OPTIMIZING TECHNICAL DECISIONS WITH A WEB PLATFORM

Case study: methods & criteria of assessing building materials to optimize selection in terms of eco-behavior

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1 Introduction

In technical problems where decisions must simultaneously satisfy several conflicting objectives, methods are based on benefit-cost analysis or multicriteria decision analysis helpful to identify the “optimal” decision. Usually big technical decisions are made by politics and influence the environment, but specialists, constructors and the society must have the ability to overview and inspect these decisions.

In the theory of economics, the level of financial growth is used as an indicator for assessing social prosperity. However, the growth rate might be accompanied by unfavorable effects on the social community’s prosperity. Such negative effects are for instance the danger against public health lying in the environmental pollution, the dangerous shrinking of biodiversity and the exhaustion of natural resources.

Within this context, the concept of the **environmental preservation** has been developed, i.e. the long-term preservation of the ecosystem’s **viability**, as well as the concept of **sustainability**, that is covering present needs but not to the detriment of future needs.

It has been observed that society develops a discerning ability on technological applications (hence an ecological predisposition) when it reaches such a stage of maturity where it comes up against the pollutants it produces itself. This phenomenon, as it is described in Environmental Psychology, is “as if you’re waiting for a building to catch fire in order to study the new safety rules regarding buildings’ fires’’. It continues then, “it is rather immoral to wait for a building to catch fire so that you’re given the criteria on how to study the new safety rules regarding buildings’ fires’’. (Cander, 1988).

A building, is a creation of humans which affects both the environment and humans themselves. A building might negatively affect humans and the environment during its construction and operation stages or can emerge as spoilage after its use. For this reason, different criteria arise to define the building’s ecological behavior so that the positive effect is maximized and the possible unfavorable effects to humans and the natural ecosystem are minimized.

Extensive analysis of the problem from several viewpoints and a presentation of the reasoning are necessary to achieve an informed decision based on understanding and knowledge. In order to optimize a technical decision for society, engineers, experts and politics, architecture of a web platform based in "common" knowledge, optimizes the decision making analysis by evaluating building materials based on ecological criteria.

2 Green architecture

In building industry, a field of modern activity that produces significant environmental impacts, the shift to viable clean technologies can directly contribute to their mitigation. The building field demands, among human activities, the largest amount of energy and natural resources, while at the same time buildings produce immense quantities of solid, liquid and gas waste. All these, have a direct impact on the natural environment and the climate, both on local and global level.

Buildings demand 1/3 of the energy generated in developed countries and the annual production of urban waste is almost equal to what is produced from construction. This occurs because human needs change on a fast pace and people demand upgrades to constructions to provide them with the comfort conditions they demand, every season of the year.

The term ecological (green) architecture also refers to bioclimatic architecture, which utilizes the positive climatic data in the direction of constructing buildings with optimal thermal, optical and acoustic condition based on minimum technological support.

In the context of these concerns, the materials being used in modern cities acquire significant importance, as in each stage of their 'life' - whether as raw materials, or as processed products or composite elements, or finally as construction litter/spoilage - they consume, in larger or smaller amounts, energy and natural resources and they affect the natural environment.

The selection of a building's materials directly depends on a series of different parameters related to construction, aesthetics, economics, the environment, energy efficiency, etc.

The turnover related with the production, transportation and use of construction materials is complex and, by extension, the criteria for the materials' ecological behavior are not easy to describe quantitatively.

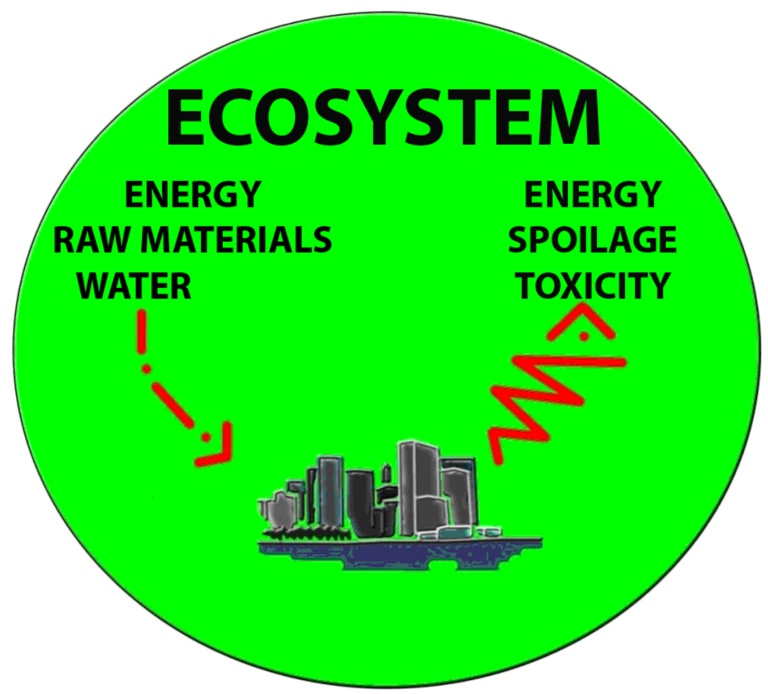


Figure 2.1: Construction activity and ecosystem

Simultaneously, the materials used affect the quality of the buildings' internal air and might significantly affect the users' health. Moreover, they determine the conditions of thermal comfort and the energy consumption, not only at the scale of buildings, but also at the scale of urban environment.

The constructed environment constitutes a subsystem of the natural ecosystem, from which raw materials, water and energy are imported. At the same time, the constructed environment extracts waste to the natural ecosystem, as well as thermal energy, possible toxic pollutants and the materials themselves as spoilage.

3 The life cycle of construction materials

The life cycle of construction materials includes the following stages:

- Extraction (collection – mining)
- Production (industrial production – processing)
- Building construction process
- Usage
- Dismantling (discard, re-usage, recycling, bio-degradation)

In the venture for ecological building, the attempt to control environmental effects imposed by buildings should be assessed throughout the whole spectrum of both the life cycle of the building and the materials' life cycle.

To this direction, the building, as a cradle of the materials' reincarnation, has an advantage in regards with other approaches. Therefore, the criterion for choice is the expected life span of the building and its materials, as well as the ability for its re-usage. Thus, one critical assessment issue is the desired life span of the building under construction.

If, for instance, a temporary construction is discussed, the environmental impact of materials with a short life span is much lesser than of those with a long life span, however if we were to construct a building with a flexible shell that is reusable instead of going to be demolished, the reverse is true.

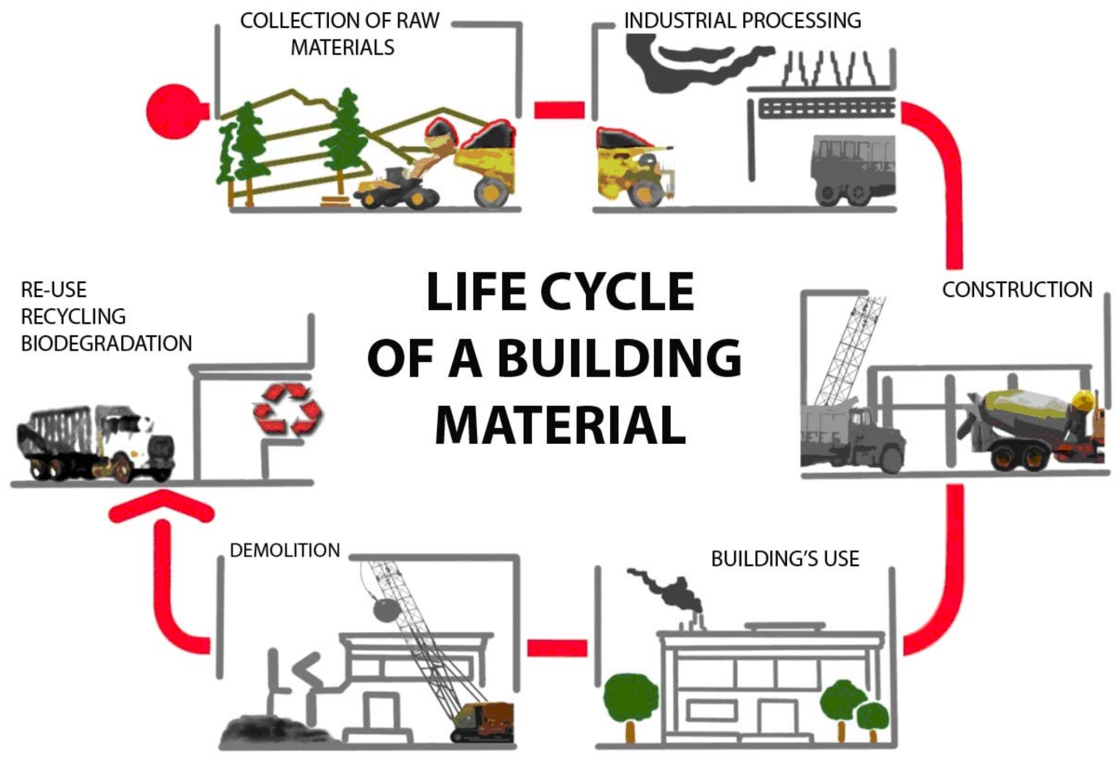


Figure 3.1: Life cycle of a building material

One additional problem is the materials' endurance over time. Especially in the case of materials that have not been qualified within the context of new environmental conditions, defining their life span can be difficult.

In regard to new materials being developed there is an ongoing effort to incorporate 'logic' various environmental criteria in their production, yet, since there are no notional materials, the engineer has to incorporate construction materials to the building that are able to meet -in total or even partially- specific indexes (criteria) in a building's life cycle stages, such as:

Figure 3.2: Cleaning of construction site

Products being discarded, without being used, consume energy both during their production and disposal, has and thus need to be included in the project's total embodied energy.

- Embodied energy of materials (depends mainly on their production and transportation process)
- Energy consumed during the operation of the building
- Saving, re-use and recycling of raw materials
- Life span
- Toxic behavior control in all stages of the life cycle
- Presence of radioactivity in the building's materials
- Other parameters, such as the materials' emissions in CO_2 , SO_2 and NO_x during their life cycle

4 Raw materials. Collection, processing, biodegradation or recycling

4.1 Extraction stage

The way we handle raw materials, i.e. which and how much we collect, how we process them and how we 'turn them into refuse' constitutes one of the main indexes for ecological behavior of the material.

Hence, for example, wood is (in theory) a renewable raw material, since reasonable lumbering can yield perpetual wood deposits in the long term (although the intense lumbering required to cover current needs does not allow for it to be renewable). In contrast, ore does not constitute a renewable raw material, since there are limited specific deposits in nature.

Figure 4.1: Mining site in Milos

The collection of raw materials requires significant amounts of energy, which are hard to convert in terms of volume or weight of the material that finally reaches the construction site.

4.2 Production stage

One of the problems emerging during the production of a material is waste of raw material. Depending on the production method of different materials, the production process potentially consumes a large part of collected or mined raw materials.

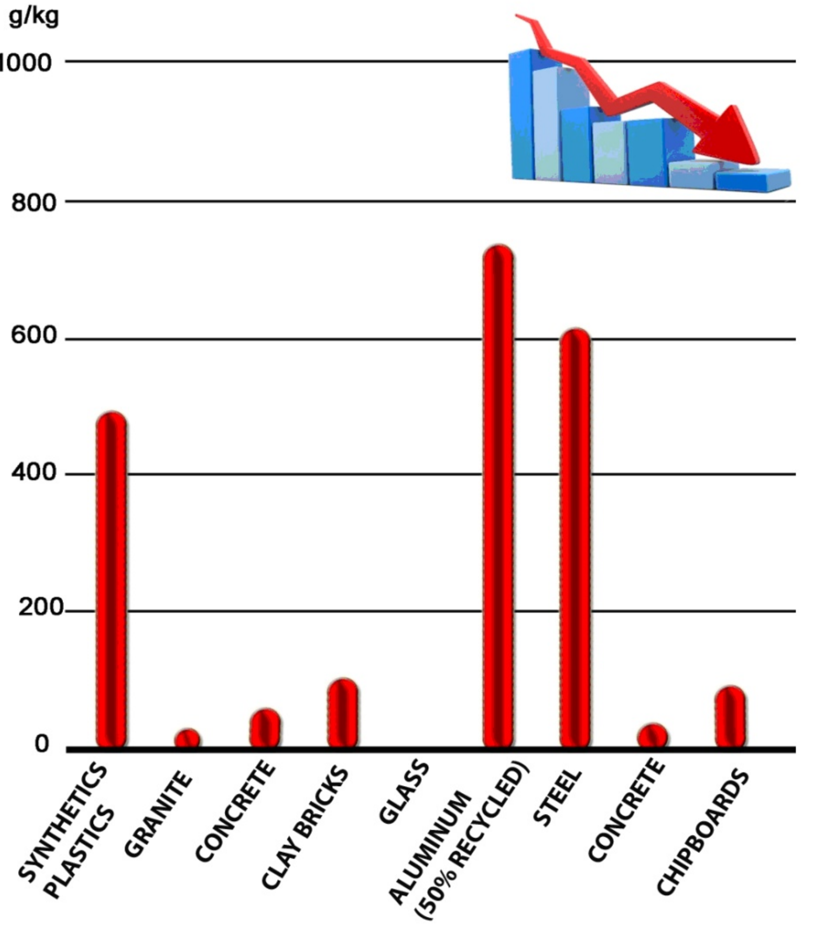


Figure 4.2: Waste of raw materials during production of common materials

Likewise, a significant part of the production stage also involves the assessment of the quantity of raw materials required to cover specific needs in construction. If for example, in order to cover a certain need, a higher mass or larger volume of material A than alternative material B might be required, which is something to be assessed.

Note that other than the material itself, possible toxic behavior in the production's sub-products or the production's wider environment should also be tested.

4.3 Construction stage

Similar testing should take place during construction, namely if materials display a toxic behavior (for instance paint substances with organic solvents prior to their stabilization).

4.4 Usage stage

A critical element during the use of a mateial is its potential for reuse. Materials that quickly deteriorate-decompose during construction and need to be replaced in 5-10 years, i.e. much earlier than the building's expected life span do not constitute a good choice.

Conditions prevailing in the buildings' internal spaces during different times of the year (winter, summer, intermediate) are directly related to the heat transportation through their shell, via conduct, transport and/or radiation. The natural and optical properties of materials are the ones determining their behavior with regards to different heat transportation procedures.

