MASTER

Sustainability as an antagonist of finiteness

de Laat, P.

Award date:
2016

Title | Sustainability as an antagonist of finiteness

Keywords | (1) resource management, (2) systems approach, (3) eco-effectiveness, (4) scarcity, (5) law of the minimum

This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Science in Architecture, Building and Planning – Building Technology.

Eindhoven University of Technology

Graduation date | 26-01-2016

Author | P. de Laat
Student number | 0679420

Graduation Supervision Committee:

- J. J. N. Lichtenberg (chairman)
- M. Mohammadi
- M. M. T. Dominicus

List of contents:

Separate summary article:

Numerous authors have indicated that the conventional manner in which resources are being utilized cannot be maintained over an extensive period of time. The concept of sustainability or sustainable development was introduced, among others as an attempt to oppose this prospect of finiteness and ensure the untrammelled continuation of human society. It is questionable however, whether or not the embodiment of the notion genuinely and sufficiently conducts as an antagonist of finiteness.

This study involves the unravelment of a certain extent of the underlying rationale of the issue in order to indicate, and thereafter understand, the different components of importance. This obtained comprehension will in turn, be employed to compare the prolonging capabilities of two distinct strategy types. The distinct difference between these types is whether the strategy aims to ‘treat’ or ‘cure’ the system’s lack of maintainability. The components of importance which are elaborated on however, do not offer a conclusive substantiation to either dismiss the current measures as insufficient or embrace them as well enough. What can be concluded though, is that conventional interventions meant to oppose the prospect of finiteness are definitely not the most effective manner of endeavour conceivable.

The current hierarchies which rank a measure’s effectiveness in addressing the issue of depleting resources are regarded insufficient to make such a comparison. An alternative hierarchy has therefore been developed which, unlike the existing ones (e.g. triad approach), includes the more elusive contributions of an intervention to a sustainable future and is also based on the notion that not all declining resources require an equal amount of one’s attention (law of the minimum).

The mentioned hierarchy is composed of two elements: the main hierarchy which ranks different variables on their influence on the degree of effectiveness and the subhierarchies which ranks, per variable, its categorized variants from most effective to least effective. Based on the insight gained from the developed hierarchy it can be concluded that conventional measures (policy and practice) are primarily focussed on the parameters of the system, which is regarded as the least effective variant of the most influential variable. It is therefore argued that more attention should be given to measures related to the rules or adaptive capability of the resource system.

Sustainability as an antagonist of finiteness

Patrick de Laat

Eindhoven University of Technology, Den Dolech 2, 5612 AZ Eindhoven, the Netherlands
E-mail: patrick_delaat@hotmail.com

Numerous authors have indicated that the conventional manner in which resources are being utilized cannot be maintained over an extensive period of time. The concept of sustainability or sustainable development was introduced, among others as an attempt to oppose this prospect of finiteness and ensure the untrammelled continuation of human society. It is questionable however, whether or not this embodiment of the notion genuinely and sufficiently conducts as an antagonist of finiteness. This study involves the unravelment of a certain extent of the underlying rationale of the issue in order to indicate, and thereafter understand, the different components of importance. This obtained comprehension will in turn, be employed to compare the prolonging capabilities of two distinct strategy types. The components of importance which are elaborated on however, do not offer a conclusive substantiation to either dismiss the current measures as insufficient or embrace them as well enough. What can be concluded though, is that conventional interventions meant to oppose the prospect of finiteness are definitely not the most effective manner of endeavour conceivable. With regard to policy and practice, it is argued that conventional measures primarily focus on a system's parameters, while interventions in the rules or adaptive capability of a system are both considered as more effective.

Keywords: resource management, systems approach, eco-effectiveness, scarcity, law of the minimum

Introduction

Some reluctance seems appropriate concerning the use of a word such as 'sustainability', due to the excessive and often divergent use of it. In this context however, no alternative term seems as adequate. The simple combination of the words 'ability' and 'sustain' out of which sustainability is composed is quite self-explanatory and might be described best as an antagonist of finiteness.

Numerous authors have indicated that the conventional manner in which resources are being utilized cannot be maintained over an extensive period of time (Boulding, 1966; Meadows, Meadows, Randers, & Behrens III, 1972; Stahel, 1984; McDonough, & Braungart, 2002). A finite supply of resources, in combination with an approach often simplistically described as 'take, make and dispose', will inevitably result in a lack of resources and an abundance of waste. Intertwined with this unmaintainable process is the ever growing physical demand of society, which aggravates the depleting effect of the aforementioned approach and also constitutes an own issue concerning finiteness (Jackson, 2009).

The concept of sustainability or sustainable development was introduced, among others as an attempt to oppose this prospect of finiteness and ensure the untrammelled continuation of human society (United Nations, 1987). Two types of strategies, each based on a distinct intervention of the resource system, can be distinguished in light of this pursuit. Wherein these types differ is whether the strategy aims to 'treat' or 'cure' the system's lack of maintainability.

