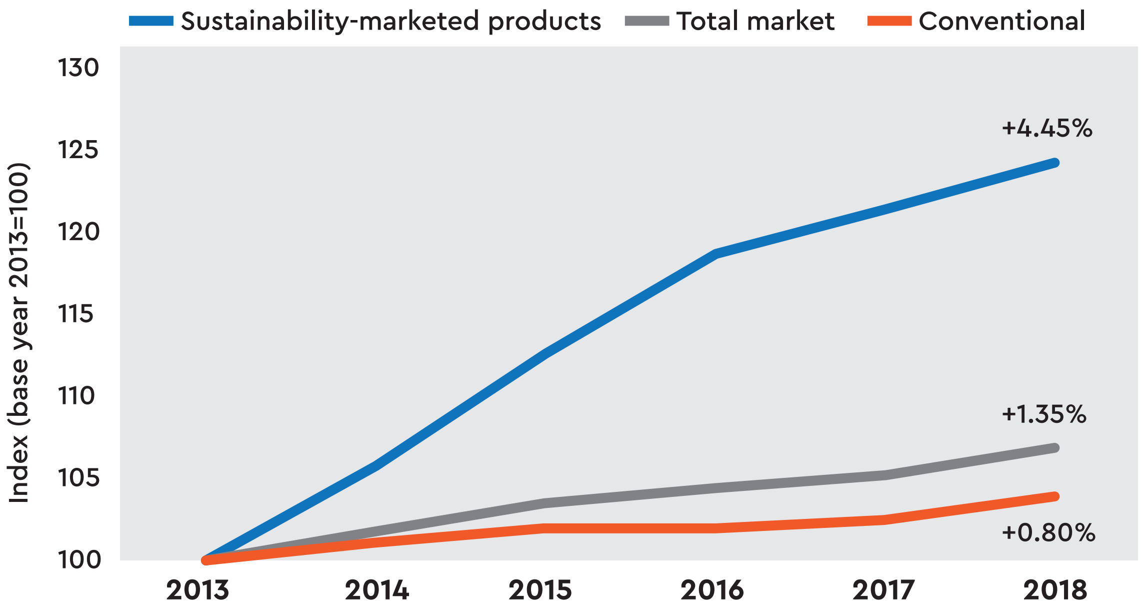

Figure 1b: Sustainability-marketed product growth compared conventional[1]

The so desired transition from a linear economy, full of waste and residues, to a circular economy, which reduces -ideally- to zero those undesired cast-out wastes requires better knowledge about the links between products, their underlying business model and the societal infrastructure and governance determining their life-cycle. Dedicated monitoring and analysis in order to identify key mechanisms and trends will be crucial in this respect.[2]

Changing drivers urge to appear, and in this context, a circularity evaluation system aimed to a new type of target is definitely needed. Generalisations should be avoided though, as there is no one-size-fits-all solution for better designing products for circular use. Again, a smart system that better understands the dynamic correlation between parameters is extremely helpful for the objective: a fully circular economy.

0.2_ Existing systems

Platforms (Idemat[3]), parametric 3d modelling (Solidworks[4], Autodesk Revit or Inventor[5]) and other softwares (SimaPro[6]) offer increasingly more outputs for the user, but several conditions keep them from being completely useful for sustainable evaluation. Different products benchmarked showed one or more of these conditions, which I considered drawbacks in the context of my research, and are explained up next:

1. Most of them offer **absolute values as output**, that without proper knowledge can be hard or impossible to understand. Not having a reference to compare with, or a score from which the user can have an idea of how good or bad those values are is definitely one of the triggers to develop a new kind of system. For example, knowing the exact amount of CO_2 equivalent greenhouse gas emissions is, unless the user is a subject expert, meaningless. On the contrary, a rating or score within a range is much more understandable for non-experts.

2. The more detailed the output of these software packs is, the more inputs they require. Managing such a tool requires **know-how and expensive licenses**. This point is extremely relevant for the elaboration of the thesis, since it defines the potential user for the guide. Know-how and an expensive software one might use for one single project are not assets frequently possessed by any given designer. Inexperienced, freelance, (lacking experience in specific field), or just budget-tight designers may definitely need an aid, while specialized team of engineers and designers working at an automotive company may not.

2. Other problem is fact that they require **time and precision** as input, usually being those available for the designer only at a developed stage of the project (Detail stage according to Ashby's design process, fig. 2). Detail stage, in fast times and running deadlines can mean a Point of No Return (PNR), and having something badly evaluated without being able to modify it, is not an ideal situation.

3. **Practicality** must not be underestimated. Parametric softwares rely on data input to achieve something else, such as a 3d model. So not only it requires sustainable-related information, but also things like geometry, colours, trims, etc., leading to a more complex process than a simpler evaluation of mere topic-related data. The output format of the sustainability report from these parametric suites is usually in data format, rather than information, requiring the receiver to have specific knowledge to understand its meaning. A tool that can be used on different stages (with vague estimations or with a fully developed data sheet) adds versatility to the proposed system. Using the tool on Concept stage (fig. 2) will offer a less precise result due to the lack of many data to fill in (i.e. weight of a specific part), but will anyway offer a proportionally good way to analyse the so-far decided aspects of the set.

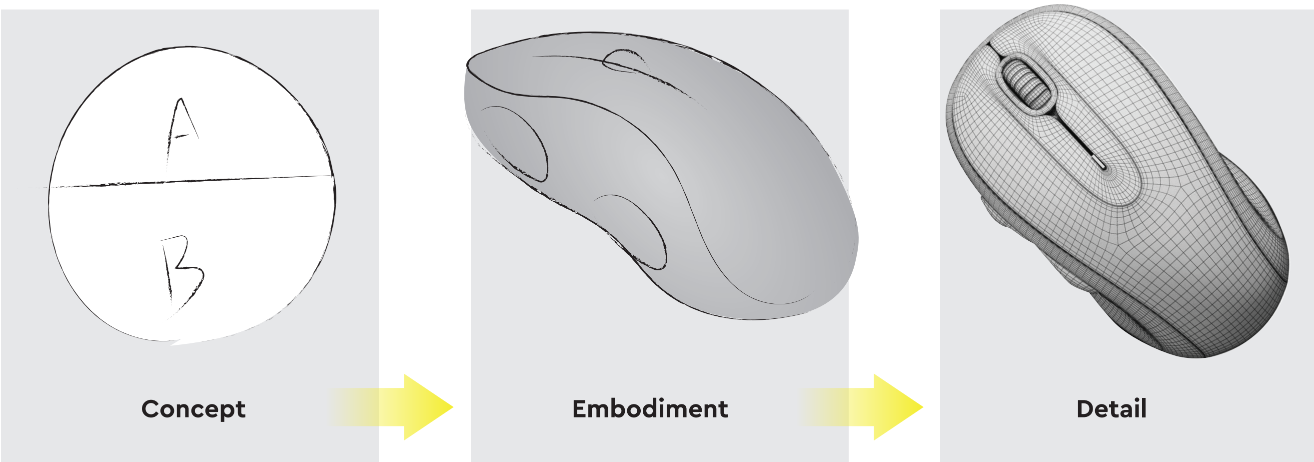

Figure 2: Three steps on design process

4. Non holistic approach

From the existing systems benchmarked, none is addressing sustainability on its whole scope. Existing platforms are mostly orientated to reduce impact on closed or ongoing projects, mostly by setting up production line adjusting manufacturing strategies to make it as resource-efficient as possible.
For on-going projects, there are already robust systems for architecture (CYPE[7]), where calculations on materials are of huge importance due to their volume, and the environmental impact is greatly considered also in service (energy efficiency), after production -or construction-. In architecture projects, 3d models (parametrically built) are easier to approach, and the so-called Detail stage (fig. 2) rarely affects initial estimations in a dramatic way. In fact, many softwares used for architecture sustainable evaluation (Design Builder[8], Calener GT or HULC) have a primitive 3d modelling input. The user generates a simple 3d model only to get the output, meaning that if the modelling would be tedious, these softwares would not be successful.

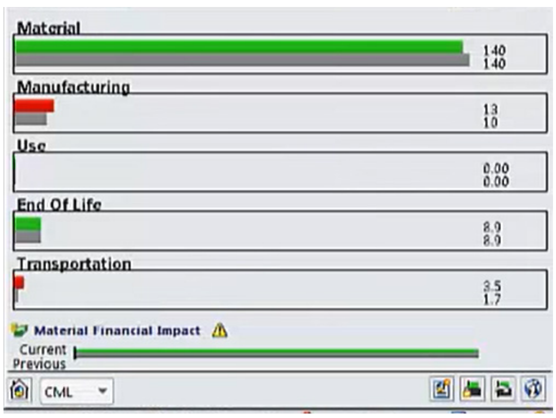

Figure 3: Dassault System: example of output

Specifically for product design, Dassault Systems (fig. 3) and Autocad offer complete modules with detailed outputs, but as stated before, they require a proper CAD model and will not address economic or social pillar of sustainability (only environmental). Ecolizer, although only considering environmental impact, proved to be a useful and more versatile tool since it is not a modelling software module or plug-in. Yet, it mostly works with a product of a material indicator times material amount, and so it turns out pretty much useless without filling the gaps for mass of each component (only available through specific CAD models or rough estimations).

Chapter 1 / **Parameters**

1.1_ Definitions

Parameters, a term that will be very much repeated on this thesis, is related with the items through which a design project can be evaluated. In generic terms, a parameter can be defined as:

> "A numerical or other measurable factor forming one of a set that defines a system or sets the conditions of its operation." (Oxford 2020)[9]

Applied to sustainability evaluation, parameters are many times decision that the person designing can take. Whether a piece is made in plastic or wood, in China or France, machined or moulded, or Child Labor Free certified or not, have implications in environments, societies and economies.

Score

Given its capacity to be quantified, each of this factors are eligible and will be used to create a score. Examples of parameters are materials, certifications, distribution logistics, end cycle, repairability, among others. To begin with, I chose which parameters

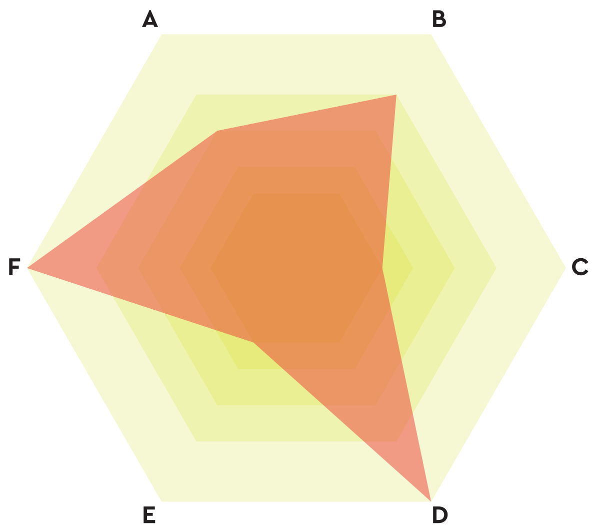

Fig. 4: A representation of a given set (orange polygon) of scores over six parameters (A,B,C,D,E,F)

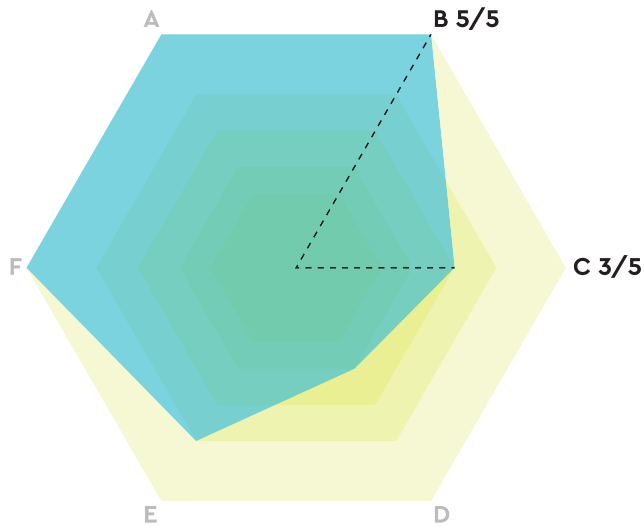

Fig. 5: On a different set (blue polygon), each parameter has a given score (5 for B and 3 for C)

will affect the evaluation. On upcoming chapters I will deeply define each parameter, and I will scheme their weight relevance on the final score. By doing this, some parameters have a higher incidence on the score than others, as it actually happens to be.

Since parameters (mass, embodied energy, transportation to consumer, lifecycle) usually have different units (kg., CO_2, km, optimal-terrible) a generic score was implemented. Once every parameter had a scale from minimum to maximum, a given set, in this case a design project, was ready for evaluation. In existing systems, the output represents simple and sometimes meaningless data, while the sought system delivers analysed results, comparing similar projects regarding location, type, etc., and probably even offering some suggestions to improve the score.

Scores can be either a decimal value between a given range, or a qualitative answer such as "yes or no" or "OK, regular or poor", depending on the parameter.

Exclusions

It is worth mentioning that the system will evaluate production sustainability, and will consider end of cycle implications as well. But the service phase[10] of the product will remain unconsidered, due to its complexity. Any given family product has vastly different impacts while being on-service, and the way to calculate that impact is through technical specifications from -for example- the electric DC motor. Nevertheless, if the design is seeking for Behavioural Change in positive terms, it will be praised positively on whatever sustainability pillar is looking forward to foster. Behavioural Design, or Behaviour Change Design is "a sub-category of design, which is concerned with how design can shape, or be used to influence human behaviour[11]. All approaches of design for behaviour change acknowledge that artefacts have an important influence on human behaviour and/or behavioural decisions. They strongly draw on theories of behavioural change, including the division into personal, behavioural, and environmental characteristics as drivers for behaviour change[12]. Areas in which design for behaviour change has been most commonly applied include health and well-being, sustainability, safety and social context [...]."

As stated, very technical and precise analysis will also remain unconsidered. Due both to the difficulty on gathering the required input from the user, and its little use on the evaluation: only experts in the field can properly understand how much a given value of CO_2/kg for a specific component of a design is fine or not.

1.2_ Choosing parameters

Among near countless parameters to choose, a selection had to be made. Lucia Rampino explains how sustainability is not only ecological[13], but also social and economic. Although it is undeniable that all three pillars are closely interconnected, calculations are not, and can therefore be, and will be evaluated in parallel.

Parameters will evaluate these three pillars, but will produce a merged result for social and economic sustainability, and an independent one for environmental. Socio-economic sustainability is complex to split in two, and even more complex to score with numeric values since their parameters are almost exclusively the existence or not of green labels or certifications, which are shown[14] to be not the most reliable way to perform evaluations.

The numeric relevance of each parameter will be defined and explained in the next part of the chapter. And the mathematical formulas to utilise those values together in chapter 3. Starting from the most obvious and ending with the least, a list of the parameters will be developed up next.

1. Material

Every project will have one or more parts, composed by one or more materials. For the evaluation, components will be segmented to get items with single materials attached to each (i.e. when evaluating a pen, the cap, the barrel, the ink tank and the ink will be analysed as 5 independent components -or parts-.). In order to put a score on each part's material (M_1, M_2, M_n), different factors will be involved into this parameter, and depending on the stage at where the project is, some or all of them could be filled. Increasing in required accuracy:

1A. Relative Material Embodied Energy (RMEE): The (absolute) Embodied energy is the sum of all the energy required to produce any goods or services, considered as if that energy was incorporated or 'embodied' in the product itself. The concept can be useful in determining the effectiveness of energy-producing or energy saving devices, and, because energy-inputs usually entail greenhouse gas emissions, in deciding whether a product contributes to or mitigates global warming.[15]
Regarding only materials, EE will include all the processes required for obtaining the product that will be used in the project. If a further process is involved post-purchase, that EE will be retrieved on RPEE.
The extraction and production of any material remains -with efficiency variations depending on technology- within a small range of values regardless of location.

To quantify RMEE, the system offers the chance for the user to fill the gap with either only the material choice (Level 1 or 2 from CES Edupack or Granta Edupack), or an estimated mass (lower/bigger than average, or average). It is again relevant to mention that since the desired output is an informative report, the user could have a neutral qualification on certain parameters. For example, a designer projecting a phone case, could perfectly estimate the TPU mass to be "average" compared to the benchmark, and then somehow keep the material mass out of the equation.

To get the absolute embedded energy, multiplying any part mass [kg] times the embodied energy [MJ/kg] ratio for the given material would be enough, but the result would be a meaningless (in this situation) amount of energy [MJ].