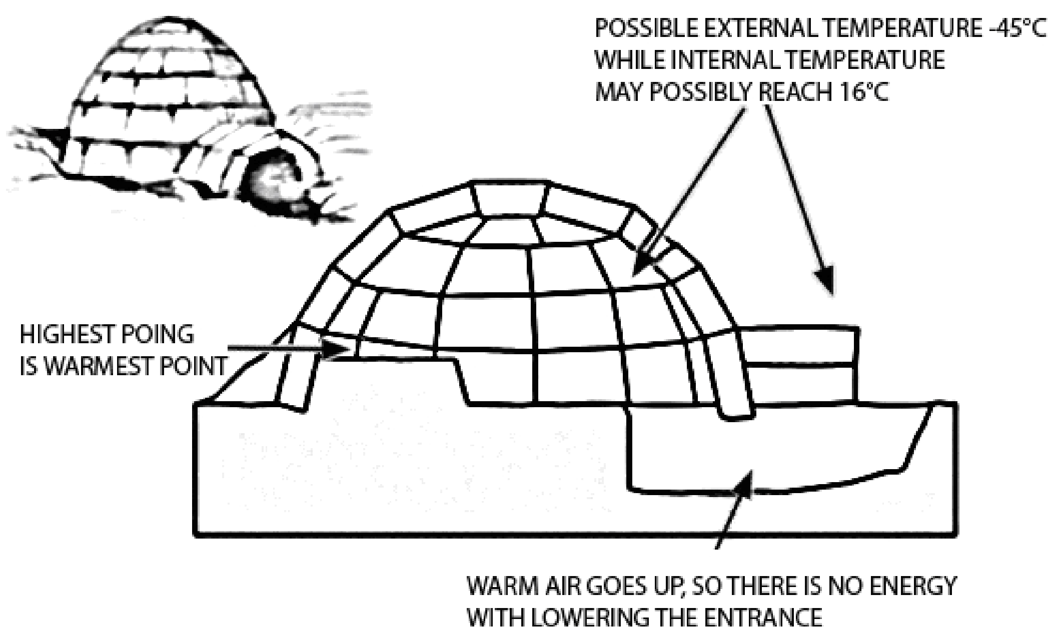


Figure 4.3: The igloo and its internal conditions

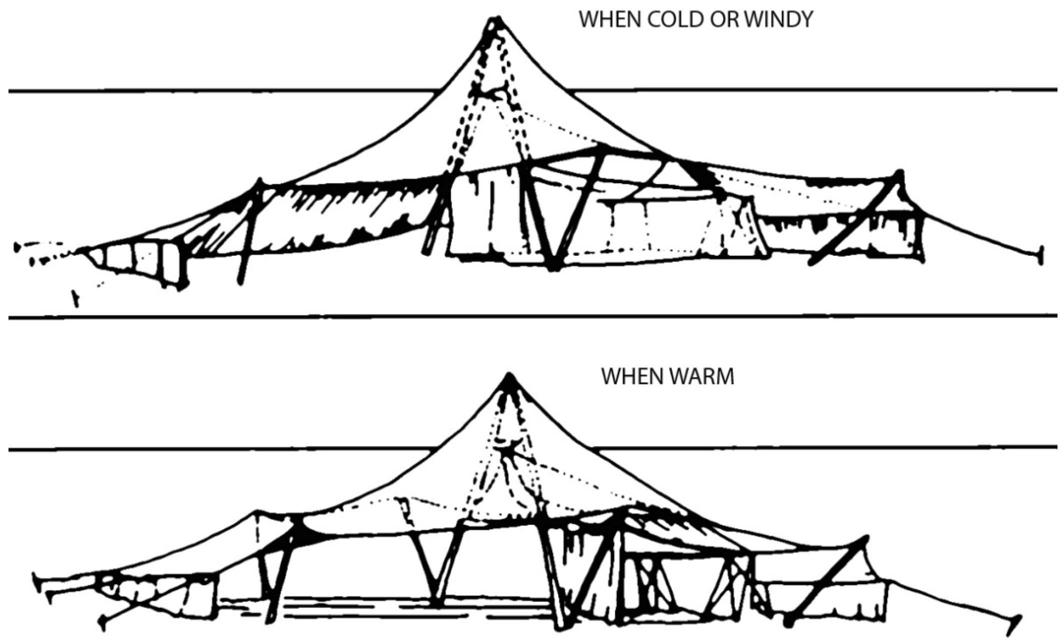


Figure 4.4: A tent in the desert

Waste of thermal energy is contained by the use of heat insulating materials and the use of double glass panes.

Taking advantage of materials with good thermal behavior, as well as overall energy-efficient planning of buildings (bioclimatic behavior, utilizing solar energy, utilizing wind power etc.) are elements that define smart and ecological building.

In order to select the materials to be used in the building's shell based on its optimal thermal behavior, scenarios (work assumptions) need to be made, and for each of these assumptions the building's thermal behavior should be solved via suitable processing software.

4.5 Discard stage

The debris of excavations, constructions and demolitions is one of the heaviest and most voluminous waste produced in the European Union. It represents about **25% - 30%** of total waste produced in the European Union and it consists of materials such as concrete, iron, bricks, plaster, wood, glass, various metals, plastics, asbestos and paint.

A construction's waste -commonly known as 'debris'- comes from technical construction and renovation projects, materials of a demolished building or technical project and from technical demolition projects.

They are non-biodegradable aggregates, which are recyclable and contain granular aggregate materials (concrete, bricks, asphalt, glass etc.), woodwork waste, steel, iron and no-iron metals and paper, aluminum, plastics etc. There are no specific quantitative data available, as there is a discrepancy between data published by The Ministry for the Environment, Physical Planning and Public Works and those published by the EEC. Indicatively, the production of construction debris in Attica amounts to 2,5 million tons per year, in Greece to 4,5-5 million tons per year, while in Europe 180-300 million tons per year. These materials consist of concrete (reinforced or not) to a 60-70%, bricks to a 30-35% and recyclables to a 5-10%. Currently in Greece less than 5% is being recycled, while in Europe this average amounts to 30%. There are European countries with outstanding recycling performance when it comes to construction debris. For instance, the Netherlands recycle 90% of it, Belgium 87% and Denmark 81%.

After the materials are produced, incorporated in the construction and have completed their life cycle in it, the following questions emerge:

- dismantle and reuse?
- demolition and recycling?
- Or demolition and discard?

It has been proved that the reuse of construction materials can reduce the materials' embodied energy to 95% (see this text's related next thematic section) and minimize the construction waste.

Construction elements that are easy to reuse are:

- Debris from stone masonry without mortar (dry-stone wall)
- Insulation material (as long as they haven't aged and are in good condition)
- Timber bearing systems
- Plaster products (plaster boards etc.)

Other reusable construction elements also include doors, windows, bathroom ceramic fixtures and furniture.

Bricks, cement and concrete are certainly not easily reusable, nor can they be reused in new constructions.

However, they can be reworked and reused as second-hand aggregates for shaping horizontal surfaces and road construction.

Recycling constitutes the attempt of humans to simulate the cycles of nature, which are perceived as archetypes of operational efficiency and stability. The natural cycles do not consume raw materials and do not create waste, being constantly in ideal balance with nature. Recyclable materials are divided in:

- Primary: materials derived from demolition debris
- Secondary: materials emerging as sub products of other works (slag, sawdust)

With the procedure of secondary recycling, the construction becomes a receiver of material 'waste' and the materials involved have been derived from some other production process. For example, wood sawdust has been utilized to produce fiberboards or chipboards, while efforts are being made to incorporate other materials as well, so that the building constitutes a creative storage space of useless materials and with limited requirement of additional collection, mining and production of new materials.

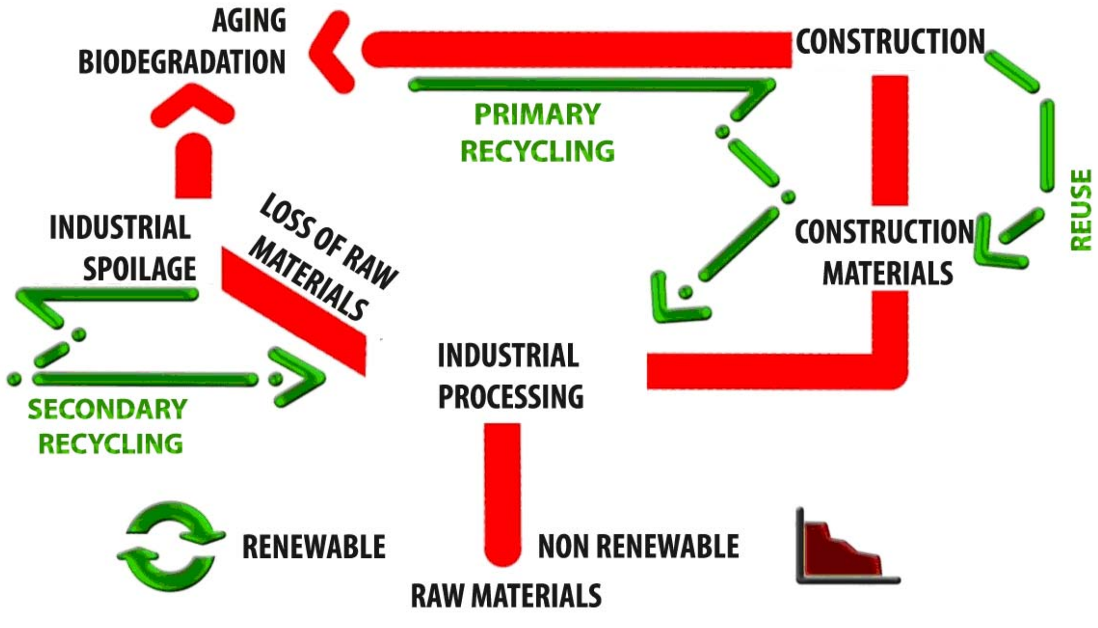


Figure 4.5: Raw materials. Collection, processing and recycling.

Thus, in regards to raw materials, the rational use of renewable raw materials with minimum loss is a must, along with the use of materials that are easily reused and recycled.

5 Environmental issues

5.1 Toxicity

Toxicity is the property of certain materials used in constructions to contain or emit harmful solid, liquid and gas substances into the soil, the water and the air in one or more of their life cycles. (Anink, et al., 1996: 17)

Toxic substances, when released during their production or use, affect the environment, the quality of a building's internal air and people's health. At the same time, they are significantly harmful for the fauna and flora and by extension the ecosystems overall.

5.2 Health issues

Among issues regarding public health, not only are ones concerning the health of the people using the spaces included, but also the ones working during the initial stages of the materials' life cycle, i.e. the extraction, production and construction. The health of people, especially in internal spaces, is negatively affected by the emissions of harmful chemical compounds included in various materials (e.g. formaldehyde from chipboards and paints).

Different studies have shown that 37% of construction materials are harmful to health (medium toxicity), while 2% are toxic or highly toxic. Among those harmful to health, products containing substances with high cancer risk and the ability to cause mutations are included. It has also been proved that 8% of construction products fall under the category of corrosive and irritating substances, bearing on their package the relevant sign as imposed by the 67/548/EE directive on dangerous substances.

The quality of air in an internal space is greatly dependent on the construction materials. Oftentimes, paints, gluing substances and other materials introduced during the construction's final stage contain volatile organic compounds – VOCs, which are highly toxic. For this reason, the stabilization of paints containing VOCs should be carried out before the space is habited.

Another problem related to buildings interior and toxicity, is that certain wooden constructions contain formaldehydes, which can be emitted by the wood for as long as seven years before they decompose. Then the building acquires the so-called Sick Building Syndrome, displaying a series of symptoms caused by the poor quality of the internal environment, e.g. eye, nose and throat irritation, fatigue, headaches, dizziness, nausea, allergies and respiratory diseases. (Berge, 2003: 142; Smith, et al., 1998: 133)

Petrochemicals used in most plastics and gluing substances are often toxic. Almost all petrochemical glues and resins used in the construction of building materials are from styrene and petrol structure chains, which are highly toxic and carcinogenic during their construction/use. This becomes evident also by the intense smells (aromatic hydrocarbons) diffused during these stages.

Indirect indications for a substance's toxicity, other than its toxic action are:

- Mobility in various media (depends on its solubility in water, the liquid's relative density, the kinematic viscosity, the steam pressure and the steam's relative density).
- The time of its 'stay' on the environment (depends on its chemical stability and its natural or biological ability to degrade)
- Its bioaccumulative tendency (depends on its time remaining in the environment and its lipophilicity).
- Surfactant action (substances with high surfactant action reduce a liquid's surface when added in it).

Mobility, chemical stability, surfactant action and toxicity are undesirable properties for the environment, yet desirable in certain uses in constructions.

High mobility, volatility, chemical inertness and stability are properties desirable for solvents, such as certain chlorinated hydrocarbons (dichloromethane etc.). These substances display toxic, carcinogenic and mutating action, while the long period of their 'stay' in the environment along with their bioaccumulative tendency makes them highly toxic.

A high chemical stability, hence longer period in the environment until biodegradation, is found in substances used as stabilizers of unstable materials (protection from corrosion and oxidization), as fire protection for wood and synthetic materials, as additives in synthetic products, in varnishes, glues for improving their elastic and plastic properties. Such substances are the multi-chlorinated biphenyls (PCB) which are at the same time bioaccumulatable, toxic, carcinogenic and mutagenic.

Products containing tension-active substances are cleaning products and emulsifiers (which allow the better mixing of different materials and surface dividing media). Surfactant substances are also used for enhancing concrete liquidity and endurance. Such types of substances are mineral oils, mineral oils with additives, mineral oil emulsions in water and water emulsions in mineral oil. Surfactant substances are especially toxic to the water environment, since they reduce the water's surface tension and destroy the microorganisms living on its surface.

Toxicity is a desirable property for the biocides used as wood preservatives, as ingredients of fungicide smears and as bio-stabilizers in synthetic products containing biodegradable components (plasticizers, photo stabilizers, endurance enhancers). Among biocides, formaldehyde, phenolic compounds, tin organic and inorganic compounds are in common use.

The majority of building materials does not only contain one, but two or more ingredients interacting with each other and acting accumulatively. The same is true also for products being used simultaneously or almost simultaneously in various constructions.

The mobility of heavy metals increases in an acid environment, the time of biodegradable substances is extended due to the presence of biocides, the toxicity of certain substances increases when their effect is combined with the effect of other substances (additive effect-synergy) and the presence of solvents causes the release of toxic ingredients that might be bound to a polymer matrix.

Obviously, use of toxic substances is commonly not deliberate, but due to ignorance of the substances' behavior.

For toxicological testing of building materials, as well as for the presentation of relevant results, several standardized methods have been developed, from different countries and organizations (DIN 38414, TCLP Toxicity Characteristic Leaching Procedure) etc.)

However, most modern materials have not been used for sufficient time by humans and the effects from their use in the construction (coexistence with humans) might later be proved toxic. For this reason, new regulations and experimental directives are being developed today, in an attempt to detect toxicity in various substances and in materials containing them and classify it into categories. Yet, due to the experiments' ambiguity, the difficulty of rendering results in longer periods and various other parameters, some reservations still exist on the efficiency of toxicity measuring.

5.3 How toxic substances work

The term 'food chain' is generally used to describe the sequence of substance and energy transport from one organism to another in the form of food. In other words, it describes a sequence (chain) related to organisms, existing in every ecosystem, where energy changes form though eating patterns.

During the energy flow from one trophic level to the next, available energy is being reduced. In every step, one part of the incoming energy equivalent of the food is used to cover the energy needs of this level and is discarded as energy via respiration or as waste, while the rest is incorporated as chemical energy to the bio-mass produced.

In general, efficiency amounts to roughly 10%, i.e. only 10% of the incoming chemical energy becomes available.

Energy loss along the food chain is responsible for the phenomenon called biomagnification, which increases the toxic effects of non degradable harmful substances.

When fro example, a non-degradable chemical substance appears in the marine phytoplankton in a concentration a, its concentration in the zooplankton (the phytoplankton's predator) will be *10a* and the concentration in small fish (the zooplankton's predators) will be *100*a. The same will occur in the next steps of the food chain, resulting in the substance's high concentration in the upper predators such as humans.