Conventional enactment of policy and practice, related to this element of sustainability, exhibits a clear preference for the former (Huesemann, 2004). It is questionable however, whether or not this embodiment of the notion genuinely and sufficiently conducts as an antagonist of finiteness. The statistics for instance, do not favour a positive hypothesis in this matter (Krausmann, Gingrich, Eisenmenger, Erb, Haberl, & Fischer-Kowalski, 2009).

This study involves the unravelment of a certain extent of the underlying rationale of the issue in order to indicate, and thereafter understand, the different components of importance. This obtained comprehension will in turn, be employed to compare the prolonging capabilities of both strategy types. All in order to provide an answer to the aforementioned question: whether or not this generally preferred strategy for sustainable development conducts genuinely and sufficiently as an antagonist of finiteness.

Society's system of resource usage

Figure 1 illustrates the (partial) decomposition of society's system of resource usage, by means of Structured Analysis (Ross, 1977). The interventions previously conducted under the pretext of sustainability are excluded from this graph, in order to establish a clear baseline for comparison. The prospect of finiteness, entangled as an inherent characteristic of the system is already visible in the most abstract representation of it (level 0), in which it is illustrated as a process dependent on the possibility to obtain a certain input and repel a certain output. For various reasons society prefers the input x over the output y, it is considered a more useful state of things.

Irreversibility

In the field of thermodynamics, such a process would be described as irreversible. An act is regarded as reversible if it is possible to re-establishing the initial state without any additional input. Irreversibility occurs due to some kind of dissipation associated with spontaneous and non-spontaneous interactions to which a force or substance is subjected to. The use of the word 'dissipation' in this context intends to describe a process in which a part or the whole of a force or substance is fragmentized and dispersed, both to an extent which generally constitutes its disappearance.

This phenomenon is most apparent with regard to the usage of energy, which might be described as much more volatile in the comparison with matter. The same phenomenon with regard to matter seems a lot less evident. It is however, brought to one's attention by the occurrence of a product's consumption. When one speaks of the technical performance of a product, it is commonly regarded as a characteristic which gradually degrades over time, up until the end of the product's lifespan has been reached and it is thoroughly worn-out. It is assumed that minute dissipations of the various substances out of which a products is composted play a major role in this loss of a product's functionality. The quantities of substances which are actually dispersed during use might be negligible, the associated deterioration of a product's configuration however, is not.

Product manufacturing

Looking at the first level of decomposition (level 1), one will notice that each of the processes either constitutes the consumption of products, requires a compensation for its occurrence or both. The middle one is applicable for the process of product manufacturing in which raw materials are transformed into products. The further decomposition of this process (level 3) shows that the manufacturing of products primarily involves mechanical work, for instance the shaping of composites to materials of commerce. Both energy and machinery are required to enable such work.

When a given amount of energy is employed to conduct an act of mechanical work it will, due to resistances opposed to it, eventually result in the force's completely dissipation as heat (Joule, 1850). In addition, a piece of machinery, as a product itself, is not immune to the effects of consumption, which means that the product will cease to function after a certain amount of time. In theory, a worn-out product primarily constitutes a loss of energy, since the dissipation of matter is negligible and a replacement of the product is required, which is also made by a process of product manufacturing.

Use of consumer products

The products resulting from the manufacturing process are dived in consumer (c.) products and process facilitating (pf.) products. The consumer products are the input for the process use of c. products in which they are eventually transformed into worn-out products. The c. products are meant to fulfil certain human demands and thus its consumption can be described as a direct contribution to the degree of material well-being, which is arguably the ultimate goal of the system.

Once an item leaves the consumption stage it is described in the figure as a worn-out product, which is conventionally regarded as waste. The notion of waste and how waste comes to be is somewhat peculiar. The term 'waste' is a judgement of value, or rather a judgement of disvalue. The value society assigns to materials and their corresponding states is related to the products whose existence it (potentially) enables.

The effort made to obtain a certain material gives some indication of its worth. However, when it comes to waste an effort is made to get rid of it. Such a transformation of value to disvalue cannot be explained by the losses of dissipation. Something else must occur somewhere during manufacturing which alters the raw materials in a manner which degrades its suitability with the process and in turn its usability and value as a resource. The chemical activities of the mixing phase (level 3a) is presumed to be the primary culprit in this matter.

Use of process facilitating product

The remaining process, the use of pf. products, might be the most interesting with regard to finiteness. The output of process inputs realized in this process compensates for the losses due to dissipation and thus enables the manufacturing to continue beyond the initial temporality it is exposed to. The means to compensate are by definition exhaustible since it originated from a demand for replenishment. As shown in the decomposition of this process (level 2b), the use of energy and machinery are regarded as the means, the two components necessary to enable the processes of product manufacturing and use of c. products.

A manner to simplify the communication of a product's consumption is to describe it in accordance with the number of its applications. For instance, a transportation truck has a technical lifespan of n_1 years in which it is able to perform n_2 rides of n_3 kilometres. Needless to say, the numbers n_1, n_2 and n_3 described in this example represent average values. The number of applications which the product in this example is able to perform is n_2. Each requirement for the use of machinery can thus be described as a withdrawal from the number of its applications. In accordance with this perspective, applications are added through the addition of pf. products and the output of worn-out products is in turn directly related to this withdrawal.