1B. Recyclability: Once a material is released into the outside world the picture changes. It has been processed to make parts that may be small; it has been assembled into products that may contain many other materials; it has been painted, printed or plated; and its subsequent use contaminates it further. To reuse it, it must be collected (not always easy), identified, separated from other materials, decontaminated, chopped and processed and more. Collection is labour-intensive, and this makes it expensive. Imperfect separation causes problems: even a little copper or tin damages the properties of steel; residual iron embrittles aluminium; heavy metals (lead, cadmium, mercury) are unacceptable in many alloys; dyes, water and almost any alien plastic renders a polymer unacceptable for its original purpose, meaning that it can only be used in less demanding applications (a fate known as downcycling).[16]

Eligibility to be recycled, degraded or composted is inherent to each material. But in order to be evaluated as such, it must check two conditions: First, if the analysed component is assembled or attached to different components, it must be able to get completely dismantled by non-specialized means. Secondly, the recycling facility has to available in the targeted market, provided either officially (i.e. multiple local recycling possibilities) or by third parties (i.e. NGOs). At this subparemeter, even a vague material family may provide enough information for a shallow evaluation. Whether the two required conditions are checked or not, may be filled in further on by the user.

1C. Renewable or fossil?: A renewable or flow resource is a natural resource which will replenish to replace the portion depleted by usage and consumption, either through natural reproduction or other recurring processes in a finite amount of time in a human time scale. When such recovery rate of resources is unlikely to ever exceed a human time scale, these are called perpetual resources.[17]

As much as a project is certified, energy efficient and made up from recycled materials, if it is not made up completely of renewable materials, it can't be considered a fully sustainable project. Responsibility and renewability are often synchronized, but that is not always the case.

1D. Labelling/certifications: The absence or presence of eco-labels on required materials may discard further insupportable activities. Since the amount of labelling

systems is huge and lacks of standards, a twin level of scoring is applied for the scoring process. The most internationally-trusted labels count for the biggest part of the value, while further alternative labels may add or take a minor grade. For example, 93% of the Material Certifications coefficient will be given if either EU Ecolabel or Fair Trade are certified, and 7% if others unstated labels are.
Ecolabels can certify different aspects of sustainability. So the user must specify which kind is it. For example, Fair Trade is addressing both economic and social pillar, while FSC is doing only environmental.

1E. Material Origin: Material transportation EE to the assembly line is completely dependent on the projected location, and carries further embedded energy. It stands for the importation (if acquired from abroad) or domestic transportation. Considering regional goods for producing objects is a great way to reduce pollution. This Subparameter stands for what carbon footprint might stand, but with a different approach. Considering both distance and location factors, the result makes it much more dependent on the energy source (therefore considering energy production efficiency and renewability) than standard carbon footprint charts. Whether that energy is generated through responsible ways or not, is to be considered as very relevant.

Distance factor is easy to estimate. Location factor will get its value after a multiplication between: Energy matrix for each country[18], and a multiplier [CO_2 emissions equivalent/ gigawatt] for every kind of energy source[19] leads to power source implication on each country. Calculations will be properly explained in next chapter.

Additional information: when deciding parameters for materials, both embodied energy and carbon footprint[20] arose as the easier to estimate score. Although embodied energy is more related with manufacturing processes and carbon footprint with transportations, it may not be always that straight forward. It turns out that many carbon footprint databases[21] include embodied energy and estimate an average efficiency of energy production to convert it MJ into CO_2 kg, which may lead to a double count error. Therefore only embodied energy is kept as the main scoring parameter, and 1E. Material Transportation will consider (as a multiplier) both power sources and distances between production place and material origin.

2. Processing

Processing as parameter, will take into account only in-house processes and their implications. Those done on a purchased goods are considered under Material. Analogically to Material, for every projected process, a different item shall be added (P_1, P_2, P_n).

2A. Relative Processing Embodied Energy (RPEE): This stands for the sum of energy employed in own production line (manufacturing processes, assemblies tasks, etc..). Energy used for the tooling manufacturing (such as dies or stamps) shall be considered, and estimated according to the projected batch size. As in Ashby's cost model's "Tooling cost"[22], the tooling embodied energy shall be wholly prorated to individual products: X amount of energy used to create a stamp for making 50 products is -relatively- much higher than if the stamp makes 50,000 products. Embodied energy in purchased material, from a process that took place before acquisition, is to be considered only under Relative Material Embodied Energy (in Material Parameter).

Power source shall affect equally PEE and MEE. (Further details in page 18, under MEE).

3. Lifespan / repairability

From a technical point of view, refers to the maximum period during which a product has the physical capacity to function[23], and from the functional life to the time a product should last regardless of external intervention to increase its lifespan[24]. As long as the product can extend its lifecycle it will prevent the user to replace it for a new one, creating all over again a harmful chain of environmental, social and economic impacts. A big problem relies on how imprecise it is to determine the lifetime of a product while it is being designed. In some cases, extended use tests can provide this information based on prototypes, but yet requires an advanced project stage to do so. Retrieving lifespans from comparable objects can be an oversimplified way to gather such information. In terms of functionality, newer technologies are usually trimming down the lifespan of properly designed-to-last objects, being that an unpredictable factor affecting it. Repairability is a factor of great relevance as it helps to avoid the manufacturing of the whole product, for just one component.

Whether or not manufacturers "programme" obsolescence purposeful or just accept premature failures due to the use of inferior materials because of cost pressure may be difficult to proof. However, whether early product failure is a fact or a myth and whether the phenomenon of non-durable products is due to intention or linked to other factors such as wear and tear is irrelevant as far as the objectives of consumer protection and environmental preservation are concerned. The decisive point is that product lifetimes currently neither live up to what consumers expect nor to what technically is possible and feasible in a cost-effective manner for consumers.[25] In principle, the environmental impact caused by offering the disposed product to a new user for reuse, is negligible.

The following five points[26] are used as guideline to evaluate lifetime of a product:

1. Design for product attachment and trust: Create products that will be loved, liked or trusted for longer. Timeless classic design: be practical – fit the design to the purpose and what people need. Think about enhanced personalisation and optimisation of initial lifetime.

2. Design for longevity: Design for easy maintenance, repairability and with a strong consumer-manufacturer relationship. Developing products that can take "wear and tear" without breaking down. Design for durability – products that last longer.

3. Modular design: The modular design of the product, facilitated by an open source approach, means that products are not only modular and reusable, they are also modifiable. Embrace open source modularity and drive the transition to a circular economy.

4. Design for standardisation and compatibility: Create products with parts or interfaces that fit other products as well to bring longevity into the product but also flexibility. Think about future upgradability and compatibility with the past.

5. Design for dismantling: Design for disassembly, deconstruction and repairability. Consider reversible interconnection technologies (for example, screws are better than glue) and labelling the parts.

In this case, the user has to estimate a minimum technical duration for the product. Knowing materials, context use, brief requisites, and repairability capabilities can help a lot, and on top of that the system will guide the user with some estimative values to fill in. Possible options are "Made to last", "Average", "Short" and "Not yet defined/ Unknown".

4. Distribution

This parameter is affected by three variables: distance, means of transport and package size. All three will constitute Distribution Embodied Energy, and of course will carry further energy employed to deliver the product. Regarding means of transport, whether the designer is planning a specific distribution logistic or not, it may add further energy employment. However it is almost impossible for the designer to know in which way its product will be ultimately distributed.

4A. Distance: is an attempt to measure how far the product has travelled before it reaches the consumer. It includes getting goods to final consumer. It is normal not to know where the product will be sold while designing, but it can happen to know that it will be used exclusively locally. Possible options are "Regional", "National", "From abroad" and "Not yet defined".

4B. Package size (PS): Under this category, smart designs that reward foldability, or easy post-purchase assembly (as in IKEA) have a raise in the score. Reducing the package size for delivery makes the distribution cleaner and easier, helping reduce energy and emissions footprint. PS could be considered as logistics embodied energy. Conventional products are boxed ready to use, and those will keep their score unchanged after this parameter. Possible options are "Responsible", "Conventional" and "Not yet defined / Unknown".

5. Added value

From an ethical point of view, design must be meaningful. Merriam-Webster defines ethics as the "rules of behaviour based on ideas about what is morally good and bad"[27]. Adding the design labour on it, then certain projects may be defined as (morally) wrong or right. If it supports human rights but does not respect human effort by being functional, convenient and reliable (and usable!), Then it is unethical. If it respects human effort but does not respect human experience by making a better life for the people using it, then it is still unethical[28]. Morally judgement is probably related with social inequity, but this parameter can attend economic justice as well.
Pricing, for example, is a strategy that may turn a (socially/economically) meaningless design into the so called Democratic Design. "(DD) underlines the importance of systemic and contextual design, and the practical enactment of democratic values such as equality, freedom and participation"[29]. Equality and participation in consumerism are achieved by letting everyone to buy the same things, and aiming to have a low selling price object clearly moves towards this kind of democracy, fostering economic sustainability.
With this into mind, is the project adding a meaningful improvement to society, economy or environment? Possible options for this questions are "No/Unclear", "To some extent" and "Definitely yes".

Unconsidered parameters:

Processing certifications: It is currently (too) hard and complex to standardise manufacturing labour conditions or environmental implications. Regulations on developed countries may work as a warranty of good conditions, whereas in developing countries that is not necessarily granted. Therefore good practices require extra eco-labels to obtain credibility. Fair Trade, Alternative Trading Organizations (ATO) and Direct Trade help address this empty space. One option was to consider either a fair labour-related label or a developed country (implying the consequent presence of advanced labour law sets) location as equally valid conditions to positively rate this parameter. The second considered route was to stick with certifications, since listing developed countries is both subjective and does not guarantees a set of laws regarding fair labour. One of Fair Trade's controversies[30] is the one regarding how Eco-labelled products from poorly labour-regulated are taking over non-certified yet fairly made products, from either the same country or a developed one (with proper labour regulations). However, UK is a great example of how a robust set of labour regulations does not stop companies or institutions to seek for certification: there are 500 Fair trade towns, 118 universities, over 6,000 churches, and over 4,000 UK schools registered in the Fair trade Schools Scheme[31].
Although process labels may seem to perform properly for the evaluation, it is more likely to give a jump start for the very little projects that may eventually get a positive score here (Processing certifications).
Addressing social and economic impact is frequently attached to an incapacity to gradually rate parameters. In this case the possible values for fair labour are "OK" or

“Unknown“.

In-service energy consumption

It was considered as a multiplier for energy efficiency when in use. Although it certainly has a profound impact in environment, it relies completely in any electric the project may have, and whether this component is more or less energy-efficient depends upon a decision virtually impossible to take on Design phase. Furthermore, efficiency on these kind of components is being already easily addresses by energy labels.
In addition, electric components are not usually present in the cluster being developed in this phase.

Embodied water: Following embodied energy, embodied water (or water footprint or virtual water) is the sum of all the freshwater required to achieve a given goods or service. It mainly depends in the manufacturing location water efficiency, that itself changes over time (industrial progress on processes results in variations of the embodied water for a given material). However embodied water is still not widely considered as an adequate sustainable index due to different reasons:
It relies on an assumption that all sources of water, whether in the form of rainfall or provided through an irrigation system, are of equal value. Also, It fails as an indicator of environmental harm nor does it provide any indication of whether water resources are being used within sustainable extraction limits. The use of virtual water estimates, therefore, offers no guidance for policymakers seeking to ensure that environmental objectives are being met. This last reason though, could be stated for embodied energies.

1.3_ Weighting parameters

Criteria:

As an overall line of thinking, and since the desired output is not hard-to-read values of, for example, emissions, the whole formula took into account the following:

Perfect sustainability is considered the "expected" value, and so anything worse than that will have a negative effect. Some parameters affect the score with exponentially growing coefficients as they score worse. To better understand, if an object is composed by 95% of properly sustainable materials and processes, but has one single part that is very environmentally harmful, the overall score of the product will remain pitiful.

Similarly, worse ranked parameters will also be weighted heavier than better ranked ones. So, if the Material score is optimal, but the Processing is low, then the latter score will have a deeper impact in the overall score than the former.

It seems necessary to mention that a perfect score may not be achieved even through the use of greenest materials, best decision-making or most certified processes. Perfect score means completely circular[1] and sustainable, and certain mechanical properties just can not be achieved with what, at least in 2021, is out there to choose from.

Finally, a perfect final score does not necessarily means that the project will have a positive impact in environments, economies and societies, but only that it will not have a negative one. Positive impact will probably remain in fields like behaviour change design or social design -of course added on top of a perfect sustainability score-.

End of life potential (EoLP):

Introduced by some already existing systems (such as Granta Edupack), this output is usually considered as separate (fig. 6)[2] to reinforce its potentiality rather than a certainly positive value. A project having a big EoLP (a large negative value for either kg of CO2 emissions of MJ of embodied energy) can certainly reduce impact if managed properly, but

1 A circular economy (also referred to as "circularity") is an economic system aimed at eliminating waste and the continual use of resources. Geissdoerfer, Martin; Savaget, Paulo; Bocken, Nancy M. P.; Hultink, Erik Jan (2017-02-01). "The Circular Economy – A new sustainability paradigm?". Journal of Cleaner Production

2 Case studio for a hypothetical project, where the last bar stands for EoLP, clearly differing from the effective values of other parameters' embodied energy.

may also loose all of that great sustainable value when not. Having said this, and since the designer does not held responsibility for end-of-life or disposal phases, I considered that generating all that End of Life Potential is already a valuable thing per Se. Following this idea, this system will consider potential sustainability as "effective" sustainability, and will act as multipliers in either Parameters (Lifespan) or Subparameters (Material Recyclability)

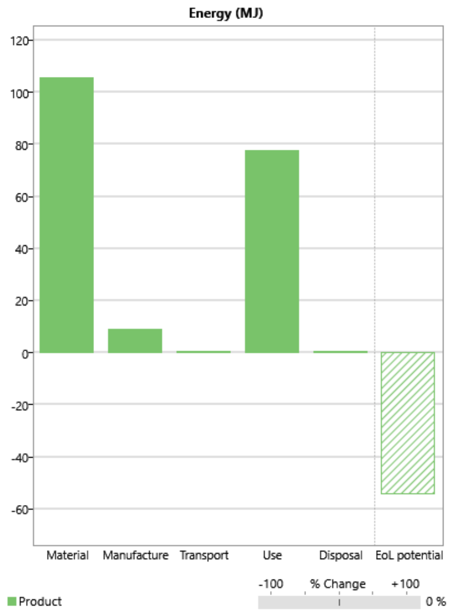

Figure 6: End of life represented as potential value

Formula structure:

In this chapter, formulas are explained in how they are composed, in an almost grammatical way. Parameters are also weighted in importance, but the full mathematical formula is not yet described. In chapter 2.2 (Calculations, First approach) the proper math equation is presented.

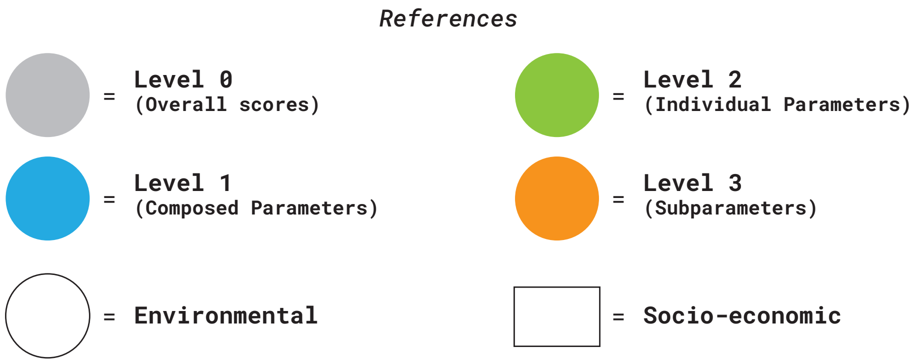

Figure 7: Formula references

Environment:

The main formula (fig. 8) will consider all five parameters, being the first two heavier in consideration, and the last three less important multipliers.