For this reason, materials containing toxic substances should be avoided, as these substances may be released during their life cycle or disposed, entering the food chain.

5.4 Radioactivity

Another possible danger that might appear in a building's materials is the presence of radioactivity.

Natural radioactivity produced by radon, but mainly extended use of radioactivity (for research, diagnosis, treatment, technology and other purposes) has negative effects when it comes to the environment.

The uncontrollable dumping of radioactive materials or/and waste has been creating -during recent years- a number of problems to the steel industry and especially the recycling scrap. The possible presence of radioactive materials in scrap possibly results in radioactive presence in products and sub-products of the construction industry.

In Greece radioactive materials have also been detected. Greece, imports large quantities of steel products, a characteristic example being the steel used for concrete arming, the import of which covers roughly 35% of the domestic demand. Only a small percentage of these types of steel originate from EEC countries and the highest percentage originates from non-EEC countries. Even though EEC products are manufactured with high level quality-control and are exported after thorough testing, the same cannot be claimed for other products from other countries.

The increasing dumping of radioactive materials in the form of scrap makes the issue of steel radioactivity one of the gravest future problems of the steel industry, with regards to control of arming concrete with steel and the use of other metallic elements in constructions.

Detecting radioactivity in various materials is easy via suitable instruments, which however has not been widely used in its every day application.

6 Embodied energy: energy 'stored' within the building materials

6.1 Definition of embodied energy.

In developing countries, a 40%-60% of energy generated is spent for construction.

During the last decades the embodied energy in buildings' materials has been studied in an attempt to correlate materials, their production, manufacture and usage procedure with their environmental cost.

Embodied energy is the energy used to create a product. The energy consumption required for the production, creation and transportation of the product constitutes its embodied energy.

A material's embodied energy is calculated as the sum of its energy requirements from the moment when its raw materials are collected, its transformation into a product, its transportation to the market, its installation in a construction, its maintenance during its life-cycle and the its dissolution-recycling-reuse.

A material's embodied energy is one of the indexes defining a material's 'ecological character', since materials with high embodied energy (generally) cause high CO_2 emissions and various waste during the production stage.

The embodied energy criterion is generally considered objective, because it is based on measurements of the energy incorporated in a building's materials. Yet, as we are going to see next, there are so many ambiguities in its calculation that its estimation can become quite subjective.

Figure 6.1: A building, perceived as a space of energy storage.

The embodied energy is referred to as hidden energy cost, since it is caused by production procedures which are not necessarily obvious. It is estimated that the indirect energy consumption, grey or invisible, represents two thirds of the total energy we consume.

Embodied energy is divided into:

1. Initial embodied energy, which represents the energy needed for the construction of a building.

2. A building's maintenance energy, which is consumed for its maintenance-repair-renewal-substitute during its life cycle and which however, due to the undetermined nature of the use, is taken into consideration on a case-by-case basis.

In general, the values of embodied energy are indicative and derived from research results in litrature, yet are differentiated according to the following observations.

The embodied energy of a material produced by means of a certain production procedure is highly possible to differ from the embodied energy of the same material produced by a different production procedure. The embodied energy also includes the energy for transporting the material to its final place (cradle-to-gate) and this depends on each construction's location.

Figure 6.2: Concreting construction site

The energy consumed in the construction site, due to its form and the way it is organized, is the easiest energy to define, however it is only a fraction of the embodied energy of the total construction.

To evaluate the criterion of a material's embodied energy we have to, first and foremost, evaluate the quantity of the materials (how many kilograms) required for its construction, e.g. an aluminum casing vs. casing from wood.

This kind of comparison, in contract to not stating that aluminum has a high embodied energy per kilogram of its production, can lead to correct evaluation results. A material's embodied energy mainly depends on the processes its raw materials are subjected to. For this reason, different forms of the same material display different amounts of embodied energy.

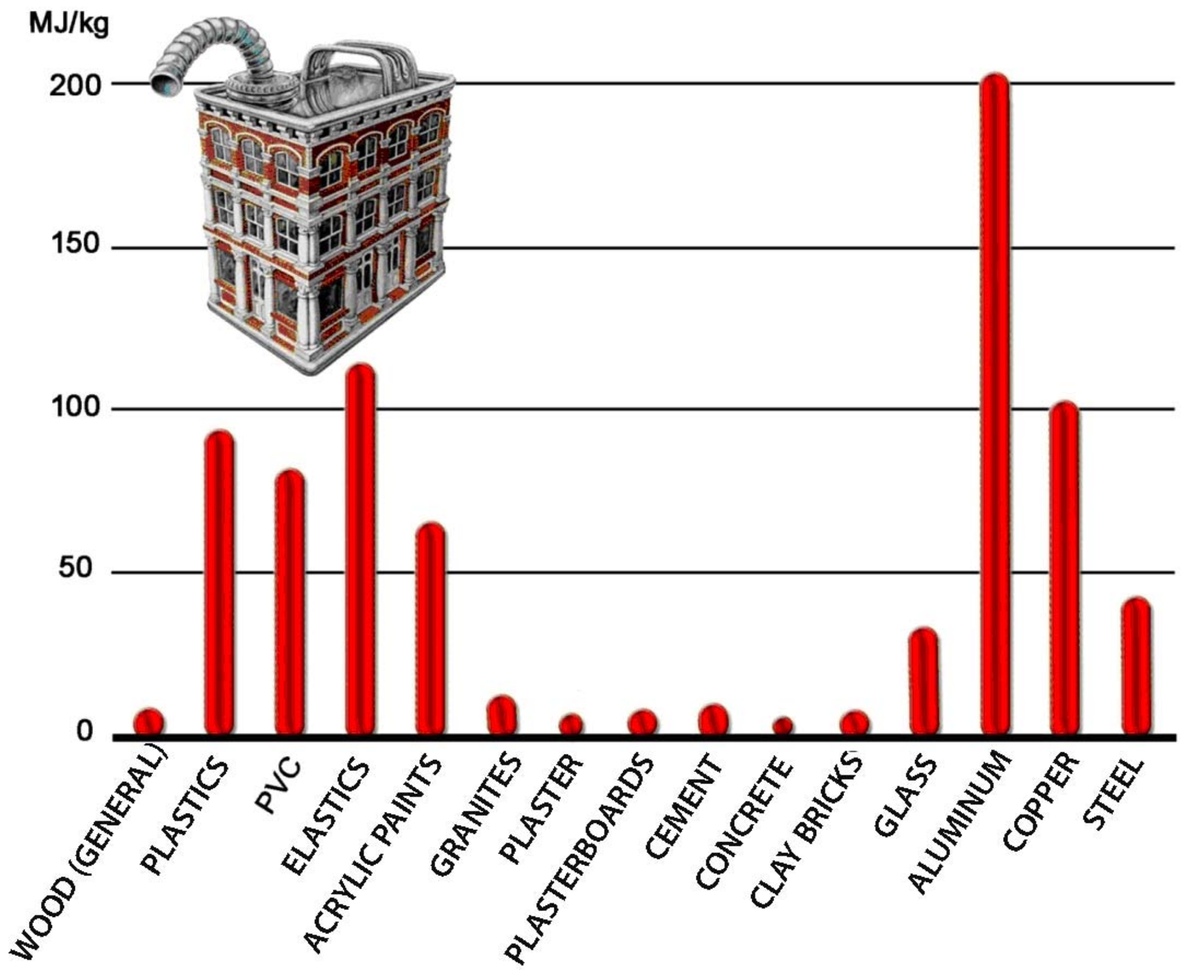


Figure 6.3: Qualitative-quantitative depiction of embodied energy in common materials

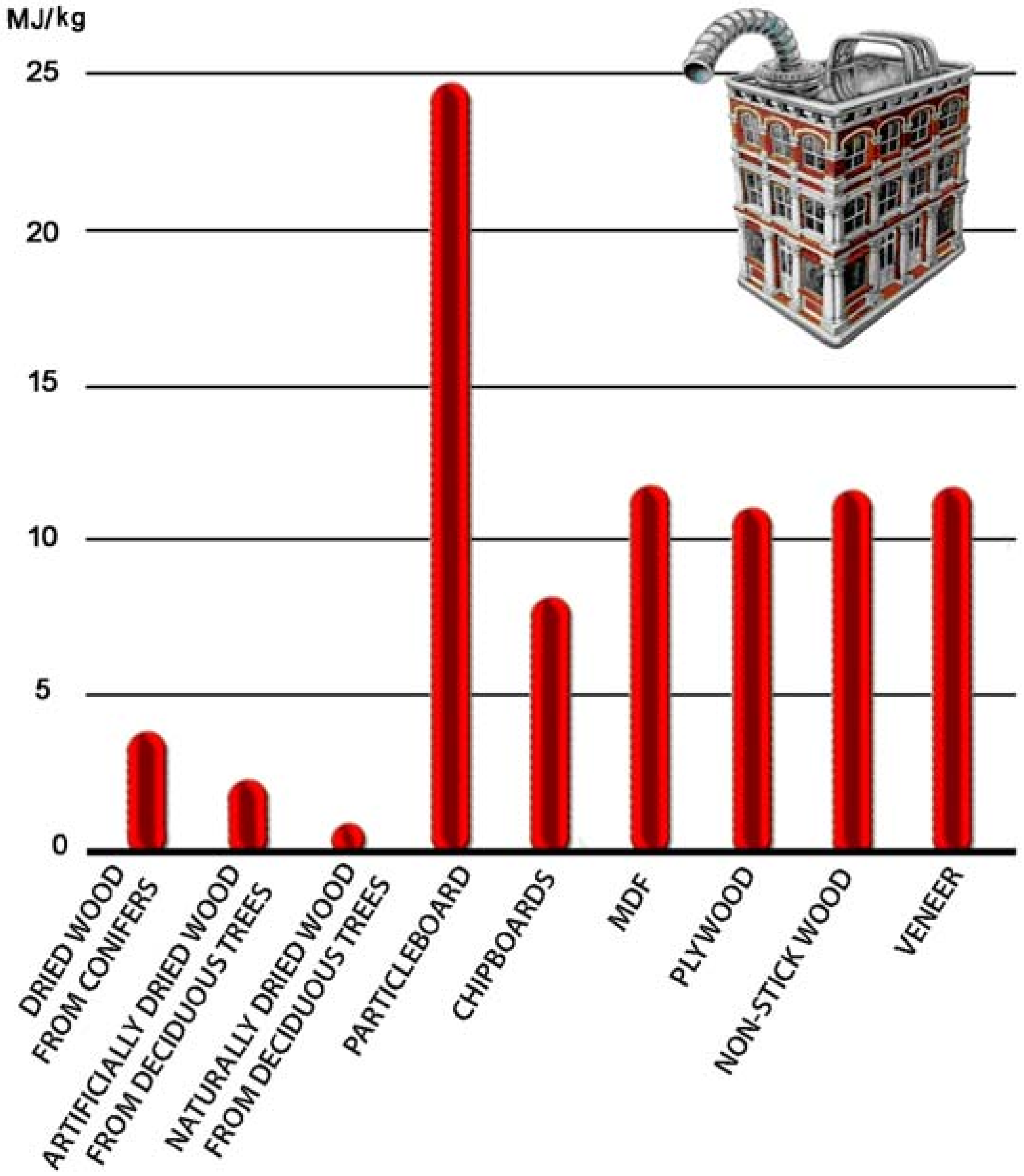


Figure 6.4: Qualitative-quantitative depiction of embodied energy of wood products.

A material that does not negatively affect the environment by means of its raw materials' extraction from nature can create ecological damage through its production procedure. For instance, ore and glass contain high embodied energy from their production procedure as they require high quantities of energy, while natural stones, which require relatively low energy for their production, require high energy for their transportation.

A material's transportation from the production manufactory to the site of its application is another criterion affecting its assessment. The importance of the transportation energy is great and can, in the case of heavy materials, exceed the energy consumed for their extraction and production. (Berge, 2003: 17). Yet, nowadays, this fact affects the selection of a material in a lesser extent. On the contrary, in older times, but even during the first half of the 20th century, the distance between a material's site and its application site was a determinant for its selection.

By choosing materials produced in the vicinity of the construction location the cost of fuel (and energy) required for their transportation is reduced. A relative index is the fuel expenses of construction sites.

Based on this, along with the results of various studies, it is concluded that railway transportation is eight times more cost-saving (and more ecological) than transportation by vehicles.

Figure 6.5: Concrete floor slab construction

The synergy of different materials for compound materials such as the armed concrete with cement-aggregates-water-ore has to be taken into consideration by separating, in terms of energy, each material for calculating the embodied energy of the compound material.

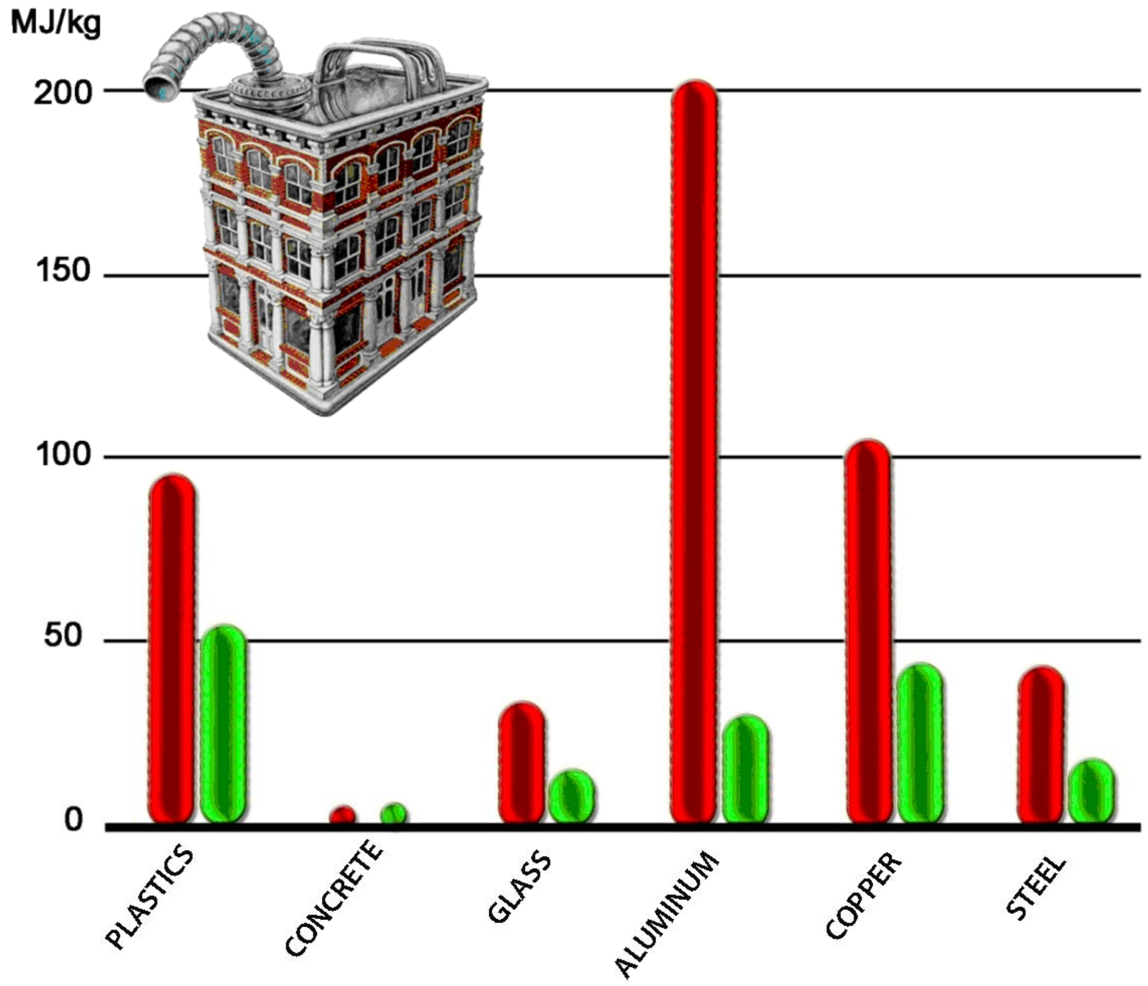


Figure 6.6: Qualitative-quantitative depiction of the embodied energy and the embodied energy due to recycling.

