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"Augmented" eco-design thanks to the methodological drivers of the "Usefulness Thinking" approach

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Abstract

Faced with the environmental emergency, eco-design needs to be "augmented" in order to further reduce the environmental impact of the products we use. To avoid products that are overloaded with unnecessary functions or that do not fully meet the consumer's needs, products whose lifespan is too short in relation to the resources consumed for their production, or products that are never fully used because they meet needs that are too infrequent, this article argues that we should consider a different frame of reference than lifecycle thinking, based on the maximum usefulness of exploitation of the extracted raw materials. This new framework called "Usefulness Thinking" focuses on the usefulness of the consumed resources in relation to 1/ the usage needs of consumers, 2/ the product exploitation time and 3/ its exploitation space/community. Following an analysis of the literature, the article presents the initial methodological drivers for an eco-design approach based on "Usefulness thinking" and applies it to the case of a cordless upright vacuum cleaner for a consumer living in an apartment or a detached house. For each configuration, a significant environmental performance is obtained, approaching a gain factor of 2.

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Keywords: Usefulness thinking, eco-innovations, upgradability, sharing, frugal innovation

1. Introduction

Faced with the environmental emergency, the current efforts are not sufficient. Eco-design needs to be "augmented" to further reduce the environmental impact of the products we use. Eco-design is governed today by Life Cycle thinking, i.e. every system is analyzed across all phases of the life cycle, from the extraction of the material to its end-of-life treatment. Life Cycle Assessment (LCA) is the tool that enables all environmental impacts to be measured in a rational way, which avoids forgetting or intuitively underestimating certain impact drivers. In theory, eco-design fits into the design process proposed by Pahl and Beitz in 1977 [1], which comprises four phases: 1) defining product specifications, 2) exploring solution concepts, 3) developing the final solution of the product, 4) developing the documents required for its production. In practice, eco-

design comes into play mainly after the specifications have been defined and rather late because the use of LCA requires an advanced level of product definition, which is not the case in the early design phase. In the first design phase, it is difficult to include environmental objectives in the functional specifications, as this requires a knowledge base on the environmental impacts of past products, and to objectivize in an actionable way an environmental performance characterized by some fifteen impact categories [2]. With regard to the second design phase, downstream from the definition of specifications, some studies, such as EcoValue analysis [3], try to propose a pre-assessment of the first concepts, by analogy with Value Analysis. But once again, it is very difficult to work without LCA data.

In parallel with this difficulty in integrating environmental issues upstream of the design process, we can unfortunately

observe a great many products that are the antithesis of eco-friendly considerations. These include products that are overloaded with unnecessary functions or do not fully meet consumer needs, products whose lifespan is too short in relation to the resources consumed in their production due to premature wear and tear/reliability or obsolescence, or products that are never fully used because they meet needs that are too infrequent, or even exceptional. To remedy these obvious discrepancies between what is designed and the practical realities of consumption, it is claimed in this article to consider another frame of reference than life cycle thinking, based on the maximum usefulness of the raw materials that make up a product. For an identified need, maximum usefulness means maximizing the number of cycles of use of the product satisfying the need of the consumer(s) in relation to the quantity of materials extracted and shaped over the life of the product. This new framework, called "Usefulness Thinking", focuses on avoiding wastage of consumed resources by 1/ adjusting the product to the usage needs of consumers, 2/ by increasing its operating time and/or 3/ its operating space/community. These areas of work can be mobilized as early as the system definition phases, and are actionable by designers since they can easily be translated into functional objectives.

After presenting these three dimensions of utility with regard to the state of the art (section 1), the article presents the first methodological axes of an eco-design approach based on "Usefulness thinking" in section 2. An experiment applying these methodological axes to the case of a cordless stick vacuum cleaner, an assessment of potential environmental gains, is proposed in Section 3. The results, which demonstrate the significant potential for environmental performance, are presented in Section 4 and discussed in Section 5.

2. Issues on utility in product design

In the literature, the notion of a product's utility is very little discussed, whether in terms of the product's 'ethical' purpose (meeting an essential or futile need), the choice of its attributes or its use to avoid all kinds of waste. The Ellen MacArthur Foundation [4] defines a product's utility as a combination of the length of a product's use phase and the intensity of its use. The material utility proposed by Stegmann includes the material use intensity, which accounts for the proportion that can be recycled, and separately the length of the material's use, which assesses duration of carbon sequestration [5]. If utility means avoiding waste, in the Waste hierarchy [6], strategies to avoid overconsumption, reduce material use and reuse products over time or across multiple people are environmentally preferable than Recycle, Recover and Landfill. Sufficiency-driven business models seek to moderate overall resource consumption notably by making products that last longer and avoiding built-in obsolescence, focusing on satisfying 'needs' rather than promoting 'wants' and fast-fashion [7] [8].