The required replenishment of energy is fulfilled in a somewhat similar fashion. However, wherein the use of a pf. product which generates energy differs from the ones that do not, is that with the former the product itself is not directly applied to support other processes. Thus with regard to these products it seems more suited to express their consumption through the use of the energy they generate. For instance, a steam engine with a technical lifespan of n_4 years in which it is able to produce n_5 joule of energy, would imply that a new steam engine would be required after the withdrawal of n_5 joule of energy.

Furthermore, the conventional method of generating energy is through the combustion of raw materials, which inevitably results in the dispersal of combusted matter through the mediums air, water and soil.

Defects of the system

In summation, there are three factors which cause the system's lack of maintainability. The first being the loss of energy related to the direct and indirect usages of it. The second factor is the loss of materials due to the combustion of materials associated with generating energy. Lastly, the third defect is the degradation of the suitability of materials with the process of manufacturing, imposed during the process itself.

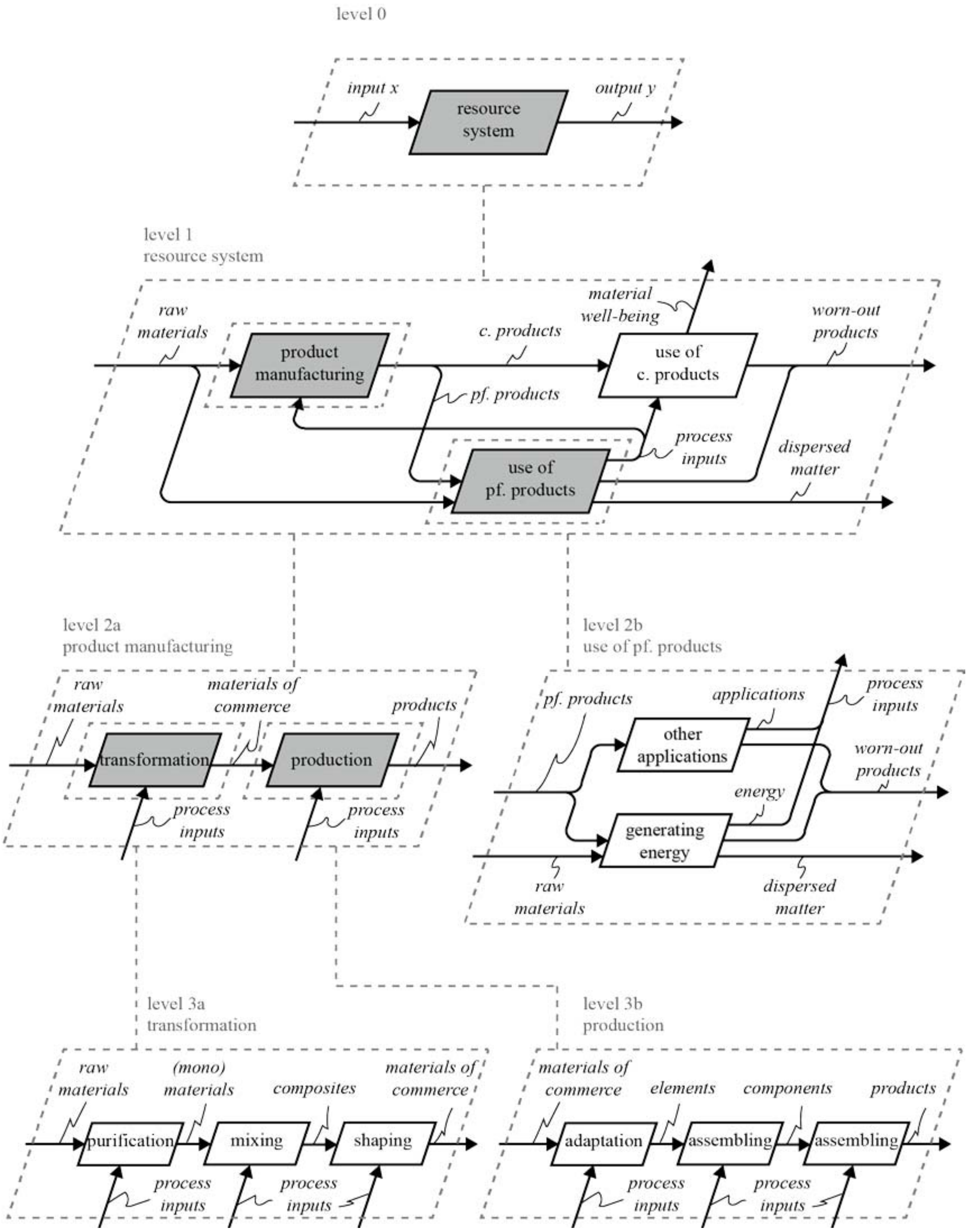

Figure 1 The (partial) decomposition of society's system of resource usage, the third level of decomposition is based on (Eekhout, 1997)

Strategy I: treatment

Now that there is some clarity on the workings of the resource system, this paper will continue on the topic of its countermeasures. The first strategy which will be elaborated on is the preferred one in policy and practice, the treatment of the system's lack of maintainability. Treating an issue is regarded as addressing the symptoms, whereas curing it is regarded as addressing the defects. The defects and symptoms are related as cause and consequence, in which a symptom acts as a sign or indication of an underlying defect.