Comparing the index of the material's embodied energy in relation to the embodied energy of the same material when it is made from recycled materials, the energy saving due to the use of recyclable materials can be quantified. In certain cases, however, the materials require higher energy and cost to be recycled than when produced from scratch.

There are various reasons why recycling is not always an option and this process is referred to in an 'ethical context' of ecological design and not on a financial/technical one.

Finally, the quantity of various materials used in a building is also important. By converting the quantity of each material to energy (based on its embodied energy), separating the value of each material's embodied energy in construction and converting to energy during its production, using fuel costing charts, the total embodied energy of a building's materials can be determined.

6.2 The Methods for determining the embodied energy

Determining a building's embodied energy is based on data bases that contain average figures of energy required to produce the materials per weight or per volume, which have been compiled by independent organizations (e.g. University of Bath, Inventory of Embodied Energy & Carbon (ICE database).

In regards with the more commonly accepted tools for this process, these are the SBTool of the UK Code for Sustainable Homes and the LEED of the U.S. Green Building Council, which can quantify a product's embodied energy, in combination with other environmental parameters.

In general, there is a number of different methods for determining embodied energy, the differences of which result from the ways energy is transformed and from what kind of system the energy requirement of the flows is rendered to.

Thus, other than the formal energy figures, some other methodologies quantify energy needs by transforming them into the so called 'greenhouse gases' equivalents. Others quantify them in fuel or/and in purely financial figures, while the methods also differ depending on the form of the system under study.

6.3 The material as energy storage

Common units for determining embodied energy are the MJ/kg or the kWh/kg (Mega Joules or kiloWatt-hours of energy required for the production of one kilogram of product (1 MJ = 0,28 kWh) (see Table).

The levels of embodied energy in materials used in buildings significantly vary, while each material's embodied energy also changes according to the form in which it is available.

It is noteworthy that, with the exclusive use of charts to determine the embodied energy, solid conclusions cannot be reached, since , in general, small quantities of materials with high embodied energy (such as aluminum) and large quantities of materials with low embodied energy (such as concrete) are used.

Materials	Embodied energy	
	MJ/kg	MJ/m^3
Aggregates	0,1	150
Asphalt aggregates (3A)	9	4930
Natural stone (local)	0,79	2030
Solid cement	0,42	819
Prepacked concrete	0,94	2350
Cast concrete (30 Mpa)	1.3	2780
Bricks	2,5	5170
Unprocessed wood naturally dried	2,5	1380
Insulating wood sub products	3,3	112
Straw bales	0,24	31
Glass	15,9	37500
Fiberglass	30.3	970
Metals		
Steel (from ore)		
Steel (recycled)	8,9	37210
Steel	32	251200
Aluminum (from ore)	220	515700
Aluminum (recycled)	8,1	21870
Copper (from ore)	70,6	631164
Copper (recycled)		
Zinc (from ore)	51	371280
Zinc (recycled)		
Bronze	62	519560
Plastics		
PVC	70	93620
Acrylic paints	93,3	117500
Insulating materials from polystyrene	117	3770

Table 6.1: Embodied energy of common materials per weight and per volume

Materials	Embodied energy	
	MJ/kg	MJ/m^3
Aggregates	0,1	150
Straw bales	0,24	31
Solid cement	0,42	819
Natural stone (local)	0,79	2030
Prepacked concrete	0,94	2350
Cast concrete (30 Mpa)	1.3	2780
Unprocessed wood naturally dried	2,5	1380
Bricks	2,5	5170
Insulating wood sub products	3,3	112
Aluminum (recycled)	8,1	21870
Steel (recycled)	8,9	37210
Asphalt aggregates (3A)	9	4930
Glass	15,9	37500
Fiberglass	30.3	970
Steel	32	251200
Zinc	51	371280
Bronze	62	519560
PVC	70	93620
Copper	70,6	631164
Acrylic paints	93,3	117500
Insulating materials from polystyrene	117	3770
Aluminum	220	515700

Table 6.2: Embodied energy of common materials per weight and per volume

Wood products	Embodied energy per weight unit (MJ/kg)
Wood products (general)	10.00
Novopan plywood	8.00
Hardboard	16.00
MDF	11.00
OSB (Oriented Strand Board)	15.00
plywood	15.00

Table 6.3: Embodied energy of wood products.

Window frame	MJ per item
Aluminum	5470
PVC	2150 - 2470
wood	230 - 490

Table 6.4: Embodied energy in 1,20x 1,20m window frame casing.

Solid conclusions can be only reached **by comparing the embodied energy to cover specific needs**, e.g. choosing different frames of same dimensions (see Table 4).

However, this kind of assessment should include possible different contribution of each construction element to the building's total energy efficiency, during the building's life cycle.

6.4 Energy assessment of materials during the life cycle

The embodied energy required for the building's maintenance is also related to the endurance of the used materials in ageing, as well as to the relevant construction systems applied on the building (their maintenance ease) and finally the building's life-time itself. The longer life-time a building has – based on planning that requires low maintenance energy- the higher embodied energy it will acquire over time.

When it comes to recycling, energy saving differ from one material to another. A lot of building materials, such as bricks and concrete, are destroyed during demolition and they require almost the same amount of energy to be recycled, as the one needed for them to be produced from the start. On the contrary, easily recyclable materials, like aluminum, save 95% of their embodied energy when recycled, in relation to glass that only saves 20% .

Yet, the reuse of certain materials can save up to 95% of their embodied energy.

In general, the simpler and lighter buildings with adequate insulation have the lowest embodied energy. Their embodied energy varies between 4,5 GJ/m2 to 5,5 GJ/m2, depending on the form of the building, its floors, stories etc. Relevant charts, from a research project on a 4.620m2 office building in Canada, presented in the following images (Cole and Kernan, 1996), show different energy needs of the materials and the building during construction and operation. As it is evident in the charts, the highest energy consumers during the building's life cycle are:

- The shell (possible modifications to which might be necessary for altering uses)
- The paint coatings (finishes), which in general require continuous maintenance.
- The building's electro/mechanical installations, which have a short life period in general and high needs of maintenance-renovation-replacement as well.

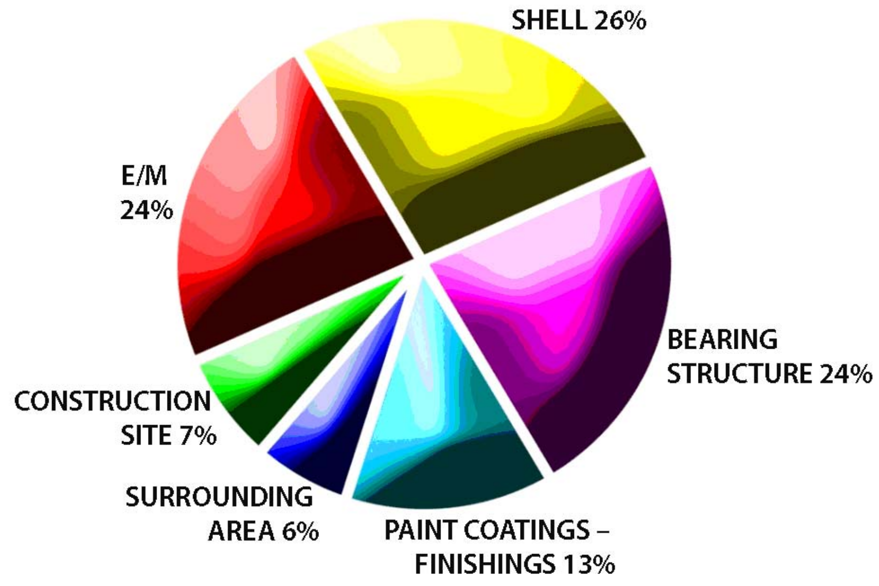


Figure 6.7: Distribution of the initial embodied energy required to build the parts of a typical office building. [source: translation and rendition from Cole and Kernan, 1996].

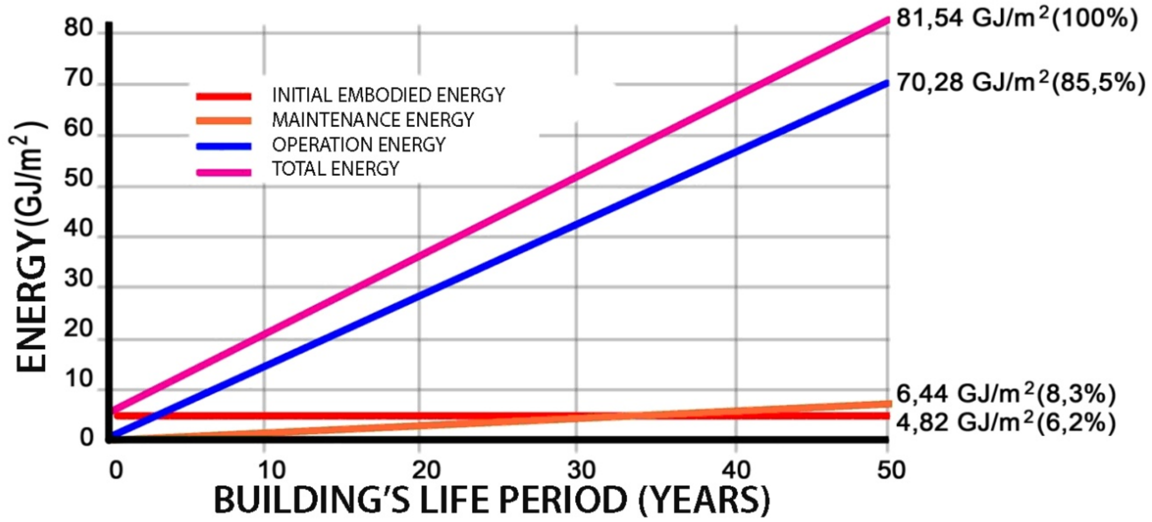


Figure 6.8: Embodied energy of the building's materials and energy of the

building's maintenance and operation (per square meter) [source: translation and rendition from Cole and Kernan, 1996].

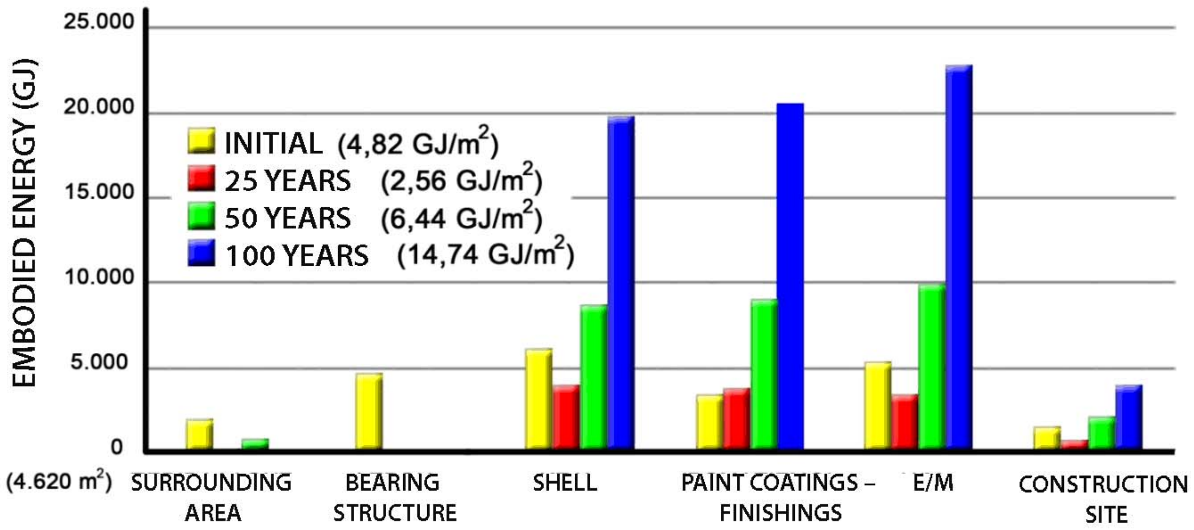


Figure 6.9: Distribution of the initial embodied energy in relation to the operation embodied energy of each construction part. [source: translation and rendition from Cole and Kernan, 1996].

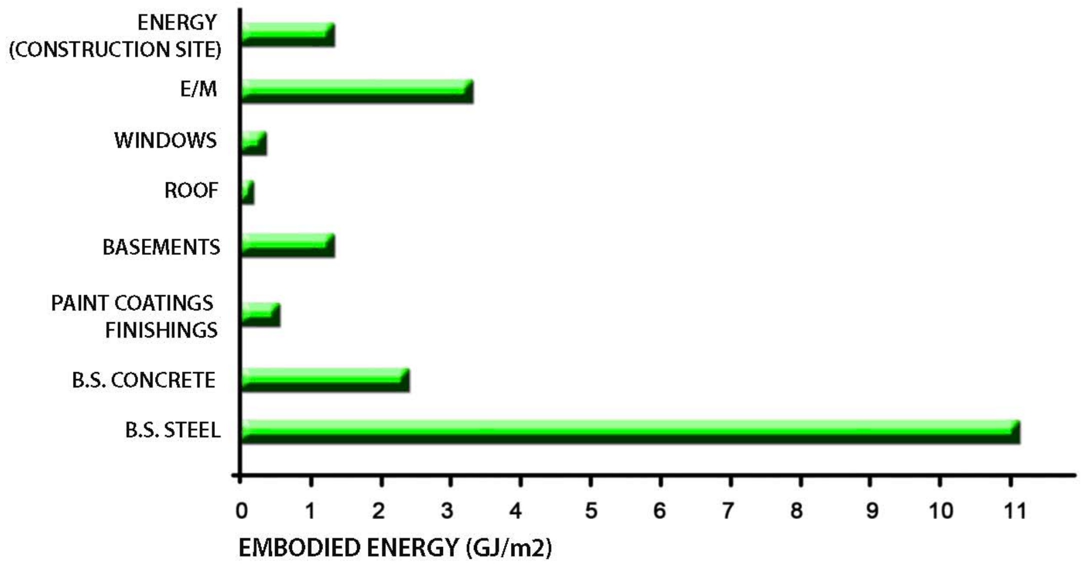


Figure 6.10: Embodied energy in GJ/m2 of each construction part (initial, to integration into the construction). [source: translation and rendition from από Cole and Kernan, 1996].