As regards the usefulness of a device in relation to consumers' usage needs, focusing on satisfying 'needs' rather than promoting 'wants' and fast-fashion [7], or concentrating on core functionalities as advocated by the frugal innovation movement [9], run counter to current norms and practices.

Traditionally, in the phase of interpreting consumer needs at the very beginning of the design process, the need is defined as the "dissatisfaction that motivates the creation of the product" [10], i.e. the marketing department uses market research to gather customer expectations that will enable the product to be attractive in relation to current trends (technological, functional, ergonomic, stylistic, etc.). The Kano [11] or Tetraclass models characterize the satisfaction/dissatisfaction generated by the presence or absence of certain functions or attributes. As a result, in a bid to outdo competitors in terms of functionality and/or technology, product specifications very often go far beyond simply meeting the consumer's need to use the product. In the frugal innovation movement [13] or the low-tech movement, systems are redefined to achieve a useful function within constraints of resources, implementation (materials available locally, at a lower cost, accessible to the consumer, etc.). But little is known about methods, approaches, or procedures that specifically support the systematic development of frugal innovations [14]. Brem et al. propose to avoid functional fixedness and simplify the system by concentrating on functions, components and their interrelations. The mechanisms for choosing the functional definition that maximizes utility have yet to be defined [13].

With regard to the usefulness of extracted material in relation to operating time, post-end-of-life processes (recycling, remanufacturing, etc.) are not considered in the Usefulness Thinking framework. This is the logic of programmed perpetuity instead of circularity. Product's utility is obtained by the length of a product's use phase [4]. Beyond the problems of sub-quality, the sustainability of the extracted and shaped material can be compromised over time by differences between what is recommended and the practices of use, storage and maintenance: the emergence of numerous potential usage drifts affect both energy consumption and the lifespan of an appliance [15]; and 50% to 70% of breakdowns or requests for assistance for large household appliances are caused by a lack of maintenance or incorrect use [16]. The way an appliance operates over time also depends on obsolescence, which occurs in response to major changes in technology, fashion, new regulatory standards, etc. To counter this phenomenon, some authors [17,18] propose integrating upgrades over time, i.e. functional improvements to counter the phenomenon of obsolescence.

The usefulness of the extracted material in relation to its space/community of exploitation is linked to the notion of sharing, mutualization, reuse products across multiple people [7]: in the case of under-utilized objects, the possible exploitation of the good by an "extended" community, by mutualizing the device between different users, increases its usefulness because the number of cycles of usage consumed during its life will then be greater. The intensity of use of the product [4] is increased. With regard to the sharing or pooling of goods, there is little literature and much of it focuses on bike sharing [19]. The EurêCook experiment [20] involving the sharing of small electrical appliances in a supermarket did not result in any environmental gains because of the many journeys involved and a service that required the product to be cleaned

and packaged in new packaging each time it was used, since the future consumer was not known a priori. It seems easier to envisage the sharing of goods within a residential complex, because the place is defined, the community is circumscribed, and a common space exists [21].

3. Methodological axes for an eco-design approach centred on utility

To go beyond the elements presented in section 2, methodological axes are proposed for designing systems that maximize the usefulness of the extracted materials in relation to the real need for use, its operating time and its exploitation area.

3.1. Methodology for maximizing the usefulness of the extracted material in relation to usage needs

As regards the usefulness of the extracted material in relation to consumers' usage needs, the approach is to 1) choose the functions and adjust the functional objectives to meet the usage need, with a utilitarian aim, i.e. sufficiently but without surplus, by eliminating mismatches between functions and needs for use (hypertrophies and/or functional shortcomings) and 2) consciously choosing a few expectations/attributes/criteria that make the good desirable/attractive to a population, so as not to hinder its dissemination. To make this adjustment, the notion of Situations of Use (SU) proposed by Pialot [22] is considered, as an intermediary object between need and function. A covered Situation of Use (SU) designates a usage capacity permitted by the product in a given context, or in other words, what the system allows the consumer to do.