Symptoms

The current state of affairs exhibits three main symptoms namely the depletion of resources, the accumulation of waste and the emission of greenhouse gases. As can been seen in figure 1 (level 1), each of the symptoms is related to a passage where substances either enter or exit the resource system. Evidently, these symptoms are interrelated however, they are commonly approached as separate entities. As separate entities, the symptoms differ in the type of issue it constitutes.

The accumulation of waste for instance, might be considered as a nuisance, an inefficiency or a burden with regard to its disposal. There is (nearly) no delay in either its creation or destruction and therefor it is probably the simplest of the issues.

Arguably the most popular issue in environmental policy is climate change, caused by the presence of an excess of greenhouse gases (United Nations, 1992). This excess of greenhouse gases is for a substantial proportion related to the combustion process conducted to generate energy. Thus this symptom is both the consequence of one issue and one of the causes of another.

Lastly, the issue of depleting resources. Unlike the previous issues, which pose more of an external threat (environmental deterioration), this issue poses an internal threat. A system can chose, to a certain extent, to ignore an excess of output but it cannot function without the required amount of input. As such, this issue might be described as the most relevant to this study.

Triad approach

Irrespectively of which of these symptoms it involves, the attitude of policy and practice towards addressing it seems similar to the way of thinking present in the triad approach (Entrop, & Brouwers, 2009). The triad approach is a hierarchy of actions, arranged in a sequence of most effective to least effective with regard to addressing a certain issue. The first step in the hierarchy is always the prevention of (unnecessary) use, followed by substitutional use and lastly prudent conduct.

As mentioned, the emission of greenhouse gases is for a substantial proportion related to energy generated in a conventional fashion. In accordance with the first action of the triad, policies aim to prevent energy usage by setting the requirement that future buildings have to be built as 'nearly zero-energy buildings' (European Parliament, 2010). Policies have also initiated, and are working towards, a shift in which the use of non-renewable energy will be replaced by its renewable variant (IPCC, 2014), which is in line with the second step of the hierarchy.

With regard to the management of waste, policies aim to stimulate the conversion of waste into a 'useful application' as the most preferred manner of disposal (Ruimte en Mileu, 2010). The idea behind this policy is that the use of disvalued materials act as a substitute for the use of the valued ones. There is, however, a great difference between what is regarded as a useful application for waste and what is regarded as a useful application for virgin material. For instance, the 'recovery' of energy from waste by means of combustion is also labelled as a useful application (Ruimte en Mileu, 2010). Ironically, this example is arguably an aggravation of both the other issues.

The issue of depleting resources differs from the others as it is not commonly acknowledged, especially in practice (MVO Nederland, 2015). The thought that depletion is not an issue because 'the free market will solve scarcity' is very common (Diederen, 2010, p. 22). The measures which are being made though, usually involve the use of renewable materials as a substitute for the non-renewable ones (MVO Nederland, 2015).

Prospects of treatment

The question from which this study originated was not whether or not actual policy and practice conducts genuinely and sufficiently as an antagonist of finiteness, but whether or not their attitude, the embodiment of the notion, conducts in such a manner. The issue of depleting resources, how it is expected to develop during treatment and in turn how it effects the system, will be used as an indicator in order to do so.

Depleting resources only constitutes a problem the moment scarcity occurs. Scarcity implies a deficient in a certain quantity. With regard to metabolic processes, such as the process represented by the resource system, the quantity of importance is a rate, meaning an amount per unit of time. In general, there are two aspects which influence the potential of the production rate, namely the state of the resource base and the state of technology.

State of the resource base

As mentioned, the value society assigns to materials and their corresponding states is related to the products whose existence it (potentially) enables. Few to none of the raw materials are, in their natural state, perfectly suited to the composition of a product which is valued, thus adjustments are generally required. The state of the resource base gives an indication of the average capacity of configurations of matter to be subjected to these changes required by the social organization.

For instance, figure 2 illustrates the amount of energy which is required for the refinement of ore into a kg of pure metal, for different grades of ore. Higher ore grades are valued more because less energy input is required in order to attain a similar amount of metal from the purification process. It seems that inorganic sources, in general, requires less work for refinement if the state exhibits a higher purity. Thus their capacity to be subjected to the required changes is regarded as superior. It should be noted that by this notion the capacity of configurations of matter to be subjected to change is described with regard to the first step of a common transformation process (figure 1), known as 'purification', thus it is applicable to specify recycling potential or source quality and not the overall usefulness of material configurations.