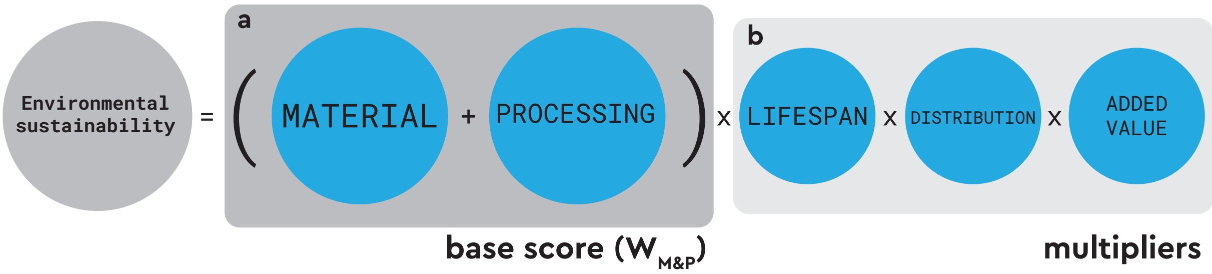

Figure 8: Main formula components

The first term (grey box "a" in fig. 9) refers to the weighted average (W) of Material and Processing scores put together (M&P). The weight of each individual score is the outcome of each score ($x_{MATERIAL}$ and $x_{PROCESSING}$) after a specific function called w(x) ($w_{MATERIAL}$ and $w_{PROCESSING}$) and a fixed weight for each: 2/3 for Materials and 1/3 for Processing. Both the fixed weight and the variable weight depending on the function w(x) will have influence. The result of the weighted average of these two parameters, called $W_{M\&P}$, ranges from 1 to 5. Since 1 is the lowest score, any multiplier being lower than 1 will decrease the result. The reason of adding more relevance to Material (66%) than Processing (33%) is due to two reasons: The physical remains of the product after its End of Life is the main struggle for the global not-yet-circular system. While Processing mainly considers energy use, on top of that, Material adds the mentioned physical qualities. In any case, and since the weight for either Material or Processing also includes the scoring weight, so the final result will not stick to a two thirds and one third composition.

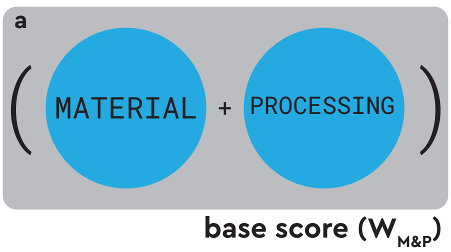

Figure 9: Base score from main formula

The second term (grey box "b" in fig. 10) refers to the multipliers. Each of these is the score for one parameter (Lifespan, Distribution or Added Value), and act as multiplier to $W_{M\&P}$ (term "a" in fig. 8). Each of these three multipliers, ranges from 0 to 1.

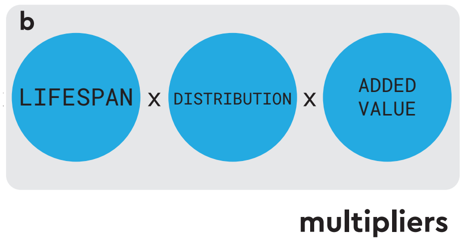

Figure 10: Multipliers from main formula

Material:
Each project is composed by one or more parts (i.e. cap, barrel, screw and nut). The Material score for each part is denominated M_1, M_2, M_n, and involves all Material subparameters (RMEE, Rec., Ren, Cert. and MO).
The whole Material score (fig. 11) comes from the weighted average of each parts' score (M_1, M_2, M_n). The weight of each individual score (w_{M1}, w_{M2}, w_{Mn}) is the outcome of each score (x_{M1}, x_{M2}, x_{Mn}) after a specific function called w(x).

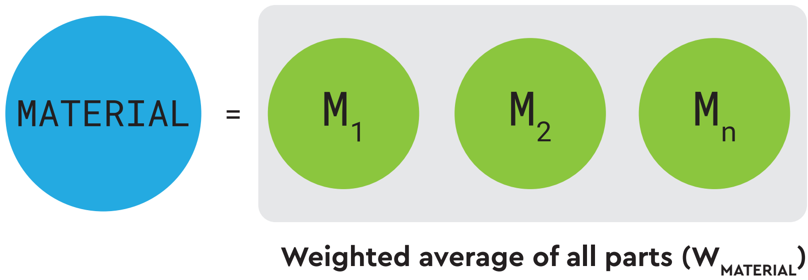

Figure 11: Material score composition

Deeper in, each parts' score (M_1, M_2, M_n) is composed by five subparameters, from which one (Relative Material Embodied Energy) is the most important -works as the base score- and the other four (Recyclability, Renewability, Certifications and Distance from Production Place) are multipliers (fig. 12).

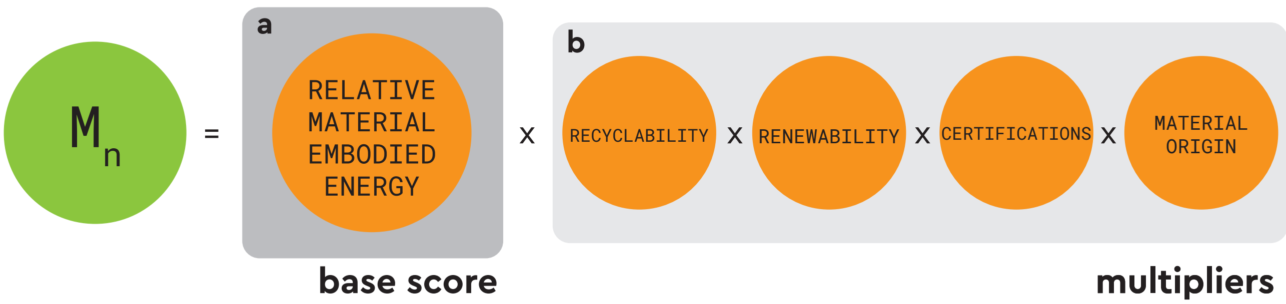

Figure 12: Material individual score formula

Processing: A very similar situation happens for Processing: each project is composed by none or some processes (i.e. , injection moulding, manual assembly and boxing).

The Processing score for each process is denominated P_1, P_2, P_n, and involves all Process subparameters (RPEE, TR, and FL).
The whole Processing score (fig. 13) comes from the weighted average of each processes' score (P_1, P_2, P_n). The weight of each individual score (w_{P1}, w_{P2}, w_{Pn}) is the outcome of each score (x_{P1}, x_{P2}, x_{Pn}) after a specific function called w(x).

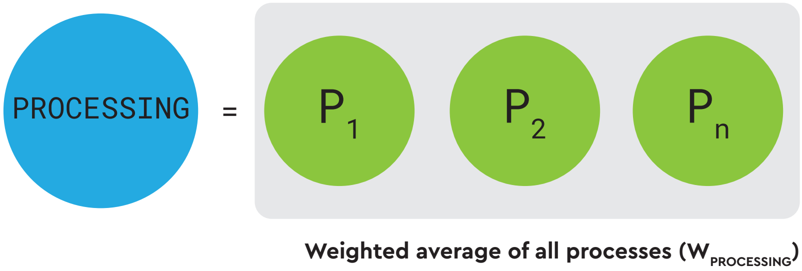

Figure 13: Processing score composition

Deeper in, each process' score (P_1, P_2, P_n) is composed by three subparameters, from which one (Relative Process Embodied Energy) is the most important -works as the base score- and the other two (Tooling Recyclability and Fair Labour) are multipliers (fig. 14).

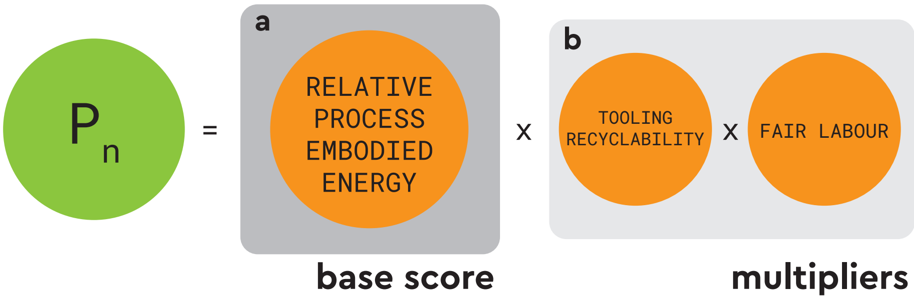

Figure 14: Processing individual score formula

Socio-economic:
Unlike environment, the formula for the evaluation of social and economical sustainability is relatively simple. It is composed by the mere sum of only three parameters (fig. 15). Therefore, the Overall Socio-economic score will range from one 0 to 3.

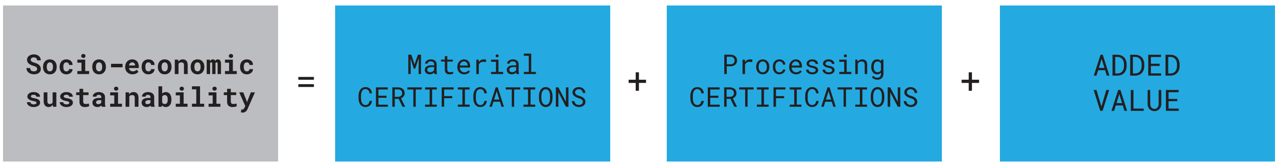

Figure 15: Socio-economic formula

Coefficients:

Up next, parameters and subparameters are given either a score range or a multiplier factor or coefficient. Score range format is for the most potentially harmful parameters, as they build most of the points, from which then multipliers from less incident parameters do the final reductions -if negative- or no change at all -if absolutely sustainable-.

Coefficients will be divided in grades (from A to Z, fig. 16), being each grade assigned to a fixed value. A is the highest grade (x1.0, meaning no change), so it is assigned to parameters with low harm potential.

*The decisions on how much incidence each parameter has on the final score are based

grade	cA	cB	cC	cD	cE	cF
coeff.value	1.00	0.96	0.92	0.88	0.84	0.80

Figure 16: Coefficient grades

on the already exposed research, but it could be easily changed in the future after expert evaluations or comments. Weighting parameters is a very sensitive task, and should be done by experts.

*When "Not yet defined" is inserted, the system will not lower the grade, but add a "Pending score" in the final report, to be clear that a specific parameter or subparameter has not been yet evaluated.

*Parameters and subparameters will be referred to as coded in part 1.2_ Choosing Parameters, page 17

*Parameters will be weighted under both environmental and socio-economic sustainability. Socio-economic sustainability only scores in three subparameters, so the grading is based upon a scale from 0 to 3.

Material (1A, 1B, 1C, 1D and 1E)

1A. Relative Material Embedded Energy (RMEE): Due to being a relative parameter, the score will be given upon comparisons with other materials. At the moment, values are taken from a Level 1[3] universe of material (CES/Granta Edupack), allowing calculations to be executed on a first prototype. Adding to a total of 69 materials, intervals were assigned

3 This database (Level 1) is aimed at introductory courses. The Level 1 Education database has records for common engineering materials (metals, plastics, ceramics, glasses, composites and natural materials). It contains more than 60 records, each with a limited set of attributes chosen by the Granta team in collaboration with our users to introduce students to materials without overwhelming them with detail.

in a logarithmic scale, in order to rank all 69 materials in 4 different score ranges (from 1 to 2, 2 to 3, 3 to 4 and 4 to 5), getting then a score for RMEE from 1 to 5. Considering that the multipliers from other parameters have their highest values at 1, and then descend as they get worse, then the score for RMEE can not be lower than 1 (or else a harmful multiplier like 0.8 could result in a rise of the score if this is, for example, 0.5).

Since all but 3 out of 69 materials range from 1 to 1000, I set up 10 logarithmic intervals within that range, allowing then materials with a lower than 1 or higher than 1000 [MJ/kg] Embodied Energy to fit into their closer interval. By dividing the -power- argument (3, because $\log_{10}3$ is 1000) from the maximum value -in this case 1000- into 10, I set the ten intervals (rising the argument each interval by 0.6). On next chapter, calculations and intervals are properly explained.

Embodied Energy	Argument	Interval/Score
0 to 1	0	5
1 to 2.7	0.435	4.5
2.7 to 7.4	0.869	4
7,4 to 20.1	1.304	3.5
20.1 to 54.8	1.739	3
54.8 to 149	2.173	2.5
149 to 405.4	2.608	2
405.4 to 1102.8	3.042	1.5
more than 1102.8	3.477	1

1B. Recyclability (Rec.): The spectrum of how harmful or potentially sustainable a material can be is not simple, and involves different aspects, and that is the reason why a simple "yes or no" needed further grades between them.

As a middle step between a mere "recyclable yes or no", downcycle[4] was considered, but almost every material can be downcycled to some extent -and was consequently discarded-.

A second -and definite- approach was to hold Biodegradability[5] capabilities into this Subparameter. Some materials are only recyclable (most of polymers), some are only biodegradable (such as woods or other natural materials), some are both and some are none. Those that are neither recyclable nor biodegradable will qualify with the worst score. Those that are either recyclable or biodegradable will get a medium score, and those who are both will get a perfect score. Since even a recyclable material often requires a lot of further ecological effort, there should not be a huge difference between multipliers from a material that allows Recycling, Biodegrading or none of those. Yet,

4 Downcycling, or cascading, is the recycling of waste where the recycled material is of lower quality and functionality than the original material. [1][2] Often, this is due to the accumulation of tramp elements in secondary metals, which may exclude the latter from high-quality applications. Ana Pires (2018). Sustainable Solid Waste Collection and Management

5 Biodegradation is the breakdown of organic matter by micro-organisms, such as bacteria and fungi. Focht DD (2012) "Biodegradation"

materials that are both rec. and biod. will step up from the other two scores (medium and low) to praise their use.

Following, possible input are "Not recyclable nor biodegradable", "Recyclable or biodegradable" and "Recyclable and biodegradable".

Possible inputs (P.Ip.)	Output (Op.)
Recyclable and biodegradable	cA
Either recyclable or biodegradable	cC
Not recyclable and not biodegradable	cD
Not yet defined	pending score

1C. Renewability (Ren.): As the two possible inputs have a very long-term difference, coefficients are to be kept similar. Until the planet runs out of oil, recyclability remains more important, or at least urgent.

P.Ip.	Op.
Renewable	cA
Non-renewable	cC
Not yet defined	Pending score

1D. Certifications (Cert.): A list of well known eco-labels will be shown to the user, making it to tick on whichever the material is certified. This subparameter is one of the three on the whole system that provides feedback for the evaluation of socio-economic sustainability.

Double screening score is used here. The material can be certified at a strong level, a basic level, or non certified at all. Strong level is attributed to the widest recognised and trustworthy[32 33] certifications entities. Depending on which problem is addressing, it will add either environmental sustainability, socio-economic sustainability, or both.

P.Ip	Env. Op.	Socio-economic Op.
Fair Trade[34]	Strong	Strong
Child labor free[35]	–	Strong
EU Ecolabel[36]	Strong	–
RoHS[37]	Basic	–
UTZ[38]	Strong	Basic
Rainforest-alliance[39]	Strong	–
FSC[40]	Strong	–
Green Seal [41]	Basic	–
bluesign[42]	Strong	–
Direct Trade[43]	–	Strong
Other environmental label	Basic	–
Other socio-economic label	–	Basic
None	–	–
Not yet defined	Pending score	Pending score

From the previous list, best score is obtained when the evaluated material is certified with one or more strong-rated certifications, medium score when one or more basic-rated certifications, and low score when none of the above. When not filled, the pending score will not affect the equation but a "Pending score" disclosure will show up in the report.

Environmental and socio-economic sustainability are evaluated independently.

Strong level	cA
Basic level	cB
Non certified	cC
Not yet defined	Pending score

Strong level	+1
Basic level	+0.5
Non certified	+0
Not yet defined	Pending score

1E. Material Origin (MO): The score is a multiplication between a value depending on how clean the energy matrix from the source country is (database), and the distance that the material is carried. For energy matrix, independent values for each type of energy source emissions (fig. 17) was interpolated with the energy matrix of six countries chosen for the case study.