The essential SUs, which are necessary to meet the reason for the product's existence and which correspond to the strict "primary" need for use, are called "service SUs". They are distinguished from non-necessary SUs, which are linked to secondary or complementary aims ("secondary SUs"), which create value more from the point of view of attractiveness than utility. Secondly, depending on the consumer target and frequency with which these SUs appear, a distinction should be made between "generic SUs", common to any user, from those more specific to a very distinct population. "Specific SUs" are characterized by a specific level of capability/performance and/or a specific context. To obtain the most useful system, it is considered that any element or functionality that contributes to satisfying the generic service SUs is useful, and that all the other functional requirements are a priori only useful under certain specific conditions, or even futile. Similarly, when translating SUs into required functions, any over-dimensioning of the functional level, whether in terms of a "utilitarian" capability/performance or the experiential satisfaction of an SU, is deemed to be "not useful" a priori.

To adjust the functional definition of a product, the following working framework is proposed:

- 1) Identify the generic SUs and their corresponding functions.

- 2) by scanning the different consumer targets, list the specific service SUs, the functions, and their required functional level, then consider adaptations (modularity integrated into the product) and extensions (addition of an external module) in terms of capabilities and/or context to transform a product that only meets the generic SUs into a system that supports also certain specific SUs. In the case of a very specific SU, adding a 'special' service to complete the range of uses covered by the product is an option.
- 3) choose secondary functions, functional oversizing and esteem functions, which are not essential in a utilitarian vision to meet the need for use, but which partly condition the attractiveness of the good in the eyes of the consumer. It is therefore a question of choosing them precisely, with an awareness of both the additional environmental impact and the added use value.

3.2. Methodology for maximizing the usefulness of the extracted material in relation to the operating time

Increased sustainability of a product's use over time is built on the following steps:

- 1) projecting the product over the long term, with robust solutions to give meaning to maximizing the sustainability of the use of the good over time.
- 2) anticipate in the design stage potential usage drifts (between nominal usage and real practices) that could be detrimental to the product's operating life, as well as wear and tear and reliability issues; and propose devices for monitoring to optimize the object's upkeep and maintenance.
- 3) faced with the obsolescence phenomenon, identify and anticipate the main functional evolutions linked to generic service SUs and those that have a major impact on attractiveness.

3.3. Methodology for maximizing the usefulness of the extracted material in relation to its exploitation area

Sharing the use of "under-utilized" goods among a group of consumers is conceived as follows:

- 1) designing a better quality appliance because it will be used intensively and because the cost of acquiring it will be spread over a number of consumers
- 2) anticipate statistically more varied usage by different users and imagine solutions that incorporate eco-use strategies or more robust components to ensure the integrity of the device.
- 3) To ensure that the sharing consumer feels comfortable with the shared product, consider solutions to depersonalize the product, i.e. avoid parts that are too quickly marked by "visual/ostensible" wear and tear, which are perceived negatively when the item is not one's own, anticipate the possibility of different ergonomic settings for the device from one person to another, the anonymization of personal digital data, poor perceptions of hygiene, etc. In particular, this redesign of certain parts should make it possible to

avoid the requirement for a product to be cleaned and packaged in new packaging each time it is used, as was the case in the EurêCook project.

4. Research methodology

The aim of this article is to show that this new eco-design approach centered on utility is an opportunity to develop sustainable systems with significant environmental gain. The proposed experimental protocol consists in:

- 1) identify eco-innovation avenues arising from each of the 3 methodological axes of eco-design centered on utility
- 2) mix solutions to respond to each product usage configuration
- 3) evaluate these solutions using Simapro LCA software.

The application case is a cordless stick vacuum cleaner (VC). Because its autonomy is limited (around 30 min at low speed, 10 min at high speed) and its charging time exceeds 3 hours, a cordless stick vacuum cleaner (cordless VC) has the characteristics of an auxiliary vacuum cleaner, used in addition to another appliance (type canister VC). Its main advantage is its practicality, as it is cordless and easy to store, thanks to its rigid "broom" shape without the cord. So, to quickly clean a small area (such as the kitchen after a meal), it's easy to access, quick to set up, easy to handle, not very tiring and quick to store.