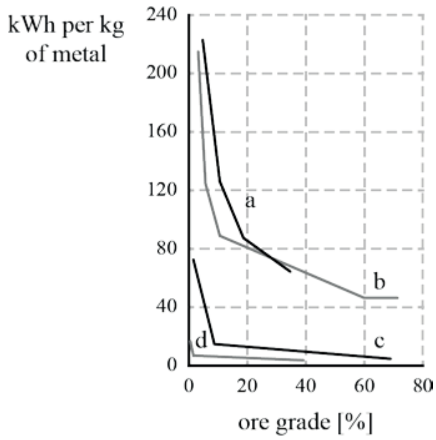

Figure 2 Energy required to produce pure metal for different grades of ore, 'a' represents aluminium in clays, 'b' aluminium in bauxite, 'c' iron in laterites and 'd' iron in hematite, adapted from (Meadows, Randers, & Meadows, 2004, p. 147)

The state of the resource base actually represents several quantities (q) each with their associated states (s), as stated by the following equation:

$$\text{resource base} = \sum_{k=1}^{n} [q_k \cdot s_k]$$

In this equation s_1 to s_n are arranged in a descending sequence from best state to worst state. Naturally, exploitation of resources will occur in correspondence with the described sequence from best to worst.

As mentioned as one of the system's defects, the suitability of materials with the process of manufacturing is generally degraded during the process itself. Thus when an amount q_x with a state s_1 is used as input for the process, its state will be degraded during transformation resulting in the same amount q_x in a lowered state, for instance s_{n-2}, as output.

Due to this occurrence, the higher quality states will continuously be transformed into lower quality states. This issue thus constitutes a depletion of quality rather than actual quantity.

This is the case for all inorganic materials in which the use of virgin material is prioritized above the use of waste. Naturally, there are exceptions where waste is actually preferred over virgin material, for instance, with aluminium since it requires significantly less work to refine as scrap (Olivieri, Romani, & Neri, 2006).

Organic material, which exhibits short-term renewal, also works a little bit different due to its ability to, over time, rejuvenate itself to its former superior state. This ability enables the state of the resource base, with regard to the organic segment, to maintain its level of quality, at least if it is granted sufficient time to rejuvenate.

State of technology

The state of the raw materials which still remain unexploited is equal at best, in comparison with that which has already been used, due to the 'best to worst' approach of its exploitation. This, in combination with the becoming of waste is why the current developments in this aspect are regarded as a negative influence on the potential of the production rate.

The premise of the treatment strategy is fairly simple, it accepts the presence of these negative influences, as a kind of unwanted by-product of the system, and endeavours to compensate with technological advances (Chertow, 2000). However, compensation alone is not enough due to the ever growing physical demand of society. The technological development are thus expected to overcompensate the degrading state of the resource base, by bigger, better or different machinery, in order to enable a continuous growth in the potential of the production rate.

Any predicting statement about whether or not the extent of technological advances is adequate for the given task, cannot be substantiated in a proper manner. Nonetheless, common faith in its capacity seems endless. Something can be said however, about technological growth in terms of bigger and better machinery.

The general function of the phenomenon of growth exhibits a universal uniformity across all disciplines in which it is observed (von Bertalanffy, 1968). It is assumed that the increase in technological efficiency is no exception to the rule. In this phenomenon one entity is expanding in an area consisting of other variables and constants which do not follow a similar trajectory. Beyond a certain point this environment will oppose some form of resistance, which will increase proportionally to the increase in growth (Verhulst, 1838). The function is known as a logistic curve (von Bertalanffy, 1968), meaning that growth starts in an exponential fashion and eventually transits into a nearly stationary state approaching an absolute maximum, as illustrated in figure 3. In the field of economics this notion is known as the 'law of diminishing returns' (Black, Hashimzade, & Myles, 2012).

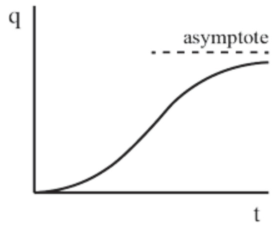

Figure 3 General function of growth, adapted from (von Bertalanffy, 1968, p. 63)

For a good example of the presence of such absolute limitations, the author refers to the Betz-Limit, which describes the maximum of the theoretically possible exploitation of wind by means of a wind motor (Betz, 1920). The phenomenon is also clearly recognizable in the improvement or enlargement of the insulation layer of a building, in which each addition of additional insulation to a building is less effective, in terms of energy savings, as the previous one (Rovers, Ritzen & Gommans, 2013).

It is the possibility of 'different' machinery, which complicates the act of predicting technological development. Bigger and better machinery will not suffice for the task of constantly improving technology by an amount which is equal or greater than the last, as it will become increasingly difficult. At the very least, 'different' technological solutions are required in order to compensate the degrading state of the resource base and also enable a continuous growth in production rate.