6.5 The subjectivity of embodied energy

Embodied energy first and foremost depends on a material's production procedure. Yet, in different locations globally, different procedures are used, whose energy requirements vary accordingly. Thus, even the most detailed analysis of the energy required for the production of a material will differ from place to place.

At the same time, different methodologies widely used (based on different concepts but basically on the same subject) produce different results, since they use different measuring scales and different empirical chart.

The subjectivity of the variables also includes integrating (or not) subjective parameters, such as transportation, based on the question: by which way and by which means; advertising, promotion-handling of the materials and other relevant actions requiring a basically undetermined amount of energy.

In conclusion, embodied energy is a term, the exact definition of which is not unanimously agreed upon by scientists, while simultaneously there are various different perceptions regarding it. It is widely agreed though, that (by using the same methodology) products can be compared with each other, so embodied energy is eventually used as an index for comparing the ecological behavior of different materials.

Some basic parameters that need to be addressed when trying to reduce the embodied energy of materials are the following:

- Constructions should be designed for covering the specific needs; they should not exceed the relevant required size; the shell's design should be oriented towards the use of the least possible materials.
- Materials' design, specifications and selection should be based on the criterion of long life-span, their replacement instead of discarding, and on reducing energy consumption during the building's life-time.

- Materials should be retrieved by the dismantling of existing buildings and then be incorporated into the construction.
- Materials selected should be easily reusable or recyclable after the expiration of their life-cycle and integrated in such a way that they can be easily separated.
- Materials used should be produced near the project's location, so as to reduce the transportation energy requirements.
- Materials selected should contain low embodied energy based on relevant charts.
- The total of incoming materials should be used, avoiding material waste.
- Relevant specification by suppliers should be required at all times.

6.6 Energy saving and ecological balance

As the generation of energy imposes an environmental cost, one could state that, for covering the same needs, products with low embodied energy are more environmentally friendly than those with higher embodied energy.

Thus, as a general rule, embodied energy is a rational index of the environmental parameters of a building's materials, which should be tested in relation to the life span and endurance of the materials, as these properties can blunt or have a countervailing effect on the initial assessment of the environmental ramifications related solely with embodied energy.

In any case though, embodied energy remains a main parameter for evaluating the building's environmental effects related with it and on a secondary level with its ramifications, yet it compares relative and objective quantities, which can lead to more safe quantitatively figured conclusions.

However by definition the ecological balance is described as the relevantly stable relation forming over time between the factors and the environmental elements of an ecosystem.

7 Other criteria

7.1 Water consumption during the materials' production.

Water is a precious natural resource therefore the amount of water consumed during a material's production procedure constitutes a criterion for its assessment.

7.2 Emissions of gas pollutants during a material's life span

A material's production procedure consumes energy, which in general results to gas emissions, except from cases in whihc it comes from Renewable Energy Sources.

During the transformation procedure of various raw materials, air pollutants such as CO_2 and other oxidizing media (SO_2, NO_x) are emitted, which disturb the natural cycles of nitrogen, of carbon etc.

It has been proved that the SO_2, NO_x emissions from the production of materials are lower in general than the emissions of CO_2, since the latter consist 90% of emitted pollutants, however SO_2 is responsible for the acid rain phenomenon, despite its small participation percentage, and is especially crucial for this reason.

There is a tendency to convert the MJs of embodied energy into SO_2. Yet this conversion is not univocal, since different energy forms (oil, air, sun, nuclear etc.) differ in their emissions of carbon dioxide. Therefore, the actual amount of carbon dioxide produced depends on the type of energy in use for the production process.

In Australia, according to its energy sources, it is calculated the average emission of CO_2 for the generation of 1 MJ of energy are 0,098 kg.

Thus, while there are certain expressions for quantifying the gas pollutants emissions per quantity of produced material, their subjectivity (which lies in the produced material's production process and the energy form used for production) does not allow their inclusion in our assessments.

Consequently, the greater complexity level each criterion has, the vaguer and more unstable it becomes.

7.3 Low-Tech architecture and its materials

"Low-Tech architecture" (a technical and non technological architecture) focuses on creating works that avoid the use of 'technology' in every stage of their life-span (materials and construction method, as well as construction's use).

For every building material some kind of technology is 'hidden' and energy is required for it to be produced and transferred to the construction site. Each material has therefore an energy and 'ecological' cost.

The "Low-Tech architecture's" criterion is avoiding use of technology and energy consumption, in combination with minimizing the financial cost. The goal for materials is to not consume energy for their production-transport; they should be available in nature (having been subjected to the least possible processing) or come from reuse/recycling, so as to have the least financial cost.

Depending on the area, the climate and the available raw materials, the "Low-Tech architecture" constructions are also guided by each area's construction traditions, which may 'hide' interesting technical approaches and solutions, such as in the aforementioned examples of the Eskimos' igloos in the North Pole, which wouldn't be applicable e.g. in Sahara, in much the same way the traditional Bedouin tents with their exemplary ventilation could not be applicable in the Arctic Circle.

8 Assessment and selection of building materials based on ecological criteria

When a decision needs to be made on an issue involving radicallydifferent criteria, the Western way of thinking and the ecological perception have developed the following methods:

8.1 Cost-benefit analysis

The theory suggests that the decision should maximize a certain useful operation. Thus, a common way to assess each criterion's usefulness is to 'interpret' it to money units. If we assume that this could be done on some selection criteria, it is very difficult for the natural parameters to be measured (such as the 'moral' side of the ecological preference) to money units.

A common method to use towards that direction is questionnaires to a certain population, to which a certain question is asked e.g**. 'how much somebody is willing to pay to live in a house with ecological certification?'** (WTP-willingness to pay). By summing up the increase-decrease of the average suggestions to each criterion the optimum selection is extracted.

Another method for analyzing cost is HPM (hedonic price method). According to this method the price of consumer goods depends on the system of decisions that is going to apply.

Thus the assessment is done e.g. with the question: if the house hasn't been built with ecological criteria, 'how much will the property's value decrease?'

A number of studies have shown that the credibility of the above methods is largely doubtful. This is because it has been proven that these methods do not reflect the tenants' real intentions, who are not properly informed and do not evaluate (or are not able to interpret) decisions, which clearly also include moral parameters, such as the 'ecological' ones to money.

8.2 Life cycle analysis / Assessment

The life cycle analysis is a technical assessment of the environmental burdens connected to a certain product, activity or process, which determines and quantifies the energy and materials used, as well as the waste released in the environment. With the life cycle analysis the effects by the use of the energy and materials, as well as of the spoilage, are evaluated, during a material's production, use and discard throughout its entire life span.

In Europe, its development was combined to the spread of the eco-label (EEC Regulation 880/92), while on international level an even wider spread of LCA is anticipated, through its integration in the series of ISO 14040 standards. According to the definition of the LCA (Life Cycle Analysis) method, for its application in the case of a building, the determining of the elements of consumption of mass and energy for its entire life cycle -from construction to demolition- is required.

For the assessment of a material's ecological behavior a large body of bibliography is available; yet there is no assessment of the materials used in Greece. Due to the lack of such data base for materials popular in Greece resorting to other countries' data bases is the only option (preferably European ones). In this case the data can be used to extract qualitative conclusions and to comparatively evaluate alternative building materials, but not necessarily to extract absolute figures.

Finally, the composition of this method as well becomes a problem of multi-criteria analysis while, the uncertainty of the parameters involved introduces even wider instability to the problem's depiction itself.

8.3 *Environmental preference method*

Another method applied during recent years for assessing building materials by ecological criteria is the 'environmental preference' EPM (Environmental Preference Method).

The 'environmental preference' has been in use in the Netherlands since 1991 for rapidly informing the public and the constructors about the building materials deemed environmentally friendly, based on one or more eco-criteria. The environmental preference is often based on a frequently updated rulebook that contains comparative charts allowing the building materials' grading according to eco-criteria.

The 'environmental preference' method is not as strict as the evaluation of all building materials based on full life cycle analysis would be. It is however easy to use, as it makes it easy to the user to select a material for the desired use by minimizing environmentally detrimental effects. Yet, the user needs to identify andselect the pool of materials forevaluation, and to this purpose, different 'eco-labels' have been established to certify the materials' eco-character.

8.4 *The ecological footprint*

To measure the human activity on earth, the so called 'ecological footprint' method has been developed. The 'ecological print' attempts to quantify the consumption of natural resources needed to cover a society's needs, by comparing it to earth's potential to produce and reproduce those resources. During this process, the absorption, by a viable way, of waste and Greenhouse effect by the activity is also evaluated.

As an expression of social creativity and action, the materials play a significant role to determining a society's 'ecological print'. However, the use of this method is usually carried out as an index of social activity.(?)

The "ecological footprint" examines the consumer's side versus the natural environment. But it is comparable to bio-capacity, a parameter that evaluates the creation of natural resources of a local community within certain limits.

8.5 *Multi-criteria analysis*

Granted the problems of cost-benefit analysis, the MCDA (multi-criteria decision analysis) is preferred, in which each criterion is individually graded, its 'weight' is evaluated based on a certain weight coefficient and a utility function is created, which leads to a numerical result.

For a more unified perception of the parameters, the Eco Balance method (multi-criteria analysis) has been developed, which includes various parameters of the environmental effects of a building and its materials. This method uses indexes reflecting (ELUs - Environmental Load Units).

So subjectively, 'environmental burdens' are deemed various phenomena during a material's production, use and discard, such as air pollution, biodiversity, human health etc. These 'environmental burdens' are introduced to an algorithm and through it they are evaluated; then the environmentally optimum technical solutions are selected.

It is however granted that the grades, the weight coefficients and finally the algorithm's composition itself -leading to the result- are all subjective.

Thus, the typical multi-criteria analysis approaches display little benefit, yet in cases of complex problems, where criteria cannot be 'measured' or 'evaluated', the human experience and deeper knowledge is essentially the one to compose the parameters in hand.

That doesn't mean that the formulated arguments are against 'rationality', yet it seems that the conflict 'rationality vs experience' and 'rationality vs holistic knowledge' does not solely lean on rationality's side. One could depict however the criteria assessment (knowledge) and correlate the criteria by some means (rationality), based on which the extraction of proven conclusions could be feasible. (Christofides 2005).

The parameters of the building materials' eco-behavior are not 'measured' in a way that allows their inclusion into an equation (e.g. how do I grade a material which is toxic, yet recyclable?).

Therefore, even if the grading system is essential as the basis to inform the decision, human experience and perception are in the end, indispensable in order to achieve the 'optimal' solution. Multi-criteria analysis via the multicriterion tableau.

A practiced way to assess a material's ecological behavior is a method able to (qualitatively) combine the LCA, along with the depiction of eco-preference in utility tables (instead of utility functions) with quality indexes of the criteria.

Thus, for the assessment of a material, or even better of the materials of a structure's architectural composition, scenarios are created (work assumptions), according to which the materials are placed into the building and -by evaluating their behavior over time- we end up with the best selection decision.

The indexes can be numerical; however, since most parameters of this problem cannot be quantified, the use of color or symbol indexes is preferred, which have been quantified after thorough study and evaluation of materials.

Such indexes are also established for use on the materials' packages.

Since the criteria for a material's eco-behavior are clearly more, in order to formulate the problem with clarity, we interpret the properties of the materials under assessment to depict them with proper visualization, so that they are easily perceivable by a user of the table. This aims at the understandability of the assessment, once it doesn't attempt to 'morph'(mask) the results with complex mathematics (utility functions) and arbitrary weight coefficients.

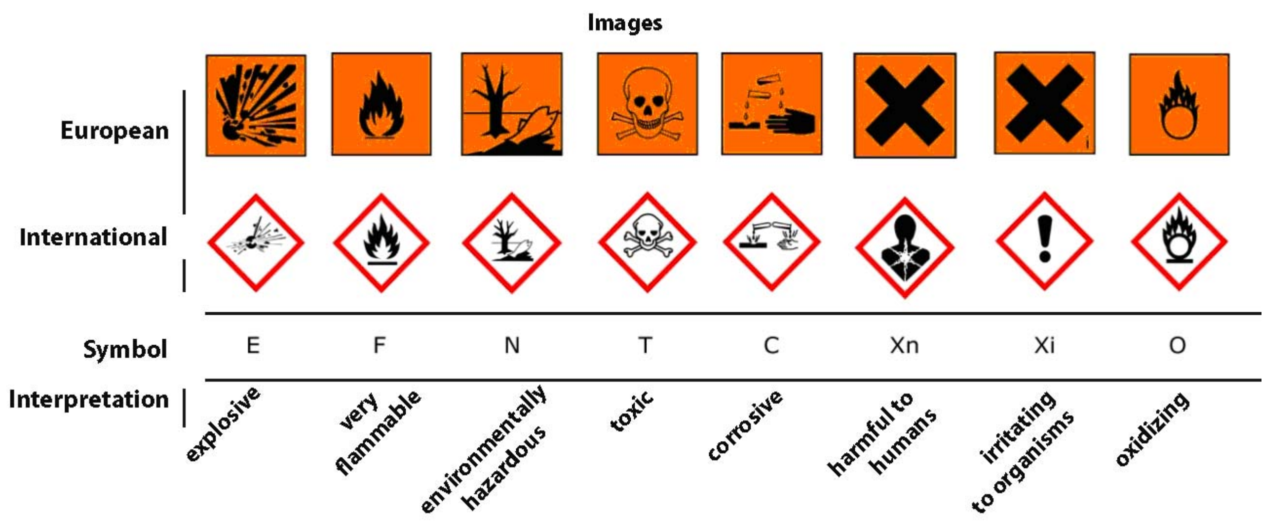


Table 8.1: Characteristic potential hazard indexes of materials found on packages

8.6 Categorization of assessment criteria for the application of the multicriterion tableau.

In the previous paragraphs different approaches to the materials' eco-behavior assessment were presented, but it was found that the multi-criteria analysis, with the use of utility tables, constitutes the most 'honest' method of evaluation.

In this context the problem of the materials' eco-behavior assessment is depicted in brief, based on the criteria described in the text.

Note that: is wrong to evaluate a material merely as such, but it should instead be evaluated when the material is inside the construction unit.

In brief, some criteria depicted and described as following.