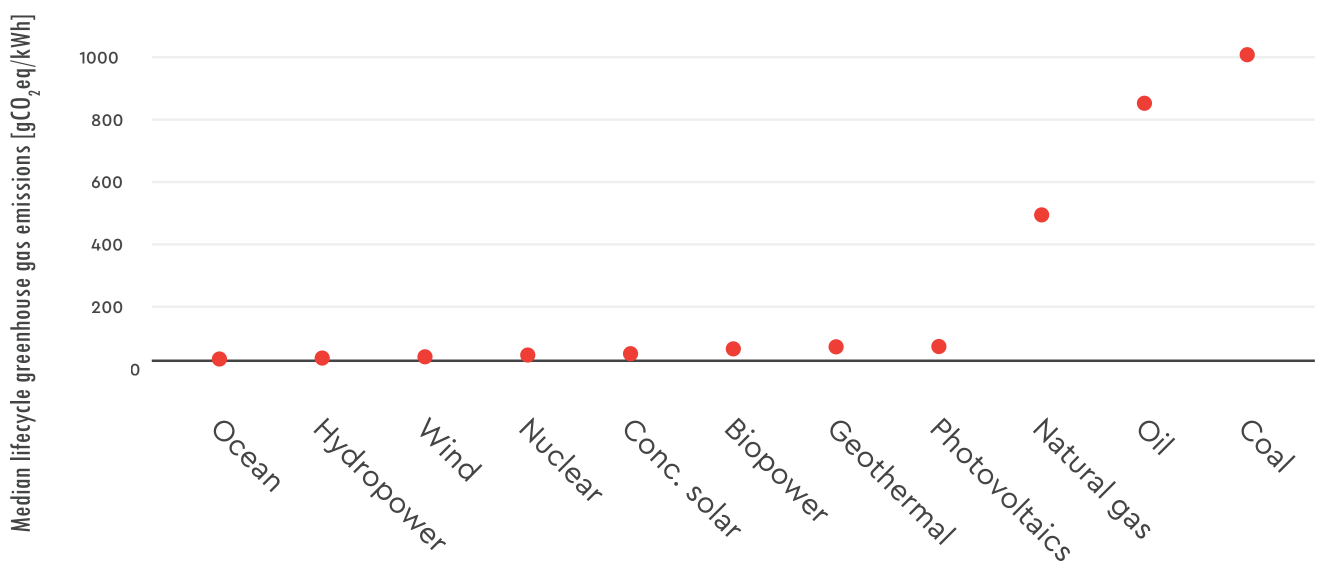

Figure 17: Emissions by energy source

Median CO_2 eq. emissions	Op.
0 to 250	cA
250 to 500	cB
500 to 750	cC
more than 750	cD

Then comes distance. Although regions and countries differ to a great extent in dimensions, it is a much easier input to follow than specific distance in kilometres. Also, regardless of the size of the country, going regional origin will always be safer than national or abroad.

P.Ip	Op.
Regional made	cA
National made	cB
Made abroad	cC
Not yet defined	Pending score

2. Relative Processing Embodied Energy (RPEE): Complexity arose when creating a scoring system for this Subparameter. There is no such thing as a value for "required processing energy" for each process. The fact that it depends greatly on which material is being processed is the obstacle in the simplification of this formula. Since this system sticks to the least possible amount of database sources[44] (to enhance reliability and consistency), I decided to use a parameter from CES/Granta edupack called "Material processing: energy" that gives -for a given process- a range of values for every eligible material. Considering the requirements for this parameter Level 2[6] Materials were chosen for this screening.

Consequently, I searched for the overall possible range of energy consumption among -virtually[7]- every material in every process and proceeded to set logarithmic intervals that score from 0 to 5 every given value of energy consumption. Energy consumption that is gotten from two inputs: process and material. When material is not yet defined (example: the case in which the designer knows it will be thermoplastic injection moulding, but does not know which thermoplastic) then the process average will be considered. On next chapter, calculations and intervals are properly explained.

P.Ip	Op.
Process	Average processing value
Process and material	Average processing value @ material

6 This database (Level 2) is aimed at more advanced introductory courses that involve project work. It contains a comprehensive set of mechanical, thermal and electrical properties, as well as Eco Properties and Durability Information, for more than 100 common materials. The materials and the content of the records were chosen by the Granta team in collaboration with our users to enable a wide range of selection studies and environmental audits of products.

7 Why virtually: some highly technical materials are sorted out, and always in Level 2.

Energy consumption	Argument	Interval/Score
0 to 1	0	5
1 to 1.6	0.2	4.5
1.6 to 2.5	0.4	4
2.5 to 4	0.6	3.5
4 to 6.3	0.8	3
6.3 to 10	1.0	2.5
10 to 15.8	1.2	2
15.8 to 25.1	1.4	1.5
More than 25.1	1.6	1

3. Lifespan / repairability: The simple fact that a made-to-last object can reduce to half the impact than one that last half the time makes this condition critical, and extremes values from the range of options should have a consistent difference.

The same 5-point guideline used for evaluation will be presented to the user to guide them through the right answer.

P.Ip	Op.
Made to last	cA
Average lifespan	cB
Short lifespan	cD
Not yet defined / Unknown	Pending score

4. Distribution
4.A Distance: Keeping the same considerations as in 1E (Material Origin), this kind of distance is most likely to remain unknown even after production. Therefore coefficients between best and worst case scenarios are kept close.

P.Ip	Op.
Regionally distributed	cA
Nationally distributed	cB
Distributed abroad	cC
Not yet defined	Pending score

4.B Package size: As a low-incidence subparameter, similar coefficients are assigned for good and bad scores.

P.Ip	Op.
Responsible	cA
Conventional	cB
Not yet defined / Unknown	Pending score

5. Added value: As a socio-economic aspect, scoring options are 1, 0.5 or 0.

This subparameter is the last from three in the whole system that provides feedback for the evaluation of socio-economic sustainability.

P.Ip	Op.
Definitely yes	+1
To some extent	+0.5
No / unclear	+0

Defining the function w(x) for weighted averages

In line with the overall criteria stated in page 24, "punishing" unsustainability is achieved by weighting parameters with a negative-pitch exponential function where weights rise rapidly as scores decrease. The weighting function is set to normalize sustainability and highlight the lack of it. This way, when doing a weighted average, if x parameter scores of 5 out of 5 (completely sustainable), then w_x -the weight for x parameter- equals to 1. On the contrary, if y parameter scores 1 out of 5 (very harmful), w_y -the weight for y parameter- equals to 5. Both score and weight values range from 1 to 5 (fig. 18).

$$w(x) = \frac{2}{3}^{x-5}$$

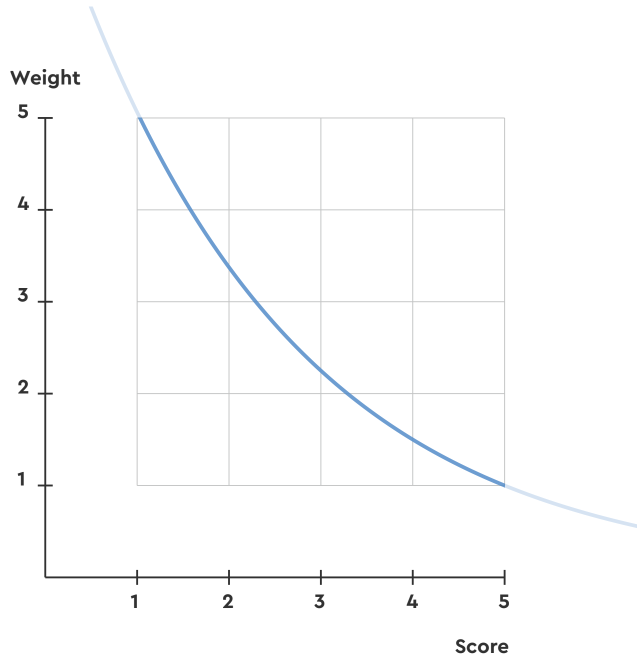

Figure 18: Weight function w(x)

Such function and graph being:
The weight (w) for the perfect score (x=5) equals to 1.
The weight for the worse score (x=1) equals to 5.
Math details are explained in next chapter.

As an example, may us consider a project with 5 parts, from which 4 score 5 points (as x parameter from previous paragraph), and 1 scores 0.5 points (as y parameter from previous paragraph).

Case A
With a conventional non-weighted average of these 5 parts, the result would be 4.35. The bad score is absorbed by the many perfect scores from the rest of the parts.

Case B
With a weighted average of the same 5 parts, the result turns out to be 2.9. It is clear how the good scores are less relevant in the result.

Chapter 2 / **Calculations**

2.1_ Choice of cluster, where to start?

To achieve immediate results on a beta version, it was decided to generate (in an initial stage) the guide for a limited type of products. By narrowing the target product, the focus achieved is deeper and more precise. Creating a guide from scratch for every possible product in the universe, would mean to literally include every material, location, process, characteristics, etc.., existing nowadays in the database. And although the final scope is to eventually get there, **starting from one small one segment will work as a starting test** for the system.

To select one segment (cluster) two aspects were considered as requisite:

1. It must be composed by products from **non-specialized industries**. The more engineering it needs, the more likely it is to be designed and engineered by big teams of experts, who most probably won't need this guide, as advanced and specific softwares replace its function. Instead, products from **smaller markets**, will probably employ less personnel to develop.

2. It must be a product with **quantifiable and open (or at least easy to estimate) values**. For instance, high-tech objects are hard to virtually dismantle to get quantities/ processes for every material involved. Whereas a wooden chair is much easier to analyse in terms of physical composition.

Special considerations:

Since this guide is mainly **aimed for the pre-engineering stage of the development**, every aspect taken into account for a given target will be a prior estimation. This means that a more complex product will be harder to estimate, and therefore less precise at the evaluation. Although this was not considered as a requisite, it for sure helped in choosing the segment.
A second consideration was to praise **objects that have more chances of being targeted by the guide**, due to current trends, batch sizes, or even those products belonging to more polluting sectors. Choosing martian rovers would result in a very limited reach.

Benchmark

After planning the search, I started to group objects into different clusters. I then crossed out those clusters from high-specialized industries, including a big part of transportation (mostly self propelled vehicles), medical, construction, industry, domestic appliances, computing, sports industry, and many more. As stated on requisite 1, these industries are equipped with state of the art technology and a lot of know how on what they do, and are able to self evaluate their projects with no further need for aid. Some other segments instead, were pointed out as potential candidates for the choice of the first cluster. These were:

A. Furniture, illumination and interior design: although there are many big companies on this market, there are also a lot of inexpert designers on stake.

B. Man-powered transportation: skates, scooters or bicycles definitely belong to a stable and promising trend. Clean transportation design will probably grow steadily for many years. Trends apart, these objects are usually simple (few components), and made by a limited number of materials and processes.

C. "Small technology": I am using this tag on hand-size objects which although are characterised by electrical components, usually have innovative shells, covers, or buttons. Examples include: bluetooth speakers, mouses, headphones, phone covers, power banks or various type of gadgets. The majority of the design interventions on this segment is made in injection moulded plastic, which results in a **not ideal cluster** for analysis.

D. "Small products": Again, this is an invented category, and includes a lot of iconic designs. Original developments of things you might find on your house like dishware, toys or board games, decoration (candles, coasters, etc..), pens, notebooks, or even a toothbrush. Sometimes more performing objects like a sport helmet, innovative footwear, wooden sunglasses. I found that a considerable amount of such developments are carried up by **start-ups or small companies, which is ideal for the scope of this chapter.** Furthermore, I used design portals (such as DEZEEN, yanko design) that post original projects everyday to see what is being designed, and published. And for sure most of the posted designs in every site belonged to this cluster. One potential drawback about this cluster is that is frequently composed by products that belong to non existent segments, so comparisons with competitors might be hard or impossible to execute.

To better analyse each option I proceeded to make a very brief (merely components and material family) case study of each of the mentioned clusters (A, B, C and D) to have a better perception of their suitability. Since the guide will be developed on a further stage, I will limit myself to try and search as many information as possible from each case study. The quality and quantity of the information gathered will be relevant for the choice of the cluster.

*The data will be invented when not available, since this is a simulation as if I were designing the following objects. In that case, I would have more detailed information.



Examples for each segment

Case study A:

Meringa ceiling lamp, by Servomuto. Handmade in Milano.
Parts: lamp shade, lamp socket, cable, ceiling rose.

Lamp shade is made of linen (x m^2) and steel wire (x m).
Lamp socket is a buy piece, containing plastic and metal components.
Cable has copper and a specific thermoplastic insulation.
Ceiling rose is made of painted iron metal sheet.
Processes involved: tube bending, manual sewing, spinning and painting.

Case study A

Case study B:

Wooden Bike, by Paul Timmer. Handmade in Amsterdam.
Parts: several wooden beams (forks, frame, chassis), seat, wheel rims, tyres, disc brakes, brake cables, brake levers, fixed gear, pedals, rubber belt (transmission), several custom joints.

Wooden parts are ash carved beams (x m).
Seat is made of synthetic materials, thermoplastic, and steel frame.
Wheel rims, brake levers, pedals, and custom joints are aluminium made.
Disc brakes are made of steel alloy.
Rubber belt is, of course, made of rubber.
Processes involved: wood cutting and carving, injection mould, lathing/spinning, die casting, 3d printing, others unknown.

Case study B

Case study C:

Gomi Speaker, by Gomi. Semi-industrially made in Brighton.
Parts: Three plastic components, speaker cones, docks, boards, other electrical components.
Plastic components are made of locally sourced LDPE waste.
Technical components have many materials, among them metals, plastics, ceramics.

Processes involved: hand-marbled plastic forming, unknown technical components processes.

Case study C

Case study D:

Scribit Pen, by Carlo Ratti Associati, handmade in Torino.
Parts: cartridge, barrel and cap.

Cartridge is made of a biodegradable composite made of natural fibres polyhydroxybutyrate (PHB).
The barrel can be made of compostable material, bioplastic or aluminium.

Processes involved: Press moulding and injection moulding.

Case study D

Benchmark results:

The conclusion after this brief case study is the following:
For segment A, the market is dominated by big companies. Although a lot of small companies project designs, it was not found as the most suitable segment.
For segment B, the market seems better distributed among brand sizes. The eventual drawback is the number of buy components, which are usually very hard to trace -not only geographically but also in terms of certifications, materials and processes-.
For segment C, as predicted, the problem is the same as for segment B but in a bigger degree. There are -if any- usually just three or four "designed" parts
For segment D, a lot of interesting products were found. Most of the products are technologically simple, with traceable materials and not outsourced production.

Any of the following exemplifications will belong only to Segment D.

2.2_ First approach

Environment:

The formula composition stated in chapter 1.3 (Weighting parameters) is mathematically composed as:

$$OVERALL\ SCORE = W_{M\&P} \cdot LIFESPAN \cdot DISTRIBUTION \cdot ADDED\ VALUE$$

Figure 19: Equation A

Where OVERALL SCORE is the final environmental analysis of the project's sustainability (figure 19). Lifespan, Distribution and Added Value are all Parameters defined and weighted in chapter 1. The function w(x) is used to get the individual weight of every argument when doing weighted averages (identified with a "W"). $W_{M\&P}$ is the weighted average of

$$W_{M\&P} = \frac{\sum w_i x_i}{\sum w_i}, \quad \frac{w_{MATERIAL} x_{MATERIAL}\ 0.7 + w_{PROCESSING} x_{PROCESSING}\ 0.3}{w_{MATERIAL} + w_{PROCESSING}}$$

Figure 20: Equation B

$$W_{MATERIAL} = \frac{\sum w_i x_i}{\sum w_i} \quad , \quad W_{MATERIAL} = \frac{w_{m1} x_{m1} + w_{m2} x_{m2} + w_{mn} x_{mn}}{w_{m1} + w_{m2} + w_{mn}}$$

Figure 21: Equation C

the composed Parameters: Material and Processing. $W_{MATERIAL}$ weighs 70% and $W_{PROCESSING}$ weighs 30% (fig. 20). $W_{MATERIAL}$ is obtained after a weighted average of each individual material score (there is one for each part) (fig. 21). Each individual score (called X_{mn}) is obtained after multiplying the scores of RMEE, Recyclability, Renewability, Certification and Origin (fig. 22).
$W_{PROCESSING}$, as that of materials, is obtained after a weighted average of each individual processing score (there is one for each process) (fig. 23). Each individual score (called

$$x_{m1} = RMEE \cdot Recyclability \cdot Renewability \cdot Certification \cdot Origin$$

Figure 22: Equation D

$$W_{PROCESSING} = \frac{\sum w_i x_i}{\sum w_i} \quad , \quad W_{PROCESSING} = \frac{w_{p1}x_{p1} + w_{p2}x_{p2} + w_{pn}x_{pn}}{w_{p1} + w_{p2} + w_{pn}},$$

Figure 23: Equation E

X_{pn}) is obtained through two different ways, depending on the amount of inputs. When only the process is filled in, then the value is the average of all materials processing energy at the given process. When also the material being processed is filled in, then the used value is the processing energy for that material at that process (fig. 24)

$$RMEE = RMEE_{Mat.} \cdot RMEE_{R.M.}$$

Figure 24: Equation F

Among the subparameters that compose Material, Relative Material Embodied Energy is a multiplication between Material (called as $RMEE_{Mat.}$) that is ranged from 1 to 5, and the coefficient of Relative Mass (called as $RMEE_{R.M.}$).

The parameter Distribution is a multiplication between Distance (called $DIST_{Dist.}$) and Package Size ($Dist_{P.S.}$) (fig. 25).

$$DISTRIBUTION = DIST_{Dist.} \cdot DIST_{P.S}$$

Figure 25: Equation G

Equations A to G (fig. 19 to 25) are present in the prototype, and represent the multiplications, addings, and other math operations that compose the main formula. But many other minor operations are also performed and yet not visible in this chapter due to presentation reasons. Many averages or sums are held in the prototype, and adding all of those, in this format, in this chapter is of little use. However, the prototype is attached as auxiliary file, where everything is present and working.