The technical developments made between the different generations of this appliance have increased its suction capacity in terms of the areas covered (floor, under furniture, on the sofa), and its suction power (to the point of being able to vacuum carpets), but autonomy remains limited. So, with today's product, we can see three usage configurations presented in Table 1: A- Private home; B- Large apartment; C- Small flat. The lifetime (LT) of a cordless stick vacuum cleaner is estimated at 5 years on average [23]. This low figure (corresponding to 500 charging cycles of the device) can be explained by the effects of the miniaturization/undersizing of certain modules and the over-sophistication of the suction head. In fact, the lack of suction power due to the structural choice of a small motor, compensated by the addition of a rotating brush fitted with an additional motor at the suction head, leads to reliability problems (motor/electronic board overheating) and progressive clogging of the suction head, which is detrimental to performance. The lifetime (LT) of a canister vacuum cleaner is estimated at 8 years on average. For each configuration, considering the same frequency/quality of suction, this lifetime is set according to the surface area of the living space to be vacuumed.

Table 1. The 3 usage configurations of a cordless VC.

Configuration	Type of VC & use	LT of VC
A Private home > 100 m ²	Canister 1,5 time /week Cordless 1,5 charge/week	Canister =7 years Cordless =6 years
B Large apartment (50 m ² <x<100 m ²)	Canister 1,5 time/week Cordless 1,5 charge/week	Canister =9 years Cordless =6 years
C Small flat <50 m ²	Cordless 2,5 charge/week	Cordless =4 years

Table 2 shows the data for each module derived from the dismantling of a cordless vacuum cleaner, which will be used for the LCA of the various solutions generated. NUC is the Number of Use Cycles to be used before failure, and a usage cycle corresponds to one charge of the appliance in this case.

Table 2. Data for cordless VC.

Mod.	Sub-modules	Material	Mass (g)	NUC (uc)
M1	Upper casings 1 & 2	ABS	307	1700 uc
	electronic board	Complex	27	500 uc
	Battery	Li-Ion	750	900 uc
M2	Lower Casings 1 & 2	ABS	703	1700 uc
	Main Motor (130w)	Steel / Copper	180	500 uc
	Turbine	PC	16	1700 uc
	Casing Main Motor	ABS	128	1700 uc
	Foam	PU	0,3	consumables
M3	Suction casing 1 + nozzle	ABS / PVC	461	1700 uc
	Suction casing 2 + wheels	PP	103	1700 uc
	Suction Motor (20w)	Steel/ Copper	60	500 uc
	Brush	ABS / Steel	41	1700 uc
	Brush casing	PC	51	1700 uc
M4	Tank	ABS	323	1700 uc
	Filter	PU	6	consumables
	Separator	PP	85	1700 uc
M5	Charger	PP / Copper	76	1700 uc
M6	Packaging	Cardboard/PS /Steel	989	Single use

For the environmental impacts of the canister VC, results from the EcoInvent database will be used.

5. Experiment and Results

The first phase of the experiment consists of identifying eco-innovations based on the 3 methodological axes of Usefulness thinking. Regarding the usefulness of the extracted material in relation to usage requirements, a generic SU is identified for hard floor vacuuming. Vacuuming of carpets or rugs can be considered as a specific SU, as it corresponds to deep or finishing vacuuming, which is not in line with an auxiliary vacuum cleaner. As Figure 1 shows, the positioning of the cordless vacuum cleaner is problematic from the point of view of its usefulness for configurations A and B. Its short autonomy means that it cannot fully satisfy the generic SU, while at the same time its characteristics mean that it has the potential for a specific SU. From this observation arise two eco-innovations for a cordless VC: Solution 1 and Solution 2.

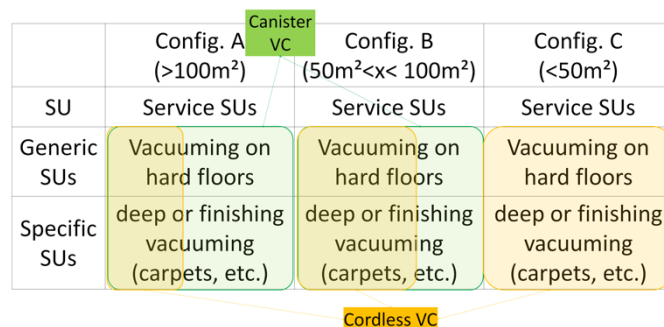


Figure 1. Scope of use of canister and cordless vacuum cleaners.