Figure 8.1: Gas emissions

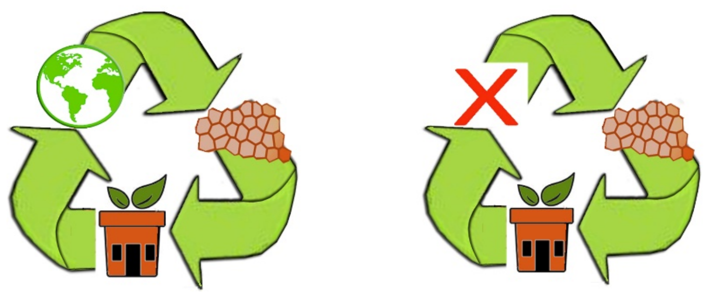


Figure 8.2: Renewable materials

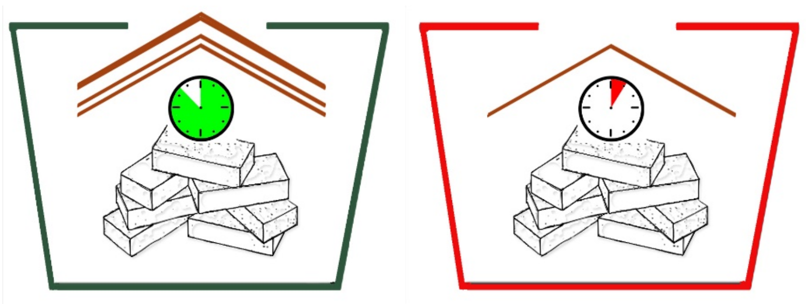


Figure 8.3: Duration-durability of the construction

Figure 8.4: Locality of the production

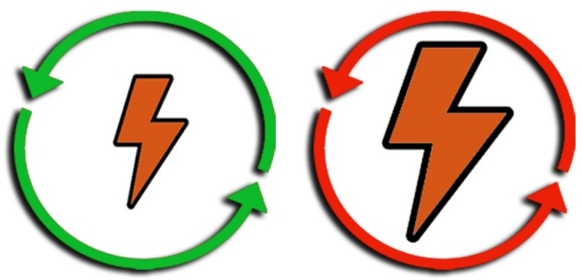


Figure 8.5: Embodied energy

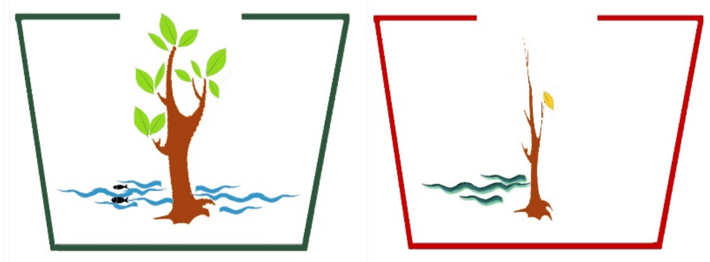


Figure 8.6: Environmental impacts

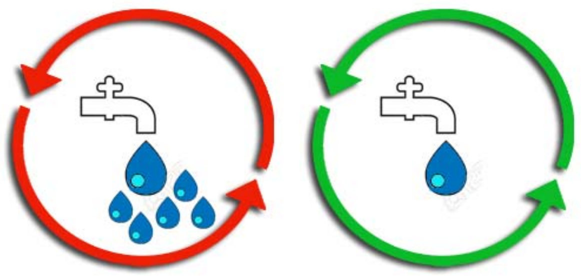


Figure 8.7: Embodied water

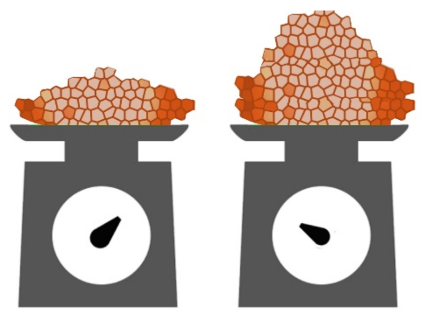


Figure 8.8: Use of raw materials

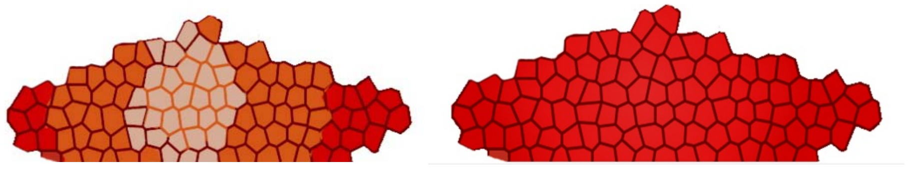


Figure 8.9: Use of recycled materials

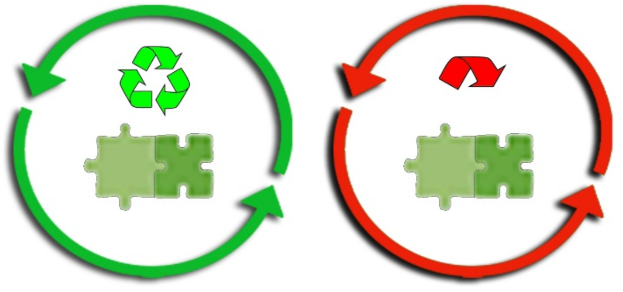


Figure 8.10: Ability for reuse

9 Development of a web platform of knowledge exchange for optimal selection of building materials based on ecological criteria

9.1 Decision making in technical problems

In technical problems where decisions must simultaneously satisfy several conflicting objectives, methods are based on benefit-cost analysis or multicriteria decision analysis helpful to identify the "optimal" decision. Usually big technical decisions are made by politics and influence the environment, but specialists, constructors and the society must have the ability to overview and inspect these decisions. **This platform is conceived with the aim to help people, organizations and governments develop their constructions (society) towards commons-based approaches through co-creating an open knowledge commons.**

Classical decision theory states that rational decisions are those that maximize some utility function. One way to construct such a function is to use benefit-cost analysis that is translating all criteria into monetary values. A common method of doing so is to make surveys and use people's willingness to pay (WTP).

A different method of benefit-cost analysis is the hedonic price method or (HPM), in which the prices of similar marketable goods, for example similar residential buildings, are compared in order to identify differences that can reasonably be attributed to the presence of a non-marketable good.

Given the problems of benefit-cost analysis, some prefer multi-criteria decision analysis (MCDA), in which the utility function is usually approximated by the weighted sum of the scores of the criteria. Of course, the scoring and the selection of weights are arbitrary to a certain extent. Proponents claim that such decisions cannot be objective in order that this arbitrariness reflects the subjective preferences of the decision, and that MCDA is valuable because it makes the subjectivity explicit rather than present the decision as a black box.

Regarding the decision-making process towards, found traditional approaches, based on quantitative methods such as MCDA has little practical benefit. In case of complex problems, where multiple, non-measurable criteria must be taken into account, human experience and intuition are necessary to compromise the conflicting criteria.

Unfortunately the discrimination between "rationality versus intuition" and "rationality versus holistic understanding" seems to imply that intuition and holistic understanding are somehow irrational; however the definition of rationality in traditional economic sense such as "complete and transitive preferences" has little to do with the everyday use of the word where it is synonymous with "reasonableness".

Extensive analysis of the problem from several viewpoints and a presentation of the reasoning are necessary to achieve an informed decision based on understanding and knowledge. In order to optimize a technical decision for society, engineers, experts and politics, architecture of a web platform based in "common" knowledge, optimizes the decision making analysis by evaluating building materials based on ecological criteria. The presentation of this process is presented by the formulation of a multi-criteria tableau.

9.2 Existing evaluation methods of the ecological criteria and the prototype of this platform

A different approach to construction with respect to the environment is the choice between materials of a platform that contribute to a sustainable and less aggravating choice for environment in various construction conditions. There are many green building materials that offer alternatives to concrete with a lower environmental impact but they too have energy footprint and their preparation also emits pollution in the environment. Construction with natural materials is an ecological process in all phases of its evolution, both for manufacturer and user, as well as for the environment. The question is how to choose the “proper” material in each case. Some of these materials are : straw bales, bamboo, recycled plastic, wood, earth blocks, rammed earth, timbercrete, ashcrete, ferrock, mycelium or grasscrete, hempcrete blocks that use a reduced portion of concrete.

Selection of building materials based on ecological criteria is a multicriterion problem with a lot of undetermined constant. A lot of the criteria can be evaluated by numbers, but other criteria cannot be easily translated into monetary value, eg. ?.

There are many attempts to address this issue, but in order to be practical, many of the criteria are inactivated, some of the criteria that cannot be assigned numerical values are evaluated by the platform controller, and as a result, the platforms finally give to the users results based on the evaluation of the platform maker.

The proposed platform interacts with the user for the evaluation of non numerical criteria and allows the user to validate all the criteria for the given problem. As the evaluation of ecological criteria is a technical problem which involves all the society, the design of this platform must be a collaborative website, like Wiki functioned. This platform can facilitate the creation of decision networks without directing them.

Figure 9.1: The logo of the wiki platform for decision making

9.3 Commons

The platform of this research is a commons-oriented peer production and its viability is based on real-world applications. Our focus on the productive potential of construction communities around the world inspires us to nurture a decision maker’s network with open collectives and more established criteria to extend environmental-friendly policy recommendations to those in the positions to promote change. By breaking down the relevant criteria into the multicriteria tableau and allowing the user to decide on their relative importance, the platform aims to make the decision-process transparent and the relative biases of human judgement explicit. This fosters reproducibility of the decision-making system and accountability of the decision-makers, as opposed to obscure and uninterpretable decision-making systems. At the same time, the openness of the platform promotes sharing of knowledge and social responsibility. The ability of the informed public to track and assess public decisions is a central concept of the democracy. Therefore, this platform serves to distribute power away from any central political figure and to allow individuals to develop their roles and contributions according to their society needs.

"The Digital Library of the Commons defines "commons" as "a general term for shared resources in which each stakeholder has an equal interest". The term "commons" derives from the traditional English legal term for common land, which are also known as "commons. As Frank van Laerhoven and Elinor Ostrom have stated; "Prior to the publication of Hardin's article on the tragedy of the commons (1968), titles containing the words 'the commons', 'common pool resources', or 'common property' were very rare in the academic literature.

This issue describes a process of sharing the knowledge as "commons". Wikis are growing because, at their core, they are about as simple as can be. That simplicity means that people find them easy to use. A wiki allows a group of people to enter and communally edit bits of text. These bits of text can be viewed and edited by anyone who visits the wiki.

Supplementary we could have a Wiki application which could be in use by a decision-maker (DM) to solve a multi-criteria problem.

Decision makers (DMs) are responsible for making the decision: they ‘own the problem’ but technical problems which evolve all the society are "common problems". To be able to take and implement a decision, DMs need hold the appropriate responsibility, authority and accountability. Web voting platforms which try to be involved to decision making progress are not doing this. These platforms are “guiding the opinions”.

9.4 Multicriterion tableau

One way to open and start modeling is to simply make the open question: "What are the issues and concerns that attract your attention?": As the discussion evolves in response to this question, the key points can be noted in a list or perhaps in a number of directories: external factors, opportunities, benefits, risk, constraints and many others .

This allows the construction of lists and groups of related concepts as the discussion continues. With this, the process can be made more effective by using formal brainstorming techniques to assist creativity and generate ideas overcoming interpersonal barriers such as misinformation or cognitive biases. The simplest approaches to brainstorming do a little more than we suggested above: ask the participants to list uncritically all the issues that seem vaguely relevant to the general problem they face, yet there are many variants which introduce more structure to the process in order to catalyze thinking eliminating the biased perspectives.

Additionally the users of this platform would be able to add criteria and evaluate them in tables with characteristic symbols and react with the data stored in the platform (opinion of the others). Platform will be able to collect the data of each user, react with the user and formulate a holistic summary of the results in symbols and colors. We could say that that this is a classic example of multi-criteria decision analysis (MCDA). Thus the problem must be summarized in a multicriterion tableau, which will describe criteria values. A value could be assigned to each criterion, then the alternatives would correspond to characteristic points of a curve lying on a 3-D objective space, i.e. the Pareto front of the relating multi objective optimisation problem (in reality, the middle part of it, which contains the most promising alternatives).

Although the Pareto front provides useful information regarding trade-offs between the conflicting criteria, a tabular representation of the problem, especially in problems with more than two criteria, is more practical regarding the decision-making process, since the table may contain additional information instead of pure (and sometimes arbitrary) numerical values.

The aim is to give to a user a supervisory view of the problem and optimized solutions suggested for it. In this way people could express an opinion on a technical problem, also analyze and visualize the opinions of others, and ultimately to draw their own conclusions.

9.5 Decision makers, users of the platform

The users of the platform could be:

- Simple users
- Engineers
- Experts.

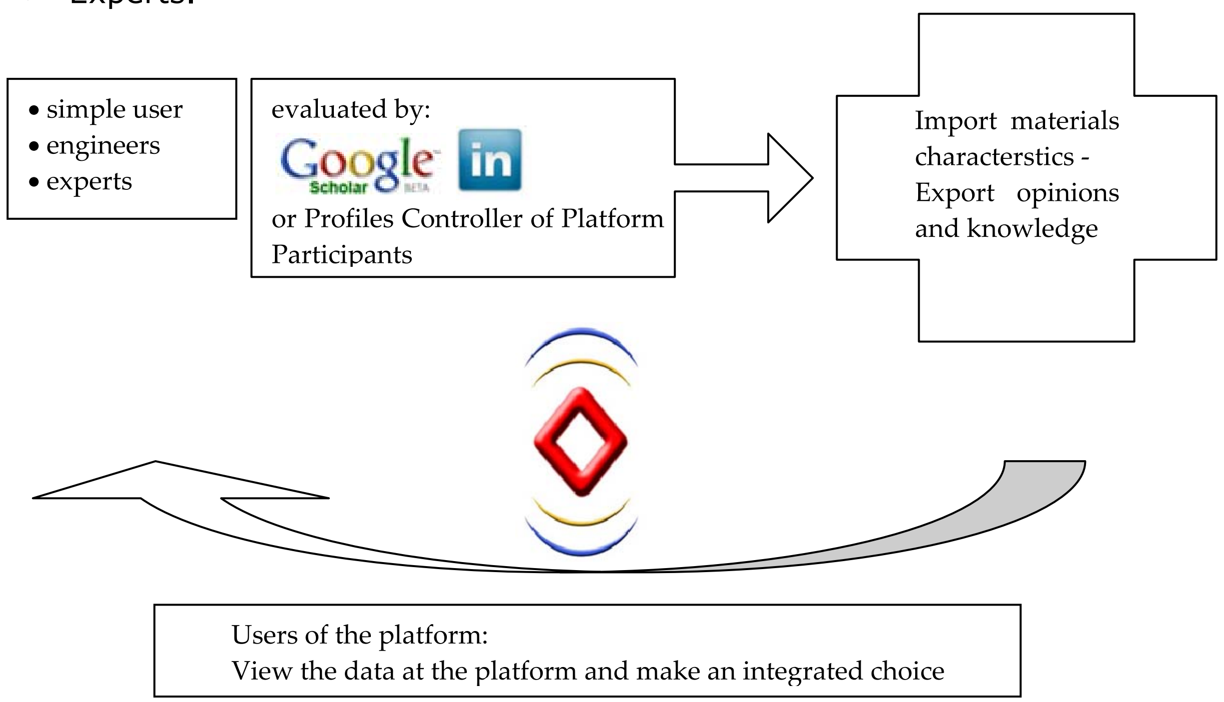


Figure 9.2: The use and the function of the platform

Engineers could be classified by Linkedin, while experts could be classified by Google Scholar for their scientific experience andby Linkedin fortheir professional experience, validated by the Profiles Controller of Platform Participants.

The three kinds of users have a different level of knowledge but all of them could import their opinion in the platform and share it with others. So one user could see the opinion or decision of one group separately of the total opinion.

9.6 Criteria

In order to choose and evaluate something, we have to know related values and measuring units. Speaking of building materials a related value could be m^3, m^2 or a part of construction (for example a type of windows 1×1 m). So the results have to be related to common units.

Most common criteria and theory of "selection of building materials based on ecological criteria" are presented at the report Methods & criteria of assessing building materials for the optimized selection in terms of their eco-behavior and this list could be as the beginning view point of the problem. This report is uploaded, and each user-member of the platform could be able to add new documentation (or just observe, inspect each evaluation).

1. Each criterion has a graphic symbolism which shows in simplicity the meaning of the criterion. This way the criteria could be summarized in a multicriterion tableau, where the values of the described criteria will be presented.