2.3_ Possible platforms

A crucial part of designing the system is thinking how to be reached by users. Different platforms have their respective advantages and disadvantages (fig. 26). Websites, mobile apps and a running software were evaluated and compared under four parameters:

	Website	Mobile APP	Software
User friendly interface	★★	★★★	★
Ease to develop	★★★	★★	★
Function capabilities	★	★★	★★★
Ease to keep updated	★★★	★★	★★

Figure 26: Platform comparison

User friendly interface

Since the system is based on the ease of its experience, the way the user approaches and engages with the inputs is fundamental. Both website and apps are easy. Apps can offer a much more intuitive interface, as they generally operate through touch screens and gestures. On the other hand, websites offer a faster experience sin there is no need to download any program (or app). A software instead remains relatively annoying, since an even more complex download is required, and then probably the interface requires some basic knowledge to cruise on.

Ease to develop

This is probably the least relevant, as it will impact only in the budget, and not in the experience. Websites and apps are nowadays easier to develop, even without deep programming knowledge. A full software stays again behind the first two platforms.

Function capabilities

Depending on how complex the system will turn to be, in terms of added functions, plug ins, or any extra feature, the platform may need to be versatile and eventually powerful. At this point a software can achieve much more. There are virtually no limits on what can be done in terms of personalised menus, data and files management, interface capabilities, etc..

Ease to keep updated

Since database and eventual formula-readjustments might evolve in time, the system should offer be easily updated by programmers. Website scored the highest just due to the fact of not being something that is downloaded, but rather accessed via internet browser. In mobile apps or softwares, every new version would have to be updated -either through a updater manager or through a new download.

Conclusion on platforms

It is hard to define how complex the system will really be once fully developed, and therefore to set priorities and requirements for the platform. As an estimation, I consider that the *Function capabilities* do not need to be state of the art, while *User friendly interface* does. Consequently, developing a dedicated software might not run as the first option, whereas Mobile APP ranks high in intuitiveness and Website in simplicity.

2.4_ Prototype and Case study

On this chapter, screenshots of the spreadsheet where all the formulas are applied are shown and explained. The spreadsheet, composed by rows and columns filled with text and formulas, is called Prototype, since it is the working principle of the system. This is by

					ENVIRONMENTAL	SOCIO-ECONOMIC
	Part 1 Material	1.A	RMEE - Material	Brick	4.0	
			RMEE - Relative mass	Below average	1	
		1.B	Recyclability	Not recyc. and not biodeg.	0.92	
		1.C	Fossil or ren.	Fossil	0.96	
		1.D	Certifications	Fair Trade	score ENV [cx]	score SE
				None	1	1
				None		
				Not yet defined		
		1.E	Material origin	France	0.99	
			Material distance	Reg	1	
		1		Part 1 score	3.512117997	1
	Part 2 Material	1.A	RMEE - Material	Concrete	5.0	
			RMEE - Relative mass	Below average	1	
		1.B	Recyclability	Either recyc. or biodeg.	0.96	
		1.C	Fossil or ren.	Fossil	0.96	
		1.D	Certifications	Fair Trade	score ENV [cx]	score SE
				FSC	1	1
				EU Ecolabel		
				Not yet defined		
		1.E	Material origin	France	0.99	
			Material distance	Reg	1	
		1		Part 2 score	4.581023475	1
MATERIAL				Material score (weighted average)	3.93	1
	Proc. 1	2.A	RPEE - Process	Coarse machining	4.5	
			RPEE - Material being processed			
		2.B	Process certifications			1
				Process 1 score	4.5	
	Proc. 2	2.A	RPEE - Process	Coarse machining	4.5	
			RPEE - Material being processed			
		2.B	Process certifications			1
				Process 2 score	4.5	
PROCESSING				Processing score (weighted average	4.5	1
		3	Lifespan	Average	0.96	
LIFESPAN				Lifespan score	0.96	
		4.A	Distance	Reg	1	
		4.B	Package size	Responsible	1	
DISTRIBUTION				Distribution score	1	
		5	Environmental added val	Yes	1	
			Socio-econmic addev val	Yes		1
ADDED VALUE				Added value score	1	1
				Final score	**3.93651675**	**3**

Figure 27: Prototype screenshot, overall view

no means the way the user will interact with it. A more studied and better looking interface (UI) would handle the inputs shown in this chapter, and it is presented in the following chapter (Chapter *2.5 Mock-up*). Also, the way the shown project is filled in is completely arbitrary and does not correspond to any real project.

To start with (fig. 27), all the parameters and subparameters compose the two sustainability evaluations (environmental and socio-economic). Shown in green cells are those inputs that the user can fill. In the same column, some elements have no green background, and those are the parameters that are filled in automatically depending on other input (i.e. 1B Recyclability is filled automatically and according to the database after filling the material in 1A RMEE – Material). To the right in the following column, the environmental score, and further more to the right, socio-economic score. From top (Material) to bottom (Added value), all parameters are involved to reach to the final score, using mathematical operations explained in *Chapter 2.2 First approach*.

Still in figure 27, the two yellow rectangles spot out two material scores. This situation would happen if the project has two different processed materials, but could have more or less components. And the prototype shows how each material has its own properties and partial score. In this case, those scores are "Part 1 score" and "Part 2 score", and inside the red rectangle, the weighted average of both of them, obtained by a weighted average between all individual material scores (in this case only two).

Inside each individual material score there are five components, some of them composed by more than one element, and were all explained in Chapter 2.2 First approach. Yet, it might be more simple to understand the way the score is composed by watching figure 28.

				ENVIRONMENTAL	SOCIO-ECONOMIC
Part 1 Material	1.A	RMEE - Material	Brick	4.0	
		RMEE - Relative mass	Below average	1	
	1.B	Recyclability	Not recyc. and not biodeg.	0.92	
	1.C	Fossil or ren.	Fossil	0.96	
	1.D	Certifications	Fair Trade	score ENV [cx]	score SE
			None	1	1
			None		
			Not yet defined		
	1.E	Material origin	France	0.99	
		Material distance	Reg	1	
	1		Part 1 score	3.512117997	1

Figure 28: Prototype screenshot, Material Part 1

For subparameter 1.A RMEE, or relative material embodied energy, a dropdown menu allows the user to choose from the 69 available materials plus 8 material families (fig. 29), and as seen on the column to the right, this score is not a multiplier (that range from 0.7 to 1), but a grade interval (that range from 1 to 5). No socio-economic evaluation belongs to this component.

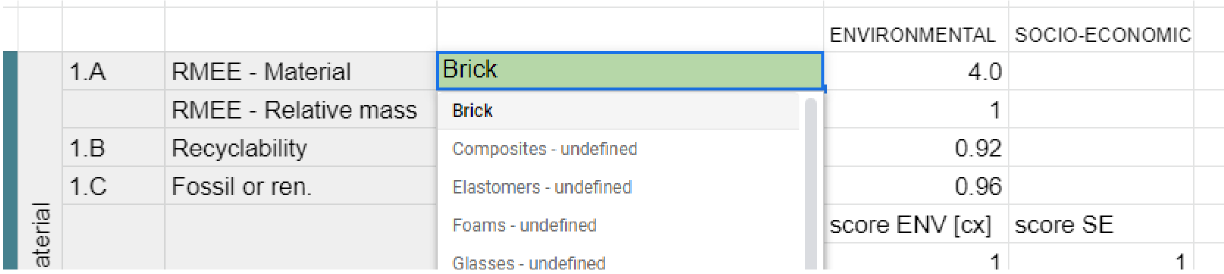

Figure 29: Prototype screenshot, dropdown menu for RMEE Material

The second component of RMEE is relative mass, that works as a multiplier and has three possible options. Again, it is set as a dropdown menu (fig. 30).

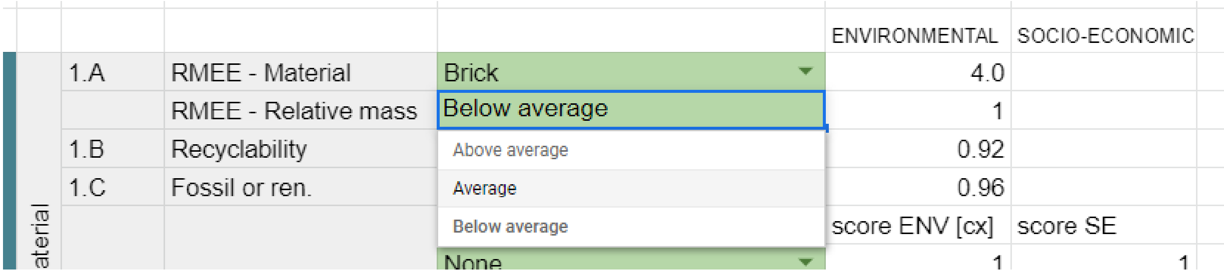

Figure 30: Prototype screenshot, dropdown menu for RMEE Relative mass

Both 1B Recyclability and 1C Renewability are not filled by the user, but depend on previous inputs and a database lookout formula. 1D Certifications on the contrary, has four gaps where the user can add certifications (fig. 31). Depending on the title, they might score for environmental or socio-economic, and in different degrees (Chapter 2.2 First approach for more details).

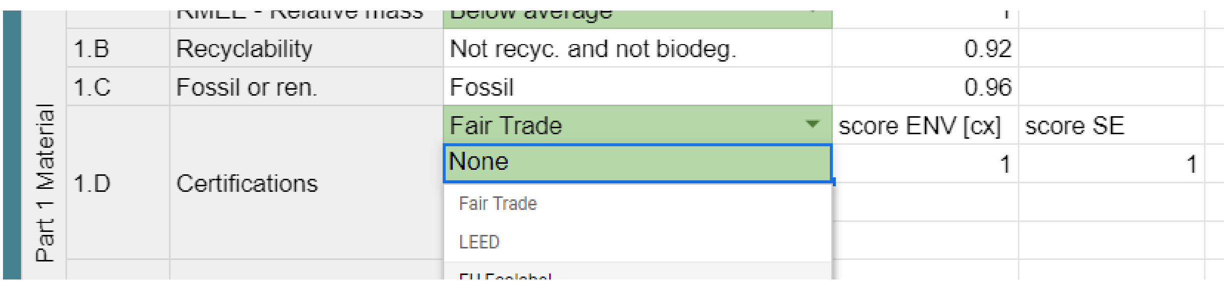

Figure 31: Prototype screenshot, dropdown menu for material Certifications

For 1E Material origin, two multipliers need to be filled in. The dropdown menu is again, as always, the way to insert data (fig. 32). In the prototype, only 6 options have been provided, since a scoring based on energy matrix and energy source scoring was made for each case study. Material origin is filled in the same way (fig. 33). Both Material origin and Material distance are multipliers for the score calculation.

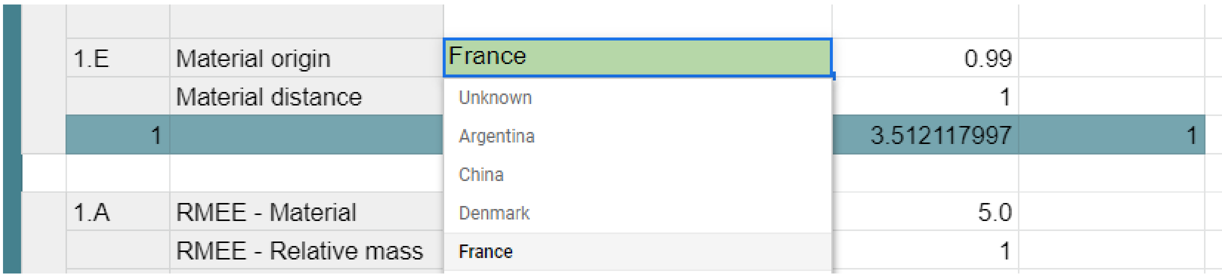

Figure 32: Prototype screenshot, dropdown menu for Material origin

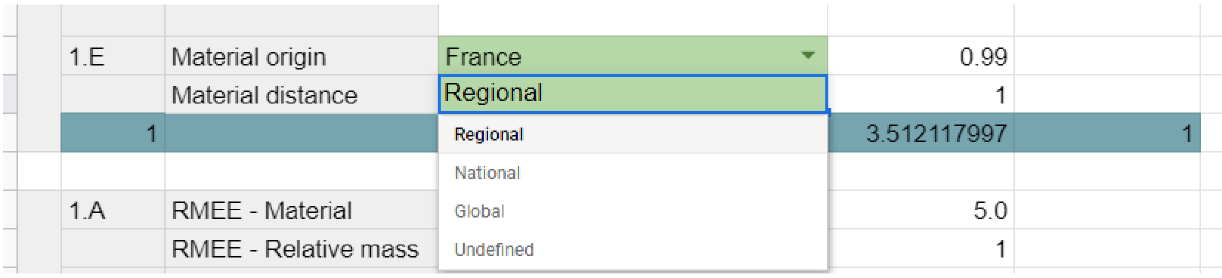

Figure 33: Prototype screenshot, dropdown menu for Material distance

After Material (that includes every part score -fig. 27-), Processing is the second parameter. Composed (blue rectangle in figure 27) by a weighted average by as many processes as the user considers, each individual process score (green rectangles in figure 27) is composed by three aspects, all of which are faced through a dropdown menu: RPEE Process (fig. 34), RPEE Material being processed (fig. 35) and Process certifications (fig. 36).

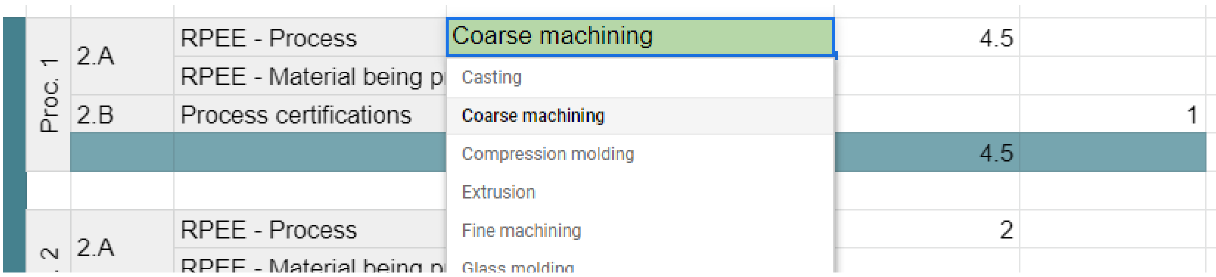

Figure 34: Prototype screenshot, dropdown menu for RPEE Process

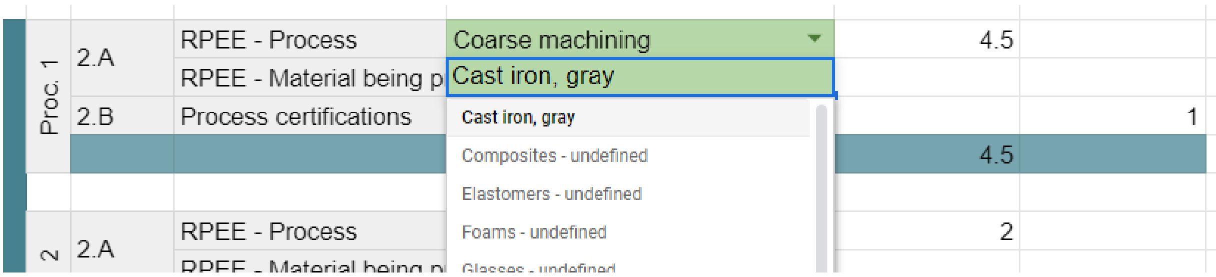

Figure 35: Prototype screenshot, dropdown menu for RPEE Material

The following parameter is Lifespan, whose value is set through the dropdown menu shown in figure 37.

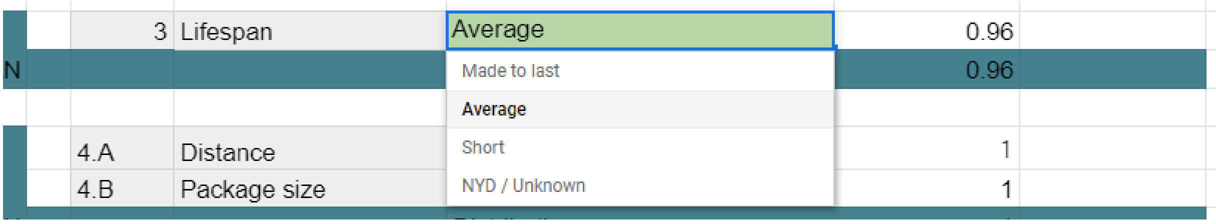

Figure 37: Prototype screenshot, dropdown menu for Lifespan

Distribution parameter has two subparameters that work as multipliers as well, Distance and Package size, and are shown in figure 38 and figure 39 respectively.