Solution 1 is a "rustic" stick vacuum cleaner focused on the generic SU of vacuuming hard floors, with a larger main motor with double the power and without the rotating brush (or else with a mechanical drive -"bissell" type- using larger wheels). Its usefulness would be limited to additional suction, in practical "easy and fast" mode, as a complement to a canister vacuum cleaner. Its lifetime, thanks to the choice of a more robust drive chain, would be increased to 900 battery use cycles ($LT_{sol.1}=900/500 * LT_{cordless}$).

The eco-innovation **Solution 2** would consist in "merging" the two types of vacuum cleaner: the cordless VC would then have only one 600 W motor (instead of 130 W + 20 W), a canister VC suction head and, to go beyond the short battery autonomy, an electric cable with a reel attached to the user's belt and a cord to the vacuum cleaner would enable it to be connected to the mains. In this way, the same appliance would offer both the practicality of a cordless VC for short vacuuming runs and the ability to vacuum large surfaces for long periods of time. In addition, buying a single appliance means investing in better quality and a monitoring/maintenance contract, which increases the lifespan of this eco-innovation ($LT_{sol.2}=LT_{canister}$).

Considering the usefulness of the extracted material in relation to the operating time, the **Solution 3** emerges using the principle of increased sustainability. Based on a product with a more robust motor and electronics, a new suction head would be integrated into the cordless vacuum cleaner every 400 use cycles to avoid clogging, loss of performance and reliability problems, and the battery would be changed after 800 use cycles to project the product to a maximum operating life of around 1,500 use cycles. For reasons of obsolescence and wear and tear of certain parts over time, it is estimated that the lifetime of the vacuum cleaner is limited to 15 years ($LT_{sol.3}=15$ years).

Lastly, to increase the usefulness of the extracted material in relation to its operating space/community, the **Solution 4** of a vacuum cleaner sharing service is emerging when the distance between dwellings is very small. This is particularly the case in multi-unit buildings. To preserve the "easy and fast" aspects of using the cordless VC, it is preferably to share canister vacuums within a community of users. Rather than avoiding under-utilization of an appliance, the principle of sharing provides access to a shared canister vacuum cleaner of better quality, with professional care and maintenance, and therefore with a longer lifetime ($LT_{sol.4}=LT_{canister} * 1.5$). The additional environmental impact of this appliance is estimated with a factor of $x=1.2$.

Table 3 shows the environmental impact of each solution, considering the extraction-manufacturing phase of the life cycle, in aggregate score (EcoPts).

Table 3. Environmental impact of each solution.

Type of Solution	EI
Canister (current product)	3,588
Canister HQ (Solution 4)	4,305
Cordless (current product)	2,321
Cordless Solution 1 ("rustic")	2,518
Cordless Solution 2 (merger "canister+cordless")	4,124
Cordless Solution 3 (with replaced modules)	3,546

Table 4 shows, for each configuration, the solutions or pairs of solutions considered, and the results obtained in terms of environmental impact (EI) and gain factor (GF) compared with the reference scenario (in gray). A minimum of one vacuum cleaner in each home was considered to cover the generic SU of vacuuming hard floors. Lifetimes are calculated in proportion to the surfaces to be vacuumed and the number of charges planned for cordless vacuum cleaners. Reference Flows (RF) are calculated for a 10-year period.

Table 4. Results for each configuration with the solution(s) considered.

Cf	Type of VC	LT of VC	RF (10y.)	EI	GF
A	Canister	Canister = 7 years	1.43	8.994	Ref.
	+ Cordless	Cordless = 6 years	1.67		
	Canister	Canister = 7 years	1.43	7.414	1.21
	+ solution 1	Sol. 1 = 11 years	0.91		
	Canister	Canister = 7 years	1.43	7.489	1.20
	+ solution 3	Sol. 3 = 15 years	0.67		
	Solution 2	Sol. 2 = 7 years	1.43	5.891	1.53
B	Canister	Canister = 9 years	1.11	7.855	Ref.
	+ Cordless	Cordless = 6 years	1.67		
	Solution 4	Sol. 4 = 13,5 years	0.74	5.478	1.43
	+ Solution 1	Sol. 1 = 11 years	0.91		
	Solution 4	Sol. 4 = 13,5 years	0.74	5.215	1.51
	+ Solution 3	Sol. 3 = 15 years	0.67		
	Solution 2	Sol. 2 = 9 years	1.11	4.582	1.71
C	Cordless	Cordless = 4 years	2.5	5.803	Ref.
	Solution 1	Sol. 1 = 7 years	1.43	3.597	1.61
	Solution 2	Sol. 2 = 11 years	0.91	3.749	1.55
	Solution 3	Sol. 3 = 11,5 years	0.87	3.083	1.88
	Solution 4	Sol. 4 = 16,5 years	0.61	4.898	1.18
	+ Solution 1	Sol. 1 = 11 years	0.91		
	Solution 4	Sol. 4 = 16,5 years	0.61	4.973	1.17
	+ Solution 3	Sol. 3 = 15 years	0.67		