Law of the minimum

Fortunately, not all declining resources require an equal amount of one's attention. A notion known as the 'law of the minimum' states that at any giving time growth of an organismic system is limited by the amount of the essential element most closely approaching the critical necessary minimum, which implies that one should only worry themselves with one resource at a time since only the most critical resource is responsible for the resistance opposed on to growth. The analogy with a barrel is used, as illustrated in figure 4, to further clarify the notion. In this analogy, each stave out of which the barrel is composed represents the relation between the available production rate ($^{q_{an}}/_{t}$) and the rate which is demanded ($^{q_{dn}}/_{t}$), for a specific resource (r_n), as stated in the following equation:

$$r_n = \frac{^{q_{an}}/_{t}}{^{q_{dn}}/_{t}}$$

The water level illustrates the physical extent of the social organization, meaning the multiplication of the population size with the general level of material well-being, in which material well-being is regarded as an amount of access to and/or possession of consumer products. In a barrel, water is able to rise until it exceeds the height of the smallest stave, in which it will overflow and any further rise would not be possible. This occurs if, for a particular resource, demand exceeds supply, thus in this example if $r_n < 1$.

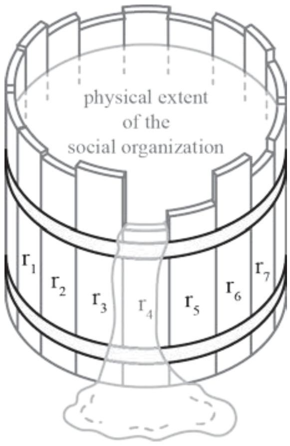

Figure 4 Law of the minimum – 'barrel analogy'

The law of the minimum, as stated, disregards the effects of 'adaptation' (Gorban, Pokidysheva, Smirnova, & Tyukina, 2011), which are the adjustments made by an organismic system, with regard to its supplies and demands, meant to even out the staves and extent the possibilities of growth. Especially, the demands exhibits a certain extent of flexibility.

Tolerance

The most basic manifestation of this flexibility is known as the concept of 'tolerance' (Shelford, 1913). The concept of tolerance states that although there is an optimum in the amount required it also exhibits an absolute minimum, meaning that as long as the amount available is not below this range it can suffice for growth. In addition, the concept of tolerance states that the width of the range, or the amount in which optimum and minimum differ, differs for each essential element (r_n). The principle is illustrated in an example in figure 5, by using the same analogy of the barrel as has been done in figure 4.

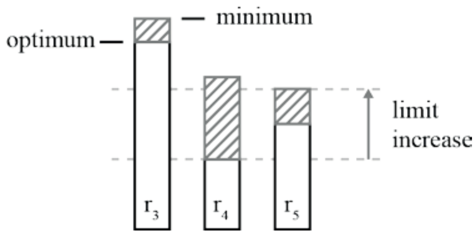

Figure 5 Concept of tolerance – 'barrel analogy'

Intertwined with the concept of tolerance is the notion that human 'needs' emerge, and vice versa fade away, in accordance with a hierarchy based on 'relative prepotency' (Maslow, 1943). When it comes to human needs, a clear black-and-white distinction between what is essential and what is non-essential is at the very least questionable. In accordance with the hierarchy of relative prepotency, at a given time, one 'need' out of the hierarchy is dominant and when a certain degree of satisfaction of it is reached, the dominance of a 'higher' need (one with a lesser priority) will start to emerge gradually. For each particular need the degree of satisfaction and the degree of dominance is assumed to be proportional, in which the degree of dominance decreases with the increase of the degree of satisfaction.

In general, it is not the material itself which is desired by members of the social organization, it is the configuration of materials, as an object of human knowledge, which bears significance (Boulding, 1966). The amount of tolerance for a deficient in a certain resource is determined by the priority of the need for the products associated with it. Thus when the social organization exhibits a great tolerance, with regard to a particular resource, it is an indication that the need for the products associated with it are of lesser priority.

Substitution

Another manifestation of the flexibility exhibited, with regard to human demands, is the principle of substitution. The principle of substitution simply means that the use of a scarce essential is replaced by the use of one which is less scarce. Thus either the need is satisfied in a different manner, with a different product, or the same product is made from a different configuration of materials. The principle is illustrated in figure 6, in a similar fashion as the previous figure. The principles are not mutually exclusive.

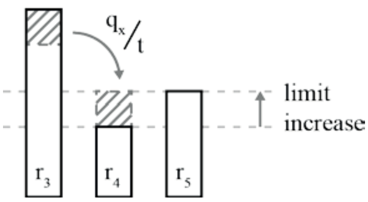

Figure 6 Principle of substitution – 'barrel analogy'

Communal interaction

The idea of the law of the minimum in combination with its adaptation effects seems similar to how people perceive the workings of the free market mechanism. A point of attention in both mechanism however, is the notion of communal interaction (Danger, Daufresne, Lucas, Pissard, & Lacroix, 2008), which can occur, either in a synergetic or a conflicting manner. This point is aside the discussion whether the free market mechanism really functions in the manner in which it is assumed to function, which is disputable (Diederen, 2010).

As a system, the social organization consists of sets of elements standing in interaction (von Bertalanffy, 1968). It is expected that between these groups, the needs differ, as well as the resources which are available in each of their associated surroundings. A synergetic communal interaction, also known by the term mutualism (McGill, 2005), may occur when the relative abundance in a resource of one group can complement the relative scarcity of another. A conflicting communal interaction, however, occurs when multiple groups experience a relative scarcity in a similar resource.