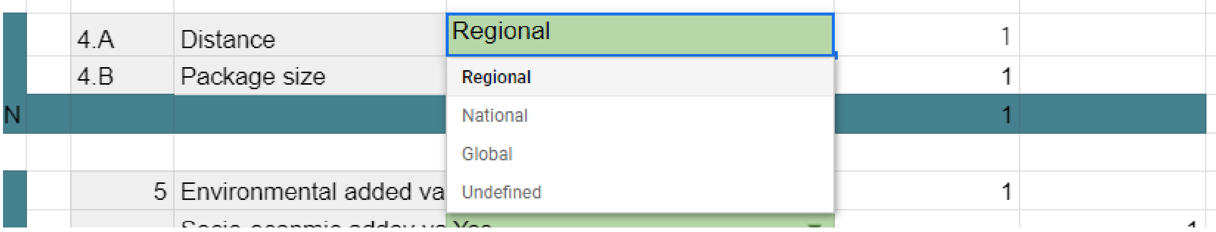

Figure 38: Prototype screenshot, dropdown menu for Distribution Distance

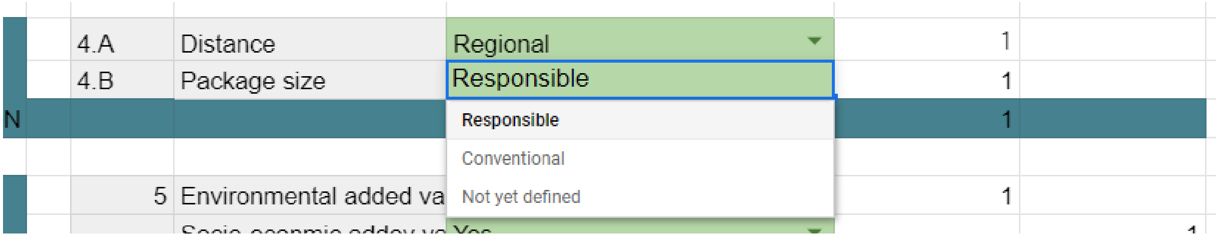

Figure 39: Prototype screenshot, dropdown menu for Distribution Package size

The last parameter, Added value is composed by two multipliers from dropdown menus: Environmental added value (fig. 40) and Socio-economic added value (fig. 41).

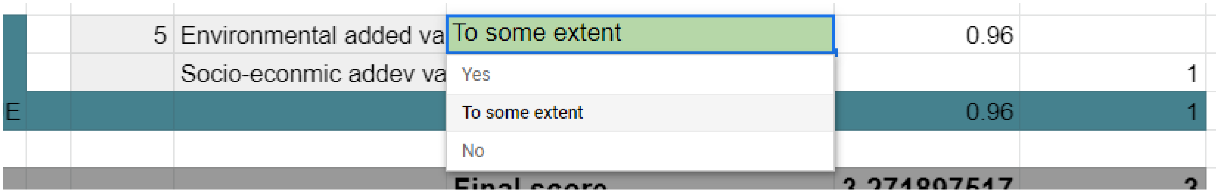

Figure 40: Prototype screenshot, dropdown menu for Environmental added value

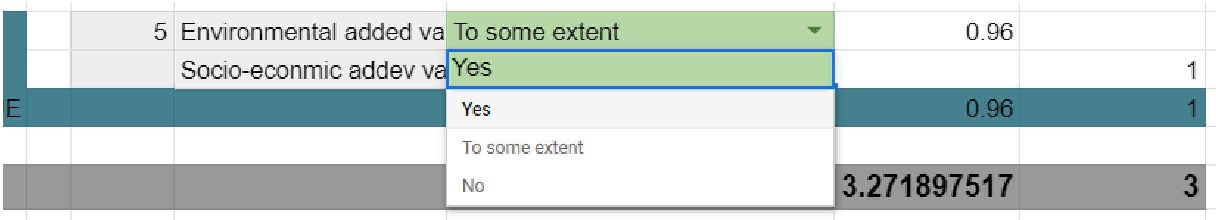

Figure 41: Prototype screenshot, dropdown menu for Socio-economic added value

After Added value, all the inputs are complete. Nevertheless, further screenshots of the prototype will show partly how it works to sort out some of the automatic parameters. However, the spreadsheet document is attached to the submission, where every single formula can be checked.

For the automatic inputs in materials (Recyclability and Renewability), a table was made with all the material options and respective qualities of each, including minimum, maximum and average embodied energy, recycle quality (T/F), biodegrade quality (T/F), and whether it is fossil or renewable. Then a formula VLOOKUP finds the row with the selected material (from the dropdown menu in figure 29) and takes their respective outputs (fig. 42).
For the scoring of energy (how much is used and how harmful it is at the way and place it

Cast iron, gray	30.8	34.0	32.4	3.0	TRUE	FALSE	Either recyc. or biodeg.	Fossil
Cellulose polymers (CA)	84.8	93.5	89.2	2.5	TRUE	TRUE	Recyc. and biodeg.	Renewable
CFRP, epoxy matrix (isotropic)	655.0	723.0	689.0	1.5	FALSE	FALSE	Not recyc. and not biodeg.	Fossil
Concrete	0.8	0.9	0.8	5.0	TRUE	FALSE	Either recyc. or biodeg.	Fossil
Copper alloys	61.4	67.7	64.6	2.5	TRUE	FALSE	Either recyc. or biodeg.	Fossil
Cork	3.8	4.2	4.0	4.0	FALSE	TRUE	Either recyc. or biodeg.	Renewable
Epoxies (EP)	122.0	135.0	128.5	2.5	FALSE	FALSE	Not recyc. and not biodeg.	Fossil
EVA	75.1	82.7	78.9	2.5	TRUE	FALSE	Either recyc. or biodeg.	Fossil
Flexible polymer foam (LD)	88.4	97.5	93.0	2.5	FALSE	FALSE	Not recyc. and not biodeg.	Fossil
Flexible polymer foam (MD)	86.0	94.8	90.4	2.5	FALSE	FALSE	Not recyc. and not biodeg.	Fossil
Flexible polymer foam (HD)	88.4	97.5	93.0	2.5	FALSE	FALSE	Not recyc. and not biodeg.	Fossil
GFRP, epoxy matrix (isotropic)	99.6	110.0	104.8	2.5	FALSE	FALSE	Not recyc. and not biodeg.	Fossil

Figure 42: Prototype screenshot, table, material data

is obtained), to be applied in Material origin, a table was made, defining grade categories for the complete possible range of values (fig. 43), and then the median emission value for each kind of energy source was assigned a different coefficient (fig. 44). Lastly, for every one of the six randomly chosen countries, a consolidated score was made, based on the percentage they employed different energy sources, known as energy matrix (fig. 45).
For processing embodied energy, a manually created table was made (fig. 46). Grabbing

	Value range	Coefficient
CO2 equivalent emissions	0	1
	250	0.96
	500	0.92
	750	0.88
	1000	0.84

Figure 43: Prototype screenshot, table, grading emissions

	Median emission	Coefficient
Biopower	32.5	1
Photovoltaics	40	1
Concentrating solar power	17	1
Geothermal energy	39	1
Hydropower	3	1
Ocean energy	0	1
Wind energy	7	1
Nuclear energy	14	1
Natural gas	462	0.96
Oil	820	0.88
Coal	1000	0.84

Figure 44: Prototype screenshot, table, grading emissions 2

	Biopow	Photov	Solar	Geothe	Hydrop	Ocean	Wind	Nuclear	N. Gas	Oil	Coal	Consolidated
Unknown												0.00
Argentina	1.24	0.57	0.00	0.00	20.01	0.00	3.58	6.08	65.12	2.51	0.91	0.97
China	1.44	2.45	0.00	0.00	17.07	0.00	5.07	4.09	3.28	0.15	66.44	0.89
Denmark	23.27	3.29	0.00	0.00	0.05	0.00	55.16	0.00	6.33	0.81	11.09	0.98
France	2.08	1.99	0.00	0.02	10.89	0.08	6.07	69.90	6.69	1.14	1.13	0.99
Germany	9.42	7.69	0.00	0.03	4.24	0.00	20.38	12.14	15.28	0.82	30.00	0.94
Italy	7.63	8.12	0.00	2.07	16.28	0.00	6.94	0.00	49.09	3.72	6.14	0.97

Figure 45: Prototype screenshot, table, energy matrix and consolidated score

data from Granta Edupack, the processing energy for a given material is only provided individually. Therefore that table was created putting all the materials in one row, and the processing energy range (minimum and maximum, and average was created in situ) for every process. After it, the average of each column also gave a more precise value for a given process.

Prototype comment

Since calculations are performed on a spreadsheet, not everything could be developed as it might be done in a proper platform. For example, the dropdown menu from "Material being processed" is currently showing every material from the database, while actually it should only show those materials available from the given process. In the hypothetical case that "Casting" is chosen as process, and "ABS" as material -a combination that does not exist, and whose cell in the table is therefore empty- the formula throws a *#N/A* problem, that then messes up all the score.
This and other problems make the prototype not robust enough, and demands specific inputs to perform properly.

Case study

	Casting			Coarse machining			Compression molding			Extrusion			Fine machining		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
ABS				11	12.2	11.6							5.76	6.37	6.065
Alumina				1.35	1.49	1.42									
Aluminum alloys	10.9	12.1	11.5							14.1	15.5	14.8	9.41	10.4	9.905
Aluminum nitride															
Bamboo				1.54	1.7	1.62							11.1	12.2	11.65
Borosilicate glass															
Brick															
Butyl rubber (IIR)															
Cast iron, ductile	10.5	11.5	11	0.966	1.06	1.013							5.37	5.92	5.645
Cast iron, gray	10.1	11.2	10.65	0.891	0.982	0.9365							4.62	5.1	4.86
Cellulose polymers (CA)				0.864	0.955	0.9095							4.37	4.83	4.6
CFRP, epoxy matrix (isotropic)							3.33	3.68	3.505						
Concrete															
Copper alloys	8.58	9.46	9.02	0.704	0.776	0.74				3.7	4.07	3.885	2.75	3.03	2.89
Cork				0.544	0.601	0.5725							1.16	1.28	1.22
Epoxies (EP)				1.49	1.65	1.57							10.6	11.7	11.15
EVA				0.72	0.796	0.758							2.92	3.23	3.075
Flexible polymer foam (LD)				0.48	0.53	0.505							0.522	0.577	0.5495
Flexible polymer foam (MD)				0.516	0.57	0.543							0.522	0.577	0.5495
Flexible polymer foam (HD)				0.48	0.531	0.5055							0.522	0.577	0.5495
GFRP, epoxy matrix (isotropic)							3.33	3.68	3.505						
Gold	6.02	6.65	6.335	0.565	0.625	0.595				1.49	1.65	1.57	1.38	1.52	1.45
High carbon steel	10.7	11.8	11.25	1.33	1.46	1.395				11.7	12.9	12.3	9.03	9.96	9.495
Ionomer (I)				0.63	0.697	0.6635							2.03	2.24	2.135
Lead alloys	5.16	5.7	5.43	0.498	0.551	0.5245				0.595	0.657	0.626	0.707	0.782	0.7445
Leather															
Low alloy steel	10.6	11.7	11.15	1.68	1.85	1.765				16.3	18	17.15	12.5	13.7	13.1
Low carbon steel	11.1	12.2	11.65	0.858	0.946	0.902				5.22	5.76	5.49	4.17	4.59	4.38
Magnesium alloys	10.6	11.7	11.15	1.25	1.38	1.315				12.4	13.6	13	8.26	9.1	8.68
Medium carbon steel	10.8	12	11.4	1.117	1.29	1.2035				9.63	10.6	10.115	7.48	8.25	7.865

Figure 46: Prototype screenshot, table, processing required energy at a given material

With the only scope to show how the scores are affected by different inputs, three scenarios with slight variations are exposed (all three could eventually belong to the same project). Scenario A has the worst score (fig. 47), scenario B is intermediate (fig. 48), and the scenario C is the best ranked (fig. 49). The environmental scores of scenarios A, B and C are 1.86, 2.29 and 3.41 (out of 5) respectively. The socio-economic scores of scenarios A, B and C are 0, 1 and 3 (out of 3) respectively.

Being aware of the problems mentioned in the previous section (Prototype comment), some processes may not correspond with materials in order to show a result regardless of the prototype flaws.

					ENVIRONMENTAL	SOCIO-ECONOMIC
	Part 1 Material	1.A	RMEE - Material	Brick	4.0	
			RMEE - Relative mass	Above average	0.92	
		1.B	Recyclability	Not recyc. and not biodeg.	0.92	
		1.C	Fossil or ren.	Fossil	0.96	
		1.D	Certifications	None	score ENV [cx]	score SE
				None	0.92	0
				None		
				None		
		1.E	Material origin	China	0.89	
			Material distance	Global	0.92	
		1		Part 1 score	2.454381119	0
	Part 2 Material	1.A	RMEE - Material	Wood, along grain	3.5	
			RMEE - Relative mass	Above average	0.92	
		1.B	Recyclability	Either recyc. or biodeg.	0.96	
		1.C	Fossil or ren.	Renewable	1	
		1.D	Certifications	None	score ENV [cx]	score SE
				None	0.92	0
				None		
				None		
		1.E	Material origin	China	0.89	
			Material distance	Global	0.92	
		1		Part 2 score	2.334329869	0
MATERIAL				Material score (weighted average)	2.40	0
	Proc. 1	2.A	RPEE - Process	Fine machining	2.5	
			RPEE - Material being p	Aluminum alloys		
		2.B	Process certifications			0
				Process 1 score	2.5	
	Proc. 2	2.A	RPEE - Process	Extrusion	2	
			RPEE - Material being p	Aluminum alloys		
		2.B	Process certifications			0
				Process 2 score	2	
PROCESSING				Processing score (weighted averag	2.224744871	0
		3	Lifespan	Short	0.92	
LIFESPAN				Lifespan score	0.92	
		4.A	Distance	Global	0.92	
		4.B	Package size	Conventional	0.96	
DISTRIBUTION				Distribution score	0.94	
		5	Environmental added va	No	0.92	
			Socio-ecnomic addev va	No		0
ADDED VALUE				Added value score	0.92	0
				Final score	**1.86539074**	**0**
					/5	/3

Figure 47: Prototype screenshot, scenario A

					ENVIRONMENTAL	SOCIO-ECONOMIC
	Part 1 Material	1.A	RMEE - Material	Concrete	5.0	
			RMEE - Relative mass	Above average	0.92	
		1.B	Recyclability	Either recyc. or biodeg.	0.96	
		1.C	Fossil or ren.	Fossil	0.96	
		1.D	Certifications	None	score ENV [cx]	score SE
				None	0.92	0
				None		
				None		
		1.E	Material origin	Germany	0.94	
			Material distance	National	0.96	
		1		Part 1 score	3.537881246	0
	Part 2 Material	1.A	RMEE - Material	Wood, along grain	3.5	
			RMEE - Relative mass	Average	0.96	
		1.B	Recyclability	Either recyc. or biodeg.	0.96	
		1.C	Fossil or ren.	Renewable	1	
		1.D	Certifications	None	score ENV [cx]	score SE
				None	0.92	0
				None		
				None		
		1.E	Material origin	China	0.89	
			Material distance	Global	0.92	
		1		Part 2 score	2.435822472	0
MATERIAL				Material score (weighted average)	2.83	0
	Proc. 1	2.A	RPEE - Process	Fine machining	2.5	
			RPEE - Material being p	Aluminum alloys		
		2.B	Process certifications			1
				Process 1 score	2.5	
	Proc. 2	2.A	RPEE - Process	Extrusion	2	
			RPEE - Material being p	Aluminum alloys		
		2.B	Process certifications			1
				Process 2 score	2	
PROCESSING				Processing score (weighted averag	2.224744871	1
		3	Lifespan	Average	0.96	
LIFESPAN				Lifespan score	0.96	
		4.A	Distance	National	0.92	
		4.B	Package size	Conventional	0.96	
DISTRIBUTION				Distribution score	0.94	
		5	Environmental added va	To some extent	0.96	
			Socio-econmic addev va	No		0
ADDED VALUE				Added value score	0.96	0
				Final score	**2.29393985**	**1**
					/5	/3