2. One user – approved member will be able to add a new criterion at the list.

3. There are values which can be measured and values without numeric value (for example toxicity). Therefore, values which could not be measured have to be approached in predictable value.

4. Values could be presented as cyclic measurement or as a box plot. In this representation both the minima and the maxima the potential base values of each criteria are shown.

Evaluating non measured crieria

Non measured criteria could be expressed with schematic types. An important note in non measured criteria is that the user could study the rating of the other users in order to formulate his/her rate.

Figure 9.3: Evaluation of no measured criteria (range 1-5)

Evaluating of the criteria

The criteria which could be measured must be shown in the same ratio (0-1) as the material which could not be measured. In this way the criteria could be comparable. But each criteria is expressed in different units and in different range. Their comparison could be made through Probability Distribution Function: each criterion is estimated by the empirical or theoretical distribution of values.

Thus, with the increased participation of new members the developing of the platform's elements will be a growing participatory process improving the representation of societal values by the probability distribution function of the criteria.

9.7 Categorization based on the order statistics

Provided that the opinion of each individual is based on multi-criteria (subjective and non-subjective), one may consider such evaluation for the materials as a random variable and assign a (unknown for now) probability distribution function, i.e. $F(x) = P(x \leq x)$, where x is the random variable of interest (evaluation criterion), F(x) the marginal probability distribution function and x the regular variable of x. In this manner, a value from 0 to 1 (by definition) will be assigned to each criterion and thus, a direct comparison among them can be achieved. As the tableau and the list of evaluated materials is growing, it is expected that the observed marginal probability distribution will reach the theoretical one, provided that everyone will finally agree on the discrimination of the categories and on the subjectivity of the evaluation criteria.

Evaluating the platform

One of the hidden technical functions could be also the self-evaluation of the platform. If the criteria with theoretical numerical value are related to the values of the platform it will be presented at the element.

Other criteria

Apart from the ecological criteria, engineering problems have to do with the technical feasibility of the construction and cost. So in order to have a DM process the materials have to be related to these values also, separated from the rest of the table.

9.8 Evaluating criteria with weight

In MDPA the scoring and the selection of weights are arbitrary, to a certain extent. Proponents claim that such decisions cannot be objective that this arbitrariness reflects the subjective preferences of the decision, and that MCDA is valuable because it makes the subjectivity explicit rather than present the decision as a black box.

So if the evaluation will be presented in an area of a circle=C pixels, how a selection of weight could be presented? For a supervisory perception of the table, the weights (importance) can multiply the area of the criteria. Presenting this in a multicriterion tableau, the evaluation of the criteria will be related to the 'surface' of the visualization (weight × area of the criterion= surface). With this definitions of weight one user can rate a criterion as insignificant (weight 0) less important (weight 1) important (weight 2) very important (weight 3). Thus weight 0 has no circle, weight 1 has 314 pixels (radius=1), weight 2 has 628 pixels (radius=1.4), weight 3 has 1256 pixels (radius=2)

Evaluating material A, material B and material C with criterion a (weight=0) criterion b (weight=1) criterion c (weight =2) criterion d (weight=3) by random evaluation of criteria, the tableau will be as in following figure.

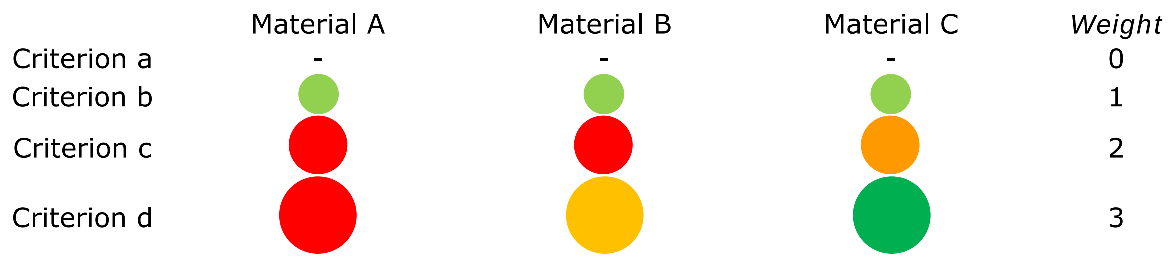


Table 9.1: Example of materials evaluation with different values of weight

Obviously, using the weights to evaluate the criteria is unreliable.

But if we have data of many people who had rank the weight of the criteria as insignificant, less important, important and very important, this could be a starting point for investigation in decision making process.

9.9 Result output and decision making

The output of the platform will be surfaces with distinct colors in a multicriterion tableau.

A function of the platform is that it would be able to store the evaluation of criteria and the selections of weights of each user. Therefore, a user could see his/her score of the criteria related with the selection of weights of the different groups, total or without them.

First level and the aim of the platform is to give to the user of the platform (the decision maker) the facility to evaluate the problem and view the opinion of the others.

Minima and maxima are presented. In criterion A minima could be good (i.e. MJ/kg in embodied energy), in criterion B maxima could be good (i.e. Kg/Kg recycling ability) but as values are presented with Probability

Distribution Function the range of the evaluation is 0-1 and the "good" is 1 and "bad" is 0.

Weights are unreliable but transparency of the evaluation of the criteria could be a good indicator.

9.10 Platform flowchart

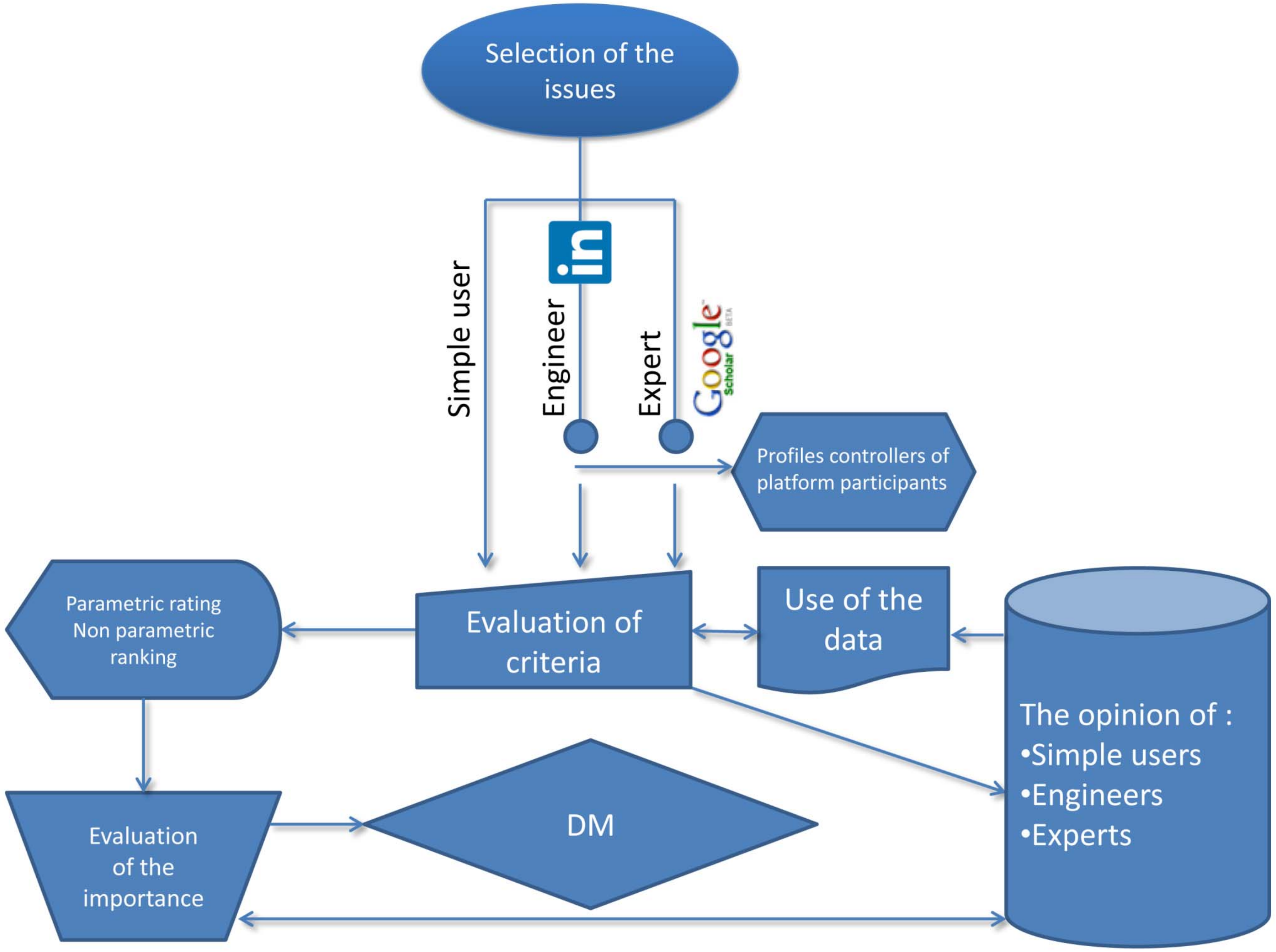


Figure 9.4: The flowchart of the function of the platform

9.11 Example of the calculations

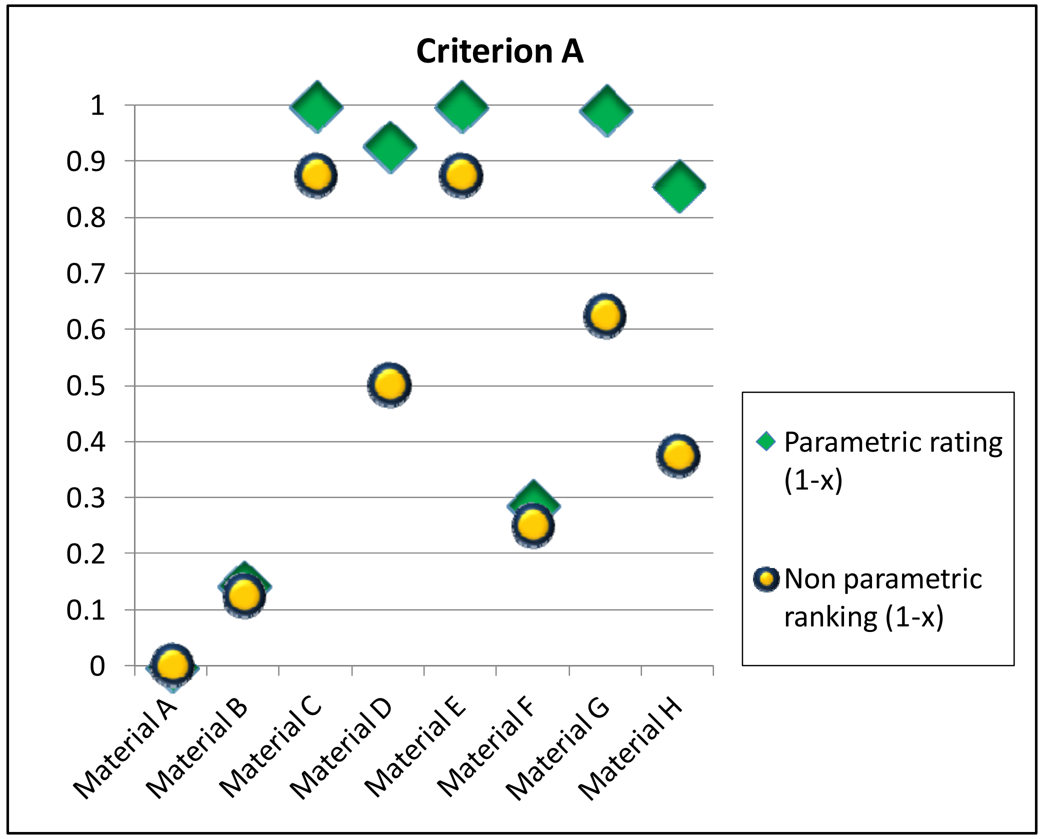
	Material A	Material B	Material C	Material D	Material E	Material F	Material G	Material H	
Criterion A	700	600	0	50	0	500	5	100	g/kg high (bad)
Criterion B	200	40	5	5	30	90	10	10	MJ/kg high (bad)
Criterion C	4	3	0	3	1	3	2	2	(non measured) range 1-5 (5-bad)

Table 9.2: Values of three criteria

Criterion A

Parametric rating	1	0.8571429	0	0.071429	0	0.714286	0.007142857	0.142857
Non parametric ranking	1	0.875	0.125	0.5	0.125	0.75	0.375	0.625

Table 9.3: Parametric rating and non parametric ranking of Criterion A



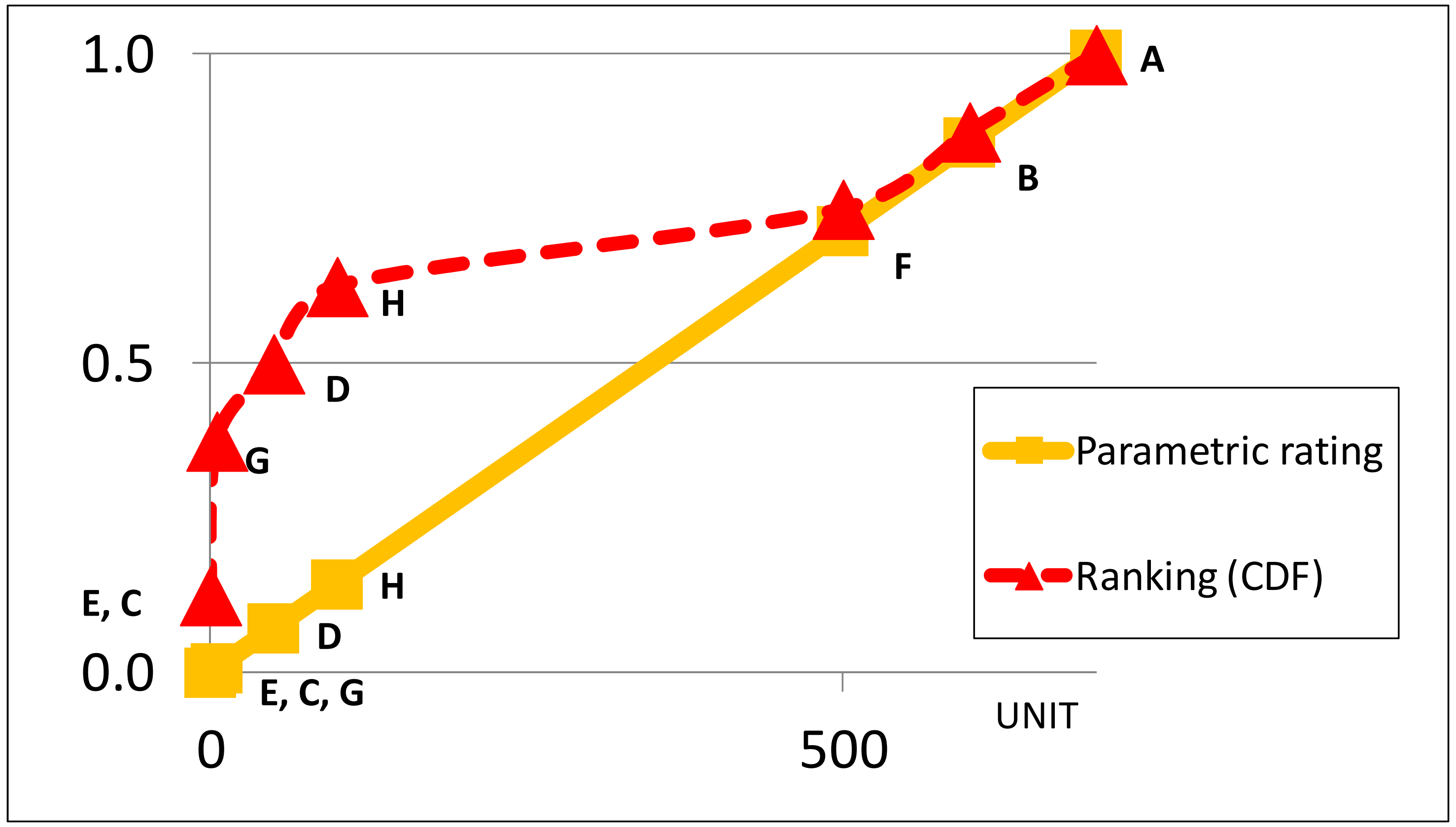


Figure 9.5: Example of the calculations of Criterion A

Criterion B

Parametric rating (1-x)	0	0.8205128	1	1	0.8717949	0.56410256	0.974358974	0.974359
Non parametric ranking (1-x)	0	0.25	0.875	0.875	0.375	0.125	0.625	0.625