A conflicting communal interaction is not unlikely since some of the resources, which are expected to become critical, are not equally divided. The upcoming economies seem generally better endowed in this matter compared to the more developed economies (Diederen, 2010). Thus a struggle of power will probably be a main issue when scarcity arises.

Strategy II: addressing the defects

Addressing the defects of a system subsequently effects the severity of the associated symptoms. This effects does not necessarily have to be an immediate positive effect. As the saying implies 'the darkest hour of the night comes just before the dawn', some approaches aimed to cure involve a stage in which symptoms will aggravate. The other way around, an intervention aimed at addressing symptoms which subsequently or simultaneously effects the defects is possible but not necessarily the case. A hard distinction in which measure contributes to which strategy is thus not quite possible.

Something can be said however, about the effectiveness of a measure or intervention in addressing either the defects or associated symptoms of a system. Donella Meadows already composted a list in which different types of interventions are ranked based on their effectiveness to alter a system's behaviour (Meadows, 1999). The sequence in question is primarily based on which intervention is expected to cause the greater 'snowball effect' with regard to the system's behaviour. The general hierarchy of the list is adopted however, some alterations have been made.

Parameters

The least effective type of intervention is an adaptation of a system's parameters. The parameters of a system are also known as the 'summative characteristics of elements' (von Bertalanffy, 1968), which are those which are the same within and outside the complex and they may therefore be obtained by means of summation of characteristics and behaviour of elements as known in isolation. An intervention in the parameters of a system alters either the number of elements, the species or both. A comparison presented in the Limits to Growth, between scenarios one (Meadows et al., 2004, p. 169) and two (Meadows et al., 2004, p. 173) is a perfect example why a parametric intervention is valued least. The sole difference between the two scenarios is the amount of available resources, for which the estimation was doubled in scenario two, and despite this seemly great difference, the behaviour of the model remained the same. Some examples of parametric interventions known in the construction industry are the addition of (extra) insulation, optimization of the bearing structure, substitution of a certain material or oversizing capacity of installations or bearing structure.

Rules

The parametric interventions are succeeded in effectiveness by adaptations of a system's rules. The rules of a system describe the manner in which things are done, it describes the boundaries of enactment. A well-known example of a possible improvement in the rules of a system is the notion of a performance economy (Stahel, 2010). The essence of the notion is that the manufacturer retains the ownership of its products at all times, in which products are sold on a performance based lease. By doing so, the manufacturer will be confronted with all stimulus resulting from both the efficiencies and inefficiencies of its products and manufacturing processes. In addition, the performance for the consumer is guaranteed at all times.

Adaptive capability

Lastly, the type of intervention which is regarded as the most effective is an adaptation of a system's adaptive capability. Similar as how the rules describe the boundaries of enactment, so does the adaptive capability describe the boundaries of self-organization. It describes the extent in which the system is able to alter its underlying characteristics. An example of what is often regarded as an improvement of a system's adaptive capability is an uncoupled or decoupled design (Suh, 2005). In an uncoupled design all functional requirements can be satisfied independently by means of its respective design parameter. In a decoupled design the same holds true but only if the design parameters are determined in a proper sequence. It should be noted that oversizing capacity is often associated with the adaptive capability of a building. However, in this paper it is not regarded as such. The adaptive capability of a system is primarily regarded as a characteristic of the relations between elements, not a characteristic of the elements themselves.

Alternative treatment

If one would give substance to the actions described in the previously discussed hierarchy of the triad approach (prevention of use, substitutional use and prudent conduct), they would generally constitute interventions in the parameters of a system. The prevention of use is primarily aimed at the number of a system's elements and substitutional use at the type of species present. As such, these interventions are in general quite ineffective in addressing the defects of the resource system.

Therefore, the author proposes an alternative manner to rank interventions' effectiveness in addressing the symptom of depleting resources, one which is more compatible with the effectiveness of addressing defects. This alternative is based on the notion that not all declining resources require an equal amount of one's attention, as elaborated on in the segment regarding the law of the minimum.

Areas of intervention

Figure 7 illustrates the three areas of intervention: (A) material inputs, (B) process inputs and (C) material selection, with regard to which every intervention can be considered as advantageous, neutral or disadvantageous.

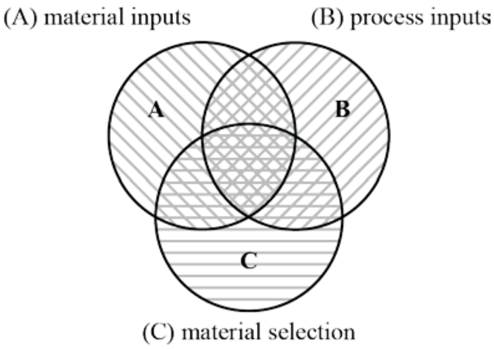

Figure 7 Areas of intervention

The material inputs concern the amounts of materials out of which products are composed. For instance, an optimization of the bearing structure decreases the amounts of material inputs required and thus is regarded as advantageous in terms of material inputs. The enlargement of the layer of insulation, however, increases the amounts of material inputs required and thus is regarded as disadvantageous in terms of material inputs. The material selection concerns the types of materials out of which products are composted, in which a substitution of the material in question for a material which is relatively scarcer is regarded as disadvantageous, in terms of material selection, while a substitution for a material which is relatively more abundant is regarded as advantageous.