Figure 48: Prototype screenshot, scenario B

					ENVIRONMENTAL	SOCIO-ECONOMIC
	Part 1 Material	1.A	RMEE - Material	Concrete	5.0	
			RMEE - Relative mass	Below average	1	
		1.B	Recyclability	Either recyc. or biodeg.	0.96	
		1.C	Fossil or ren.	Fossil	0.96	
		1.D	Certifications	Fair Trade	score ENV [cx]	score SE
				None	1	1
				None		
				None		
		1.E	Material origin	Denmark	0.98	
			Material distance	National	0.96	
		1		Part 1 score	4.329718728	1
	Part 2 Material	1.A	RMEE - Material	Wood, along grain	3.5	
			RMEE - Relative mass	Below average	1	
		1.B	Recyclability	Either recyc. or biodeg.	0.96	
		1.C	Fossil or ren.	Renewable	1	
		1.D	Certifications	EU Ecolabel	score ENV [cx]	score SE
				Other socio-economic label	1	1
				None		
				None		
		1.E	Material origin	Italy	0.97	
			Material distance	Regional	1	
		1		Part 2 score	3.246012519	1
MATERIAL				Material score (weighted average)	3.63	1
	Proc. 1	2.A	RPEE - Process	Fine machining	2.5	
			RPEE - Material being p	Aluminum alloys		
		2.B	Process certifications			1
				Process 1 score	2.5	
	Proc. 2	2.A	RPEE - Process	Extrusion	3.5	
			RPEE - Material being p	Copper alloys		
		2.B	Process certifications			1
				Process 2 score	3.5	
PROCESSING				Processing score (weighted averag	2.9	1
		3	Lifespan	Made to last	1	
LIFESPAN				Lifespan score	1	
		4.A	Distance	Regional	1	
		4.B	Package size	Responsible	1	
DISTRIBUTION				Distribution score	1	
		5	Environmental added va	Yes	1	
			Socio-econmic addev va	Yes		1
ADDED VALUE				Added value score	1	1
				Final score	**3.410538282**	**3**
					/5	/3

Figure 49: Prototype screenshot, scenario C

2.5_ Mock-up

For further understanding, the system is presented as a mock-up on a mobile app. Although it should be further developed by a programmer, the basics of the layout is thought to be

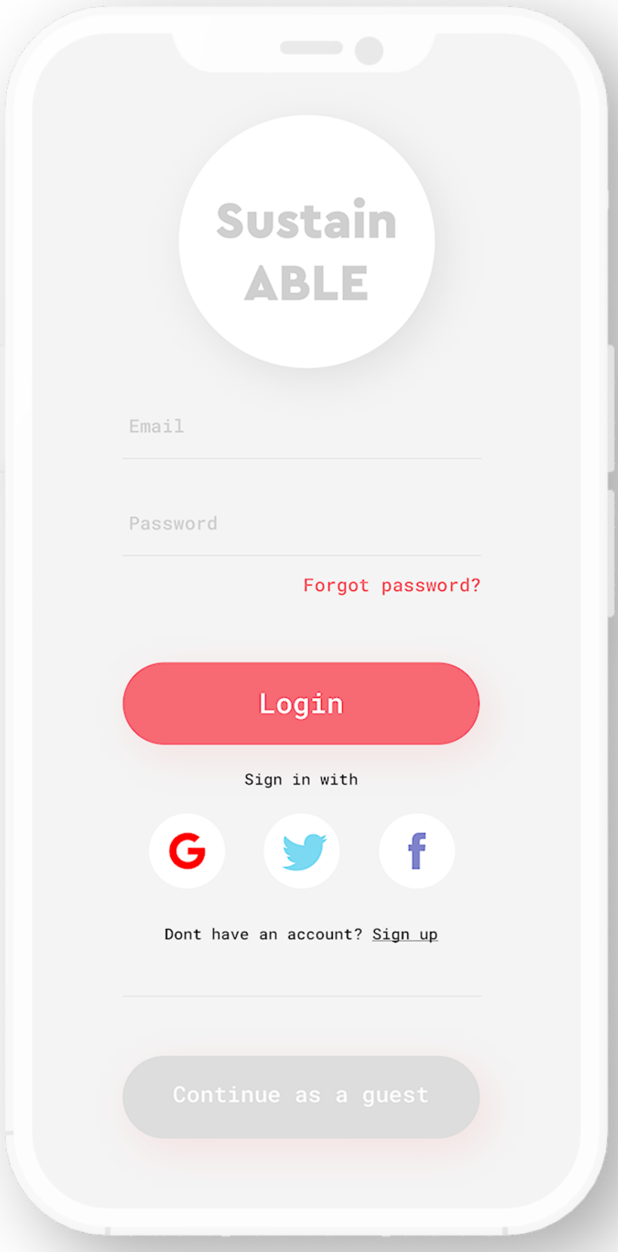

Figure 50: Mock-up, welcome screen

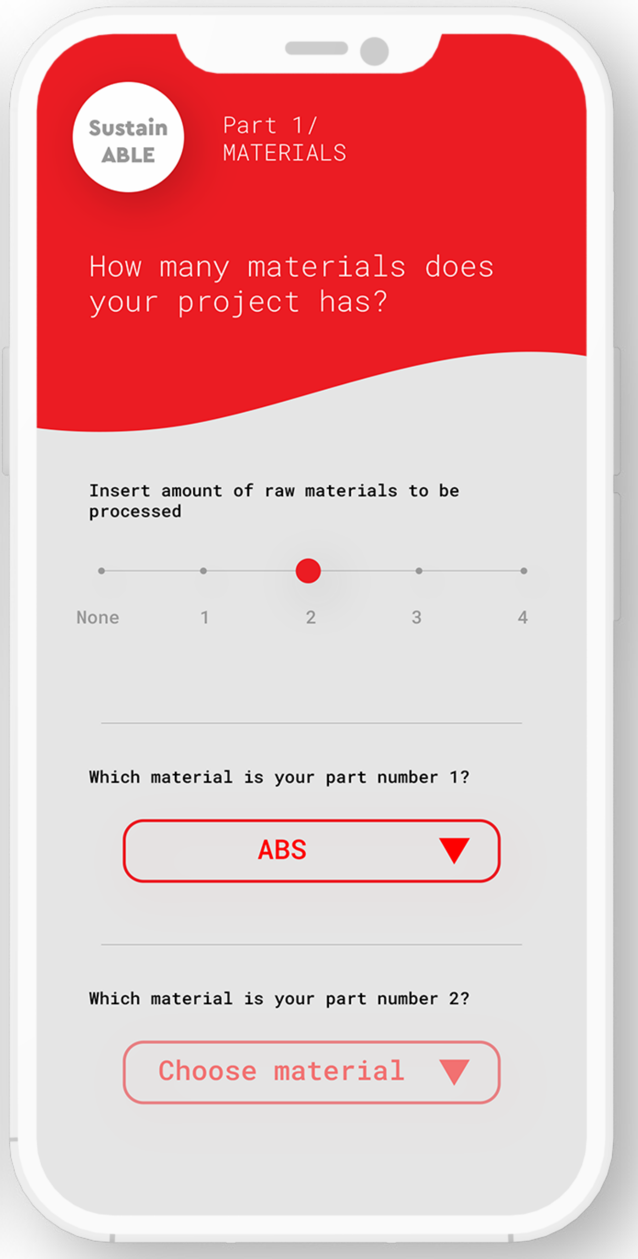

Figure 51: Mock-up, input screen

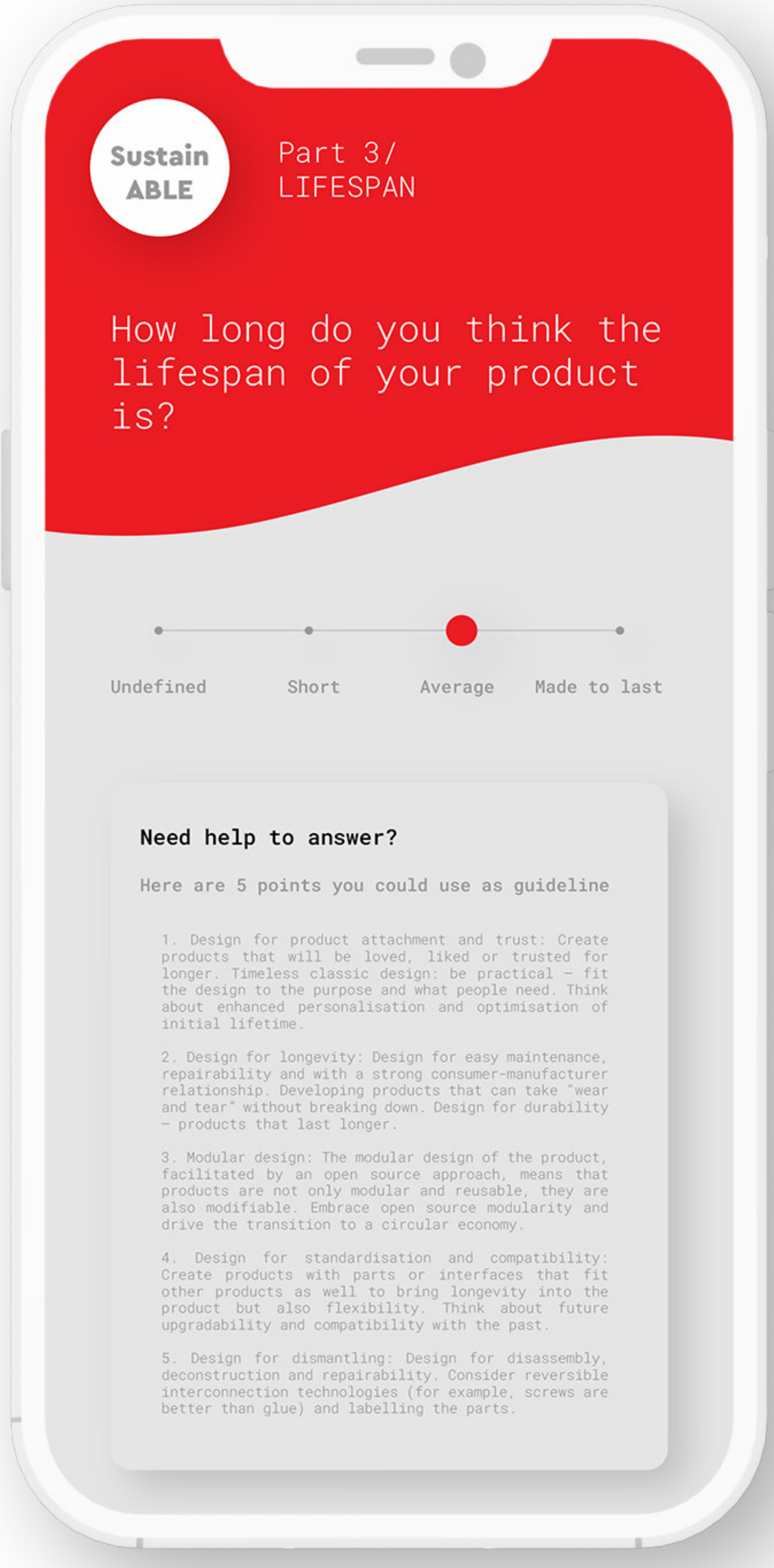

Figure 52: Mock-up, guided input

as in figures 50 to 53. The name SustainABLE is by no means the definitive name of the system, it was set to have any logo and better understand the UI as such.

As stated in chapter *2.3 Possible platforms*, it is undecided if a website or a mobile app is the most suitable platform, but since mobile apps usually have a more synthetic UI (interface) design. Consequently, a mobile mock-up was created.

A welcome screen (fig. 50) allows the user to sign in. After that, comparison between previous projects is enabled. Eventually sharing and exporting offers extra functionality.

Then, a generic input screen (fig. 51) shows two kinds of input entry: a slider and a dropdown menu. Since all the inputs are easy to fill, there is never the situation in which the user needs to write down numbers or information.

A guided input (fig. 52) shows how the system gives some guidance to the user to help they decide. The guidance is done through plain text. On certain situations, guidance is required because the user might be completely unaware of the subjects (as explained in chapter *3.2 Potential scopes*).

The last type of layout is for the final output of the system (fig. 53). A screen with overall scores of environmental and socio-economic sustainability evaluations. Since the quality of having a user-friendly input and output interface is key on the definition of the system, this last screen is of huge importance. The delivery must be accurate, instantly and visually clear in terms of how bad it is (this is addressed by having a mark out of 5 or 3), and then pedagogic by teaching and showing the user the weakest parameters of the project. The how-to-improve feature is done through a further click on the result. After that, the systems offers an overview of the chosen parameters, emphasising those whose impact is higher in the result.

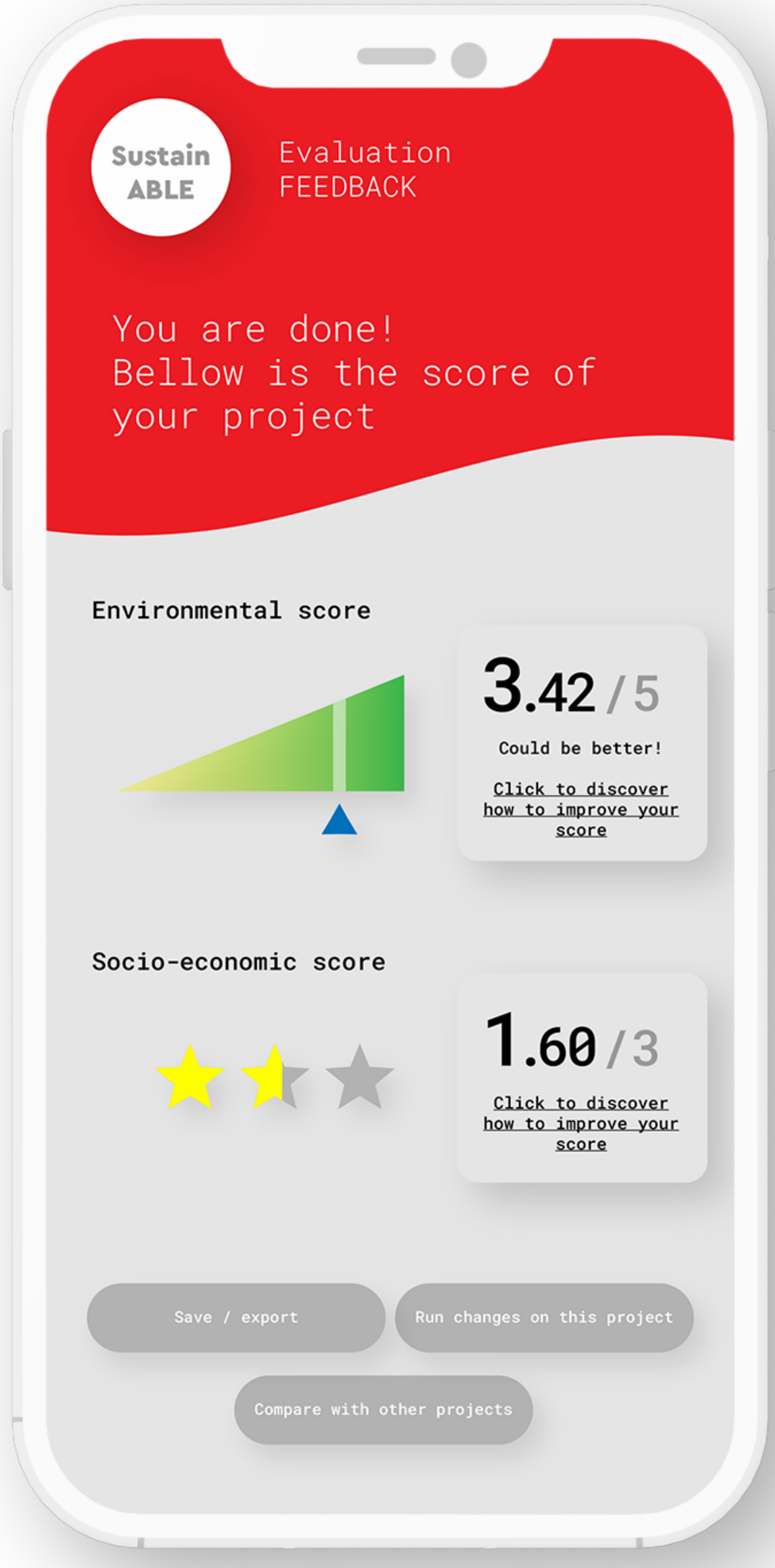

Figure 53: Mock-up, final evaluation screen

Chapter 3 / **Capabilities**

3.1_ Definition

Although it has been described and explained in different chapters already, it is of great importance to describe this system as it is, with all of its qualities:

- It is a system. Regardless of the final platform, it works as a system, a calculation device. Through inputs and formulas, this tool throws an instant result to the user.