Table 9.4: Parametric rating and non-parametric ranking of Criterion B

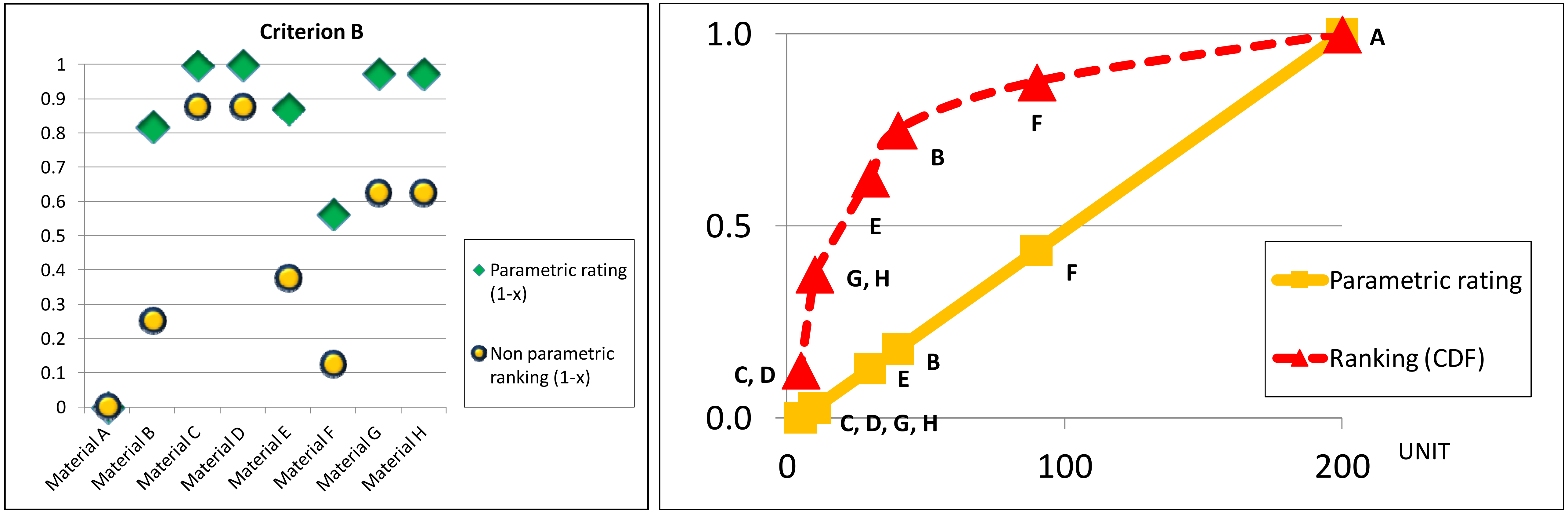


Figure 9.6: Evaluation the calculations of Criterion B

Criterion C

Parametric rating	1	0.75	0	0.75	0.25	0.75	0.5	0.5
Non parametric ranking	1	0.625	0.125	0.625	0.25	0.625	0.375	0.375

Table 9.5: Parametric rating and non-parametric ranking of Criterion C

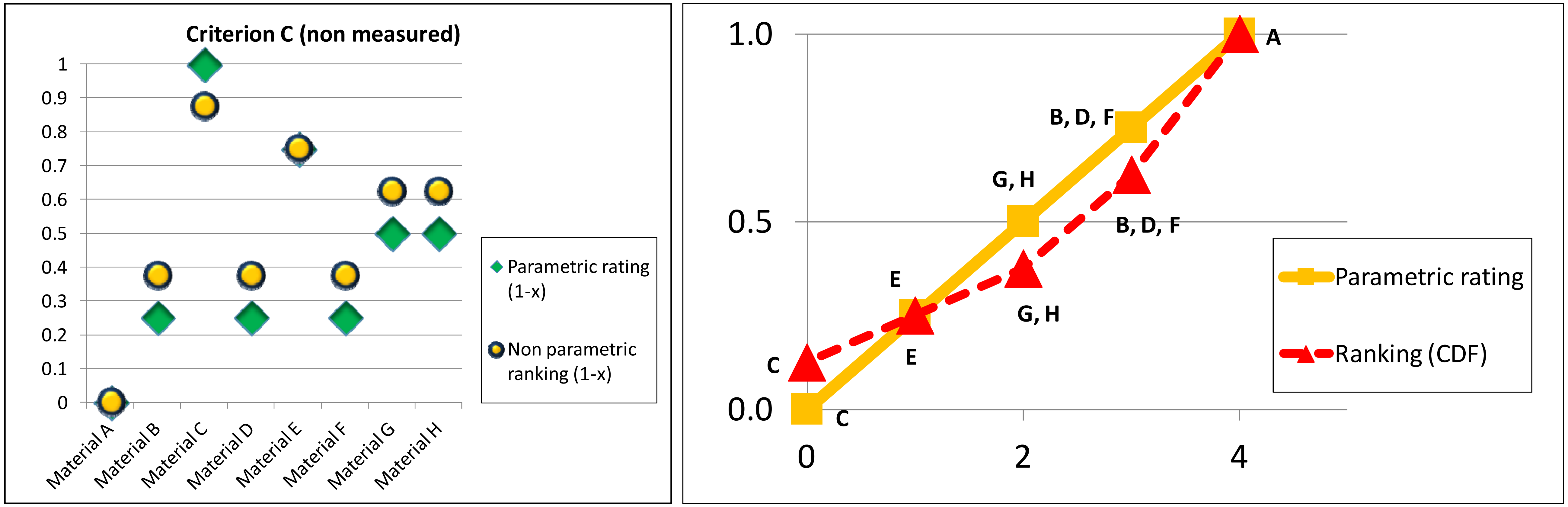


Figure 9.7: Evaluation the calculations of Criterion C

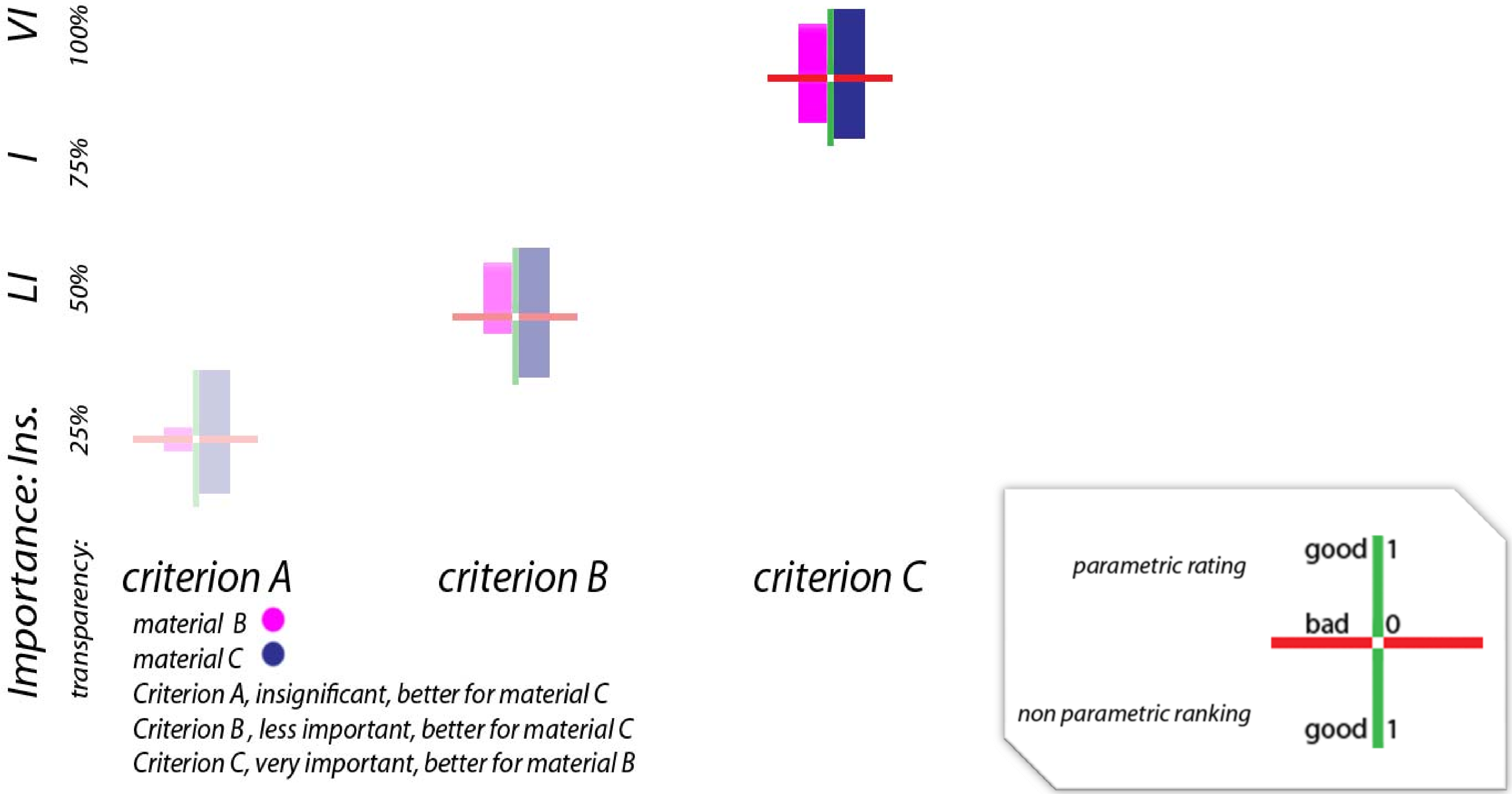


Figure 9.8: The three criteria presented in the multicriterion tableau

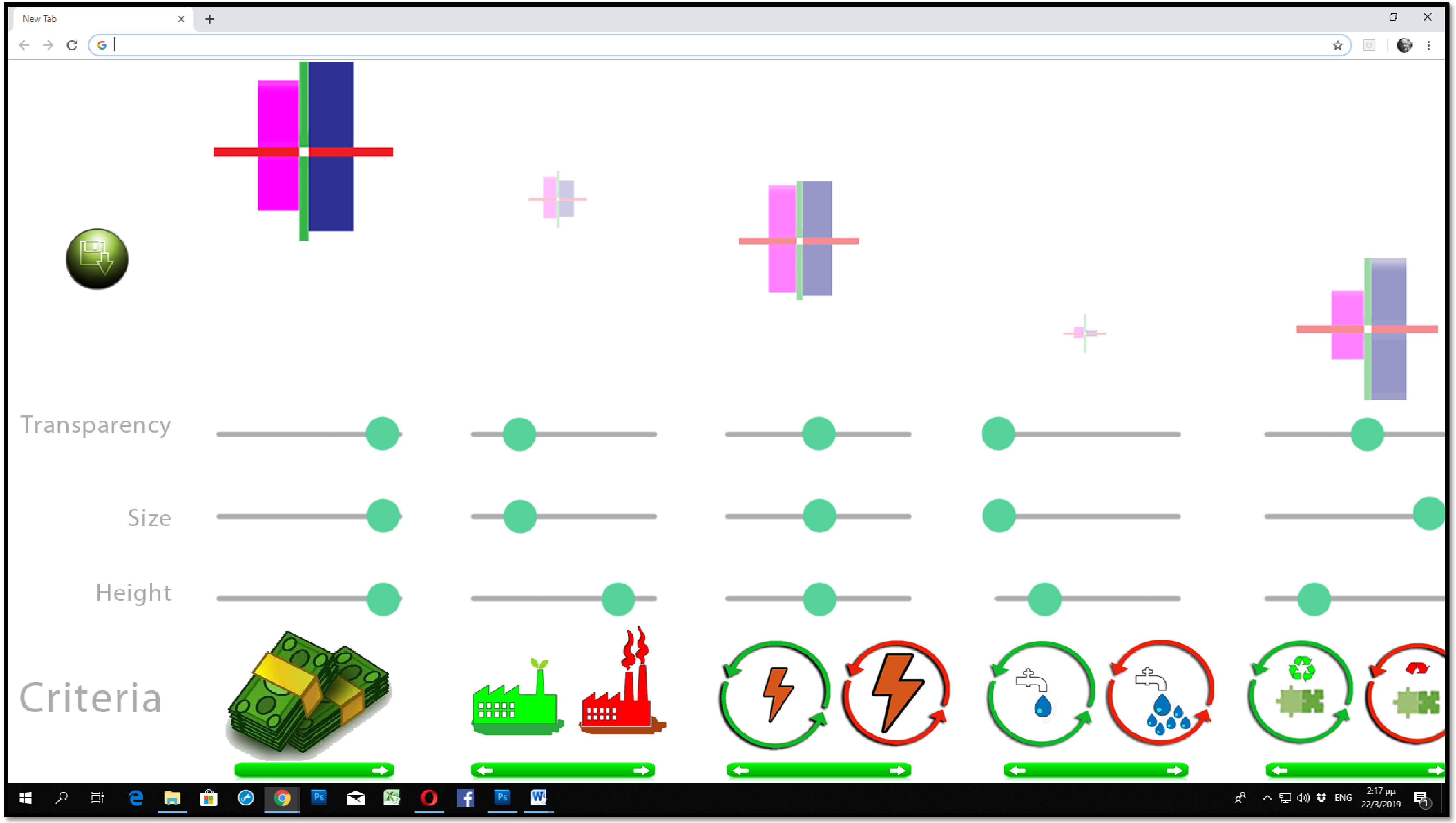


Figure 9.9: Example of the interface of the platform

9.13 Conclusions

Open decision making platforms are promising, but the regional variation of building materials, regulations and codes is challenging for their worldwide application. Although this platform will reflect the best practices based on construction experience and technology, local techniques vary from country to country. Regional diversification of building materials, regulations and codes can be tricky or confusing. Therefore, locality of each user must be taken into account. For instance, introducing locality as a criterion for material selection could be a future direction for improvement.

The central premise of the platform is that: as engineering problems are "Common" problems, these type of platforms could serve as an application of exchange of knowledge and opinions and ultimately, an impactful application of democracy in decision making.

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