The results show environmental gains for each configuration considered and with each type of solution proposed. For Configuration A, the sharing solution is not accessible and the best strategy with the data used seems to be to "merge" the qualities of the cordless and canister vacuum cleaners into a single product, as proposed by solution 2. For Configuration B, several options offer significant gain factors (of the order of 1.5 to 1.7): sharing the canister VC with a more "robust" cordless VC, or merging the cordless and canister VC. For configuration C, because the reference appliance is functionally adjusted to the need, the potential savings lie more in robustness. Solution 1 is acceptable if the user has no carpets or rugs. Solution 3 which is the increased sustainability solution enables the cordless VC to be projected over the long term, with a gain factor of 1.8.

6. Discussion and Conclusion

Experimentation with the utility-centered eco-design approach proposed in this article and applied to the case of the stick vacuum cleaner shows, firstly, how easy it is to generate different eco-innovative avenues by considering the three dimensions of utility.

Secondly, each methodological axis of usefulness thinking contributes to obtaining an environmental gain. The results show the possibility of environmental gains approaching a gain factor of 2, with the data and assumptions used (household with

good hygiene, i.e. frequent vacuuming). Some of the data is estimated because the four proposed solutions do not yet exist. The environmental assessment focuses on the extraction and manufacturing operations, and takes into account the material inputs of the product and of the modules integrated/changed over time and other consumables. Energy consumption during use, which is considered to be identical whatever the scenario, and end-of-life impacts are not considered in this article. More locally, the impacts of the infrastructure of a sharing service within a residential complex (including, for example, a set of connected locks, RFID chips and an app) are not taken into account, and in the other direction the benefits of immobilizing less material in a sharing system to meet the needs of several users are not modelled. Further work is needed on these issues.

Thirdly, efforts in the three areas of Usefulness thinking can be translated into functional objectives, such as adjusting the functional definition of the product to the need for use, judiciously choosing certain specifications to ensure a certain use value for the customer, extending the lifespan of certain modules, improving their robustness, or making them easier to dismantle. However, anything that can be easily translated into functional objectives is actionable by the designers and can be dealt with from the very first phases of system definition.

Fourth, beyond the adjusted functional definition of the product, Usefulness thinking also proposes to extend the scope of design to the consumption system, in order to make the best use of the good over time, with the logic of increased sustainability because it is anticipated, and/or intended for a given population, via sharing between several users.

In summary, as Figure 2 illustrates, the design activities of Utility Thinking, which are concentrated upstream of the specifications, fill the gaps in life cycle thinking, which takes place downstream of the definition of product specifications. In this way, Useful Thinking increases both the scope of eco-design, through complementary activities that can be carried out by designers at the earliest stages of the design process, and the potential for environmental gains. This is how Usefulness thinking leads to "augmented" eco-design.

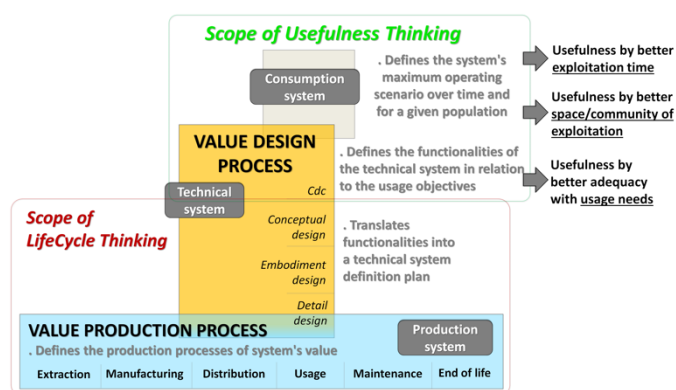


Figure 2. Scope of Usefulness Thinking for eco-design.

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