- It evaluates sustainability. The system considers sustainability through two lenses: environmental impact, and socio-economic impact.

- It is user-friendly. The outputs of the system are orientative and relative. This means that the user gets a score from 1 to 5, that might be influenced by what is already on the market. No technical unit is given that requires specific know-how (such as a result in CO_2/g, which can be unclear to understand for many).

- It is aimed for evolving projects. Since it allows a different degree of vagueness in the inputs, users can take profit of it by running evaluations on -very- estimated parameters, compare, and then decide what is best. It runs short on evaluation for LCA for a completely defined compared with existing systems.

3.2_ Potential scope

Beforehand, it is worth to mention the phases achieved in this thesis, and those expected to be achieved in case of further development.

All the phases showed in figure 54 were preceded by the exploration of potential topics, always having sustainability as the core issue to address. A pre-benchmark was done before starting and choosing the ultimate plan, to explore feasibility and practicality. Some encounters with related professionals were held to get insights into usability and drawbacks of existing systems. Then I proceeded to start with the phases from the following figure.

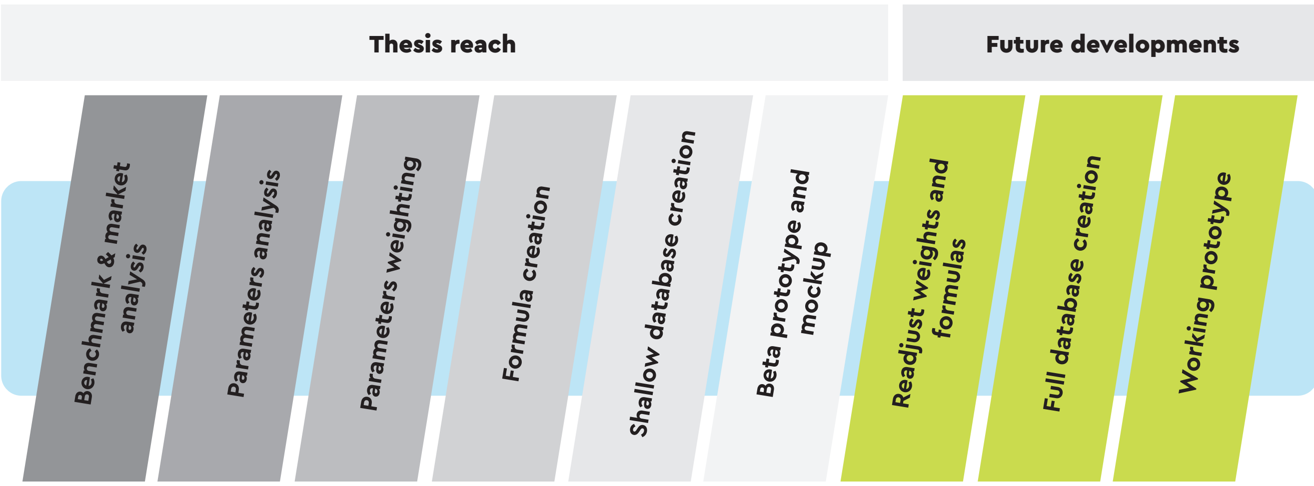

Figure 54: Development phases

In the case that this system turned out to be fully developed, it would have a huge aiding capacity in the design community (fig. 55). As stated in the introduction, the novelty is set to be in the type of the evaluation result. Not needing to have sustainability-related expertise is probably the biggest asset of this system and could therefore be utilised by:

A Students
As an educational pack suggested by universities or independently by students or people interested in it.

B Designers with undefined projects
Being this system very flexible with the amount of input you choose to insert allows

evaluation of both vague ideas or precise and defined projects.

C Non-expert designers
As a guide to follow, either permanently or as a way to learn how to evaluate projects to then proceed to do the assessment without further system assistance.

D Engineers or entrepreneurs
Or virtually any other area not related with design, in which user might need to take project decisions and need a fast and easy to read output.

E Others
Just users curious to know how many variables are there to evaluate sustainability in a project, willing to learn differences on decisions for personal interest.

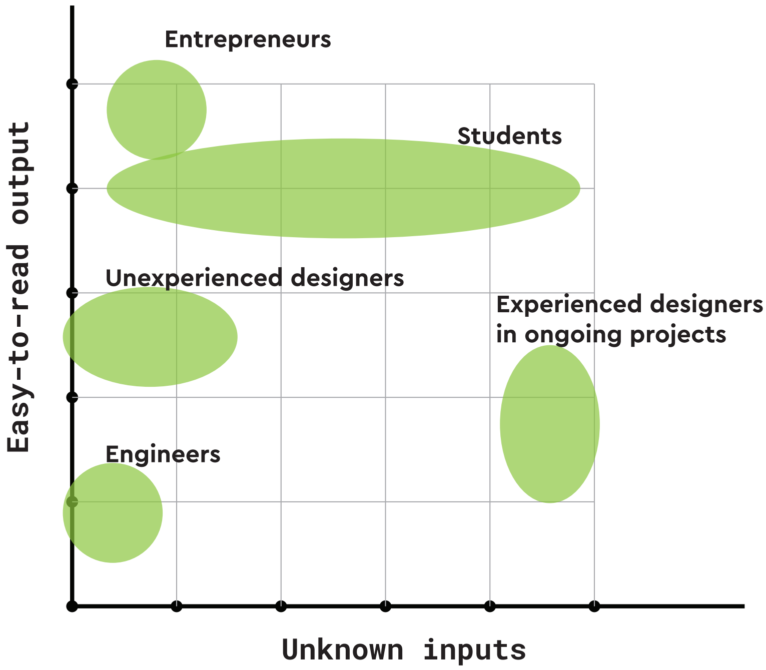

Figure 55: User scope

However, with fully developed databases and checked formulas, the same system once thought for ongoing projects, could then work perfectly for a full Life Cycle Assessment[1]

1 Life-cycle assessment or LCA (also known as life-cycle analysis) is a methodology for assessing environmental impacts associated with all the stages of the life-cycle of a commercial product, process, or service. For instance, in the case of a manufactured product, environmental impacts are assessed from raw material extraction and processing (cradle), through the product's manufacture, distribution and use, to the recycling or final disposal of the materials composing it (grave). Ilgin, Mehmet Ali; Surendra M. Gupta (2010). "Environmentally Conscious Manufacturing and Product Recovery"

(LCA). There are already several LCA softwares that work very well, but if LCA was incorporated as an internal module in addition to ongoing project analysis it would certainly be a novelty and a comparative advantage on the competitors. Also, a relative user-friendly output for LCA would also be of great use for user.

Possible addings to the system

While creating the system, some elements were dismissed not because they were inappropriate, but because they would imply an unnecessary amount of job done for a "Thesis stage". Knowing that, I consider that these elements should be considered to be developed and added to the system in any future development. These elements are considered in the three last phases from figure 54 but will be listed and explained up next.

1) Adding all processes to RMEE. So far, the only processes included where only the ones GRANTA Edupack has in the category "Material processing: energy", and add up to a list of mere 18 options. Adding more processes would have mean to add values from a different database, making a potential observational error.

2) Adding Level 2 Material to RMEE. The existing options for material choice, required to estimate Relative Material Embodied Energy, Material Recyclability and Material Renewability, are only from Level 1 category. Frequently, materials being defined at Level 1 are precise enough to allow the system to do proper estimations. Examples of this situation can be stainless steel, brick or bamboo, where the material properties are set in a small range of values, and most qualitative parameters such as renewability are defined. On the contrary, many polymers are hard to define beforehand, and the choice might not even exist in the Level 1 list. PLA for example is not available at Level 1, or whether to choose a renewable PE or conventional and fossil PE. Polyethylene is made out of ethanol, which can be made from various feedstocks including sugar cane, sugar beet, and wheat grain. The final product (polyethylene), has identical mechanical, recycling and processing properties to those of conventional polyethylene[45]. Knowing the formula and how multipliers work, choosing a renewable plastic over a fossil one may result in a wrong, or at least imprecise evaluation.

3) The same applies to material choices for the estimation of Relative Processing Embodied Energy, where the material being processed is so far only available at Level 1. Here the extra precision provided by Level 2 would have a lesser impact, as the lack of precision only affects one subparameter (RPEE) and in a smaller degree.

4) Energy matrix for every country and possible even regions needs to be created. The source found and used for the matrix creation for the six examples is reliable, user friendly, and updated frequently enough to remain useful. In more developed countries, specifying regions or provinces would add further precision for the evaluation.

5) Adding a sub-multiplier for both Material origin distance (1E) and Distribution distance

(4A) considering the country size and distances will also provide further precision. Having a product nationally distributed in Australia or in Switzerland have critically different implications.

6) As mentioned before, a Life Cycle Assessment plug-in module would be the proper way to evaluate, among other things, the lifespan of the product. Nevertheless, and according to the benchmark, existing LCA softwares proved to deliver results efficiently, so adding one as a side module would only make sense considering the final product as a sort of very complete software pack or suite.

7) Tooling recyclability: More than a process choice, this would depend in the material being processed, and geometric conditions of the part. For example, if a complex component is designed in aluminium, it will be most probably made by die casting process. Die casting moulds are steel made. On the other hand an injection moulded component with a small batch size might use an aluminium made mould. Since aluminium is easier (requires less energy) to recycle than steel, Tooling recyclability would be rewarded higher for an injection moulded part than for a die casted one. It has not been considered in this stage due to the complexity it requires for development. It implies many combinations between processes, materials, batch size, geometry and others. The database to allow a possible outcome for every input is out of my development reach.

3.3_ Required investments

Development:

There is a clear need for expert know-how to elaborate a system this ambitious. My scope was -and is- to show a correct approach on a global understanding for all the circumstances that surround every project, some of them usually forgotten. Although sharp accuracy and environmental engineering is needed to weight parameters, this first approach aims to give a panorama of how it can work.
Databases require completion and constant updates, and pragmatically speaking, they should be either license-free or rights-acquired by the system. So far a big portion of the values are gathered from Granta/CES Edupack which was legally accessible for me thanks to the student license.
Mathematics help may also be helpful to elaborate equations that behave precisely and more alike to what sustainable experts may consider adequate in terms of weighting and score behaviours.

Zeitgeist[1][46]:

As the thesis was developed, I realised how much of work would be needed to arrive to a hypothetical final -or commercial- output. The mere planification of which parameters to include, how to weight them, and how to put them altogether in one formula was a very complex task, that certainly remains unfinished. Everyday new parameters arise, better ways to make calculations, newer and improved certifications, new social problems to address or new game-changers manufacturing processes. Consequently, what was developed in this framework is just the best possible approach for the picture watched until 2021. Fortunately the picture evolves, and so will have to do this or every system claiming a holistic understanding of the time and context we live in. And in order to address that, constant updates are required.

Platform:

Whether it is an App (my first suggestion), a website or a dedicated software, programmers or IT experts are required for its creation and maintenance, and of course professional opinion on the platform choice.

1 The general intellectual, moral, and cultural climate of an era.

Chapter 4 / **Conclusion**

4.1_ Discussion & controversies

Several problems arose when trying to put all the parameters in one line of a math formula. To test it, I would change materials or parameters that I considered would have a great score, but the outcome of the evaluation would not be that high. One part of this is right, and implies an adequate reflection of how hard and complex it is to achieve complete circularity in production. There are so many -sometimes negligible- circumstances that can absolutely turn an overall responsible design in a relatively low score. In other words, to keep the perfect score, the product has to be completely sustainable in every aspect. And achieving that can be in most scenarios, and with the technologies available today, impossible. On the other hand, the complexity that surrounds sustainability makes it impossible to put it straight in numbers, because factors and parameters are not static and necessarily quantifiable. Frequently, a material can be an excellent choice in one process or country, and a terrible choice in others, and therefore the attempt to score elements from good to bad turns out to be, in many situations, wrong. However, the system prototype still provides a solid reference when comparing two projects, and the unstatic -or dynamic- quality of parameters could possibly be addressed by experts and put into equations.

Certifications have been an obstacle for the development of this system in almost every way. Deciding which certifications are trustworthy and which ones are lesser recognised as standard was based on the scale at which they operate (world wide or not, and everywhere or barely used), and subjective opinions from experts[32 33]. I consider this a weak, and to some extent arbitrary, method to proceed. In addition, certifications are just documents attesting to a status or level of achievement. Meaning that their presence certainly reflect something good. But their absence does not mean the opposite. Getting official Ecolabels or green certifications requires an economic investment: both to apply for the document, and normally also to set up -minor or greater- changes in the production process. Consequently, the absence of certifications can be an unfair score punisher, since the material or process could be as or more sustainable than a certified one. Next, the existing greenwashing in numerous labelling entities is clearly standing in front of transparency and evaluation ease. Labels do not always demand proper processes to get certified, and if they do, the extension in time may not be as precise as the initial certification. Companies can then get the certification and then smartly evade further inspections. Seals granting safe and sustainable fishing policies, for example, have had many controversies in the last year, since apparently some of them are absolutely unreliable.

Considering the carbon footprint was also problematic. The values given by databases rely upon median values from a big range of values. Adding a Material Origin Distance as a multiplier somehow addressed this point, but it is no near to solve it. The size of a country may as well lead to confusing results. Claiming that a material comes from the region -or equivalent organization unit- in Switzerland or in United States should not have the same multiplier. Quantifying the inputs is not straightforward, particularly in regard to the "system boundary". The energy-accounting includes transport, but should it also include the energy required to build the ship, truck or plane? And what about the energy to make the equipment that made the ship? That line of reasoning could go on forever and leads nowhere, so the system boundary is usually set at the first remove only: the energy to mine and transport the ores and feedstock, for example, but not that to build the equipment to do it. Even so, system boundaries are a source of uncertainty.

Following, some parameters offer values that are not to be compared, and yet, the objective of the system is to compare parameters by their value to get to a conclusion. That is the case, for example, for processing energy. Some processes' energy, like casting or polymer extrusion are measured by energy over mass of material processed [MJ/kg], while others, like grinding or machining, are measured by energy over mass removed [MJ/kg]. Although the unit is the same, putting those two type of values on the same scale to cast a ranking on which is better is absolutely wrong, and I found no way to solve this problem, except for making different parameters and separating them: one box to fill moulding processes and a different box for machining, grinding, or similar processes. The complexity obtained at the moment in which the user fills in the gaps would result in undesired experiences.

User inputs may as well bring problems. Parameters such as relative mass estimation, or expected lifespan can be easily miss-filled, specially when considering that the user target is often a non-expert profile.

And lastly, the social and economic sustainability remains as the ultimate problem for this system. Relativity, expertise and understanding on each specific society are the only way to understand how different situations alter their people and economies. Although socio-economic-oriented certifications develop criteria and assessment to specifically evaluate this, scoring a project by the mere presence or absence of these labels is at the very least fragile.

Personal thoughts:

While elaborating the system and thesis, I wondered at every single moment -and still do-, if it would be worth carrying out a further development of it. The answer for that has been constantly changing from yes to no. The initial approval was given by the conviction of how useful it would be for so many people, but that thought was slowly replaced by the idea that instead of "so many people", the target would be specific.

The problems I encountered, stated in the previous section of this chapter, are *considerable, but not irresolvable. I think they belong to a type of problem that arises in regular conditions of research, they are unconsidered obstacles, but nothing big enough that could refute the ultimate objective.*

I consider this system to be truly valuable for specific users, and worth enough to be properly developed.

End notes

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Abbreviations *(In alphabetical order)*

App	Mobile application
CAD	Computer Assisted Design
Cert.	Certifications
CO_2 eq.	CO_2 equivalent
cX	coefficient (of x)
DC	Direct Current
DD	Democratic Design
DIST	Distribution
DPP	Distance from Place of Production
EE	Embodied Energy
Env.	Environmental
EoLP	End of Life Potential
EU	European Union
fig.	Figure
FL	Fair Labour
Ip.	Input
LCA	Life Cycle Assessment
LDPE	Low density Polyethylene
MEE	Material Embodied Energy
MO	Material Origin
M&P	Material and Processing
NGO	Non-governmental Organisation
Op.	Output
RMEE	Relative Material Embodied Energy
RPEE	Relative Processing Embodied Energy
PEE	Processing Embodied Energy
P.Ip.	Possible input
Rec.	Recyclability
Ren.	Renewability
TR	Tooling Recyclability
UI	User Interface
w	Weight
W	Weighted Average