The process inputs are those generated by the process facilitating products in order to enable both the different phases of the manufacturing process and the operating of the products in general, as illustrated in figure 1. Whether an intervention is regarded as advantageous or not, in terms of process inputs, should always be determined on a life cycle basis. For instance, replacing a coupled design by a decoupled design is regarded as advantageous in terms of process inputs, both due to the expected extension of the product life cycle (Stahel, 1984) as due to the diminished effort which is required in the phases of maintenance, disassembly and eventually remanufacturing or recycling.

Overlapping circles

The overlapping areas illustrated in figure 7 indicate either a conflicting or synergetic relation. For instance, if an intervention is categorized in the area (AC) in which circle 'A' and circle 'C' overlap, it affects both the material inputs and the material selection, but it has no significant effect on the process inputs. If the effect on both material inputs and material selection is regarded as positive the relation is synergetic. However, if for instance less material inputs can be achieved by substitution of the material in question for a material which is relatively scarcer, the relation is conflicting.

The main distinction between interventions in the areas 'A' and 'B' and interventions in area 'C', is the knowledge which is required to distinct advantageous from disadvantageous. Each reduction of inputs is regarded as advantageous in both the areas 'A' and 'B', while an increase of inputs is regarded as disadvantageous. For interventions in area 'C', however, it is required to known how the available production rate ($^{q_{an}}/_{t}$) and the rate which is demanded ($^{q_{dn}}/_{t}$) relate to each other, for both the resource (r_n) which is substituted as for the one which is used as a substitute. Only then can a substitution be judged as either advantageous, neutral or disadvantageous. Where all areas are considered to be similar, is how the extent to which an improvement can be regarded as effective is determined, which is by the degree of criticalness of the resource which is saved by the intervention.

Sequence of area effectiveness

In order to establish a hierarchy of effectiveness of the area of intervention it is necessary to determine the proper sequence of the three areas: material inputs, process inputs and material selection. Naturally, the presented nomenclature of A, B and C is not a result of coincidence. A is regarded as least effective and C as most effective, in the established sequence. The area of material selection is regarded as most effective due to the nature of the associated advantageous interventions, which are bound to, eventually, result in the most optimal situation, meaning no relative scarcity or abundance.

The area of process inputs is next in line, since the associated interventions affect combinations of resources, while an intervention associated with the area of material inputs only affects a single resource. A reduction in process inputs is in essence a reduction of the necessity of the associated process facilitating (pf.) products to be and to operate. Thus it not only constitutes possible savings for the resources required to enable its operating, but also savings in the resources out of which the pf. products are composed. Naturally, the probability of a combination of resources containing some which are critical is greater than the probability of a single resource being critical. Although a single intervention will not be made random, determining which resources are most critical is not the simplest of tasks. In addition, the pf. products are generally associated with the dependency on scarce metals (Diederen, 2010).

Figure 8 illustrates examples of the effect associated with interventions, one for each area of intervention, in a fashion similar to the one used in the figures 5 and 6, in order to clarify the difference in rank.

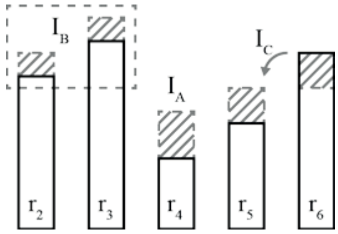

Figure 8 Comparison of example interventions in areas A (I_A), B (I_B) and C (I_C) – 'barrel analogy'

Moments of intervention

As mentioned, the extent to which a measure can be regarded as effective, with regard to addressing the symptom of depleting resources, is by the degree of criticalness of the resource which is saved by the intervention. Of lesser importance but of importance nonetheless, is the quantity of the savings associated with each intervention. Where the area of process inputs differs from the other two is that the actual allocation of the associated resources is spread over a variety of moments, while the actual allocation of the amounts and types of materials out of which products are composted is primarily affiliated with their moments of construction.

Thus an extended specification of the area of process inputs is required which will be a hierarchy based on which moments are generally associated with the highest usages and sequentially, the highest potential for improvement.

With regard to the use of energy, as one of multiple process inputs, it is well-known that the consumption or operational phase of a buildings constitutes as the greatest percentages of the overall usages (Ramesh, Prakash, & Shukla, 2010) (Liu, Li, & Yao, 2010) (Blengini, & Di Carlo, 2010). It is probably safe to assume that also for the overall process inputs the operational phase is the greatest contributor, especially considering the long lifespan of building products.

The remaining phases of extraction, transformation and production are typically referred to as either the construction or the deconstruction phase. In this study construction in general is regarded as 'the act of putting things together', whereas, deconstruction is regarded as ‘the act of separating things’. With regard to figure 1, deconstruction is the process of product to (mono) material or in case of the initial cycle resource to (mono) material. Sequentially, construction would be the process of (mono) material to product, including the process of ‘shaping’ of which it is arguable whether or not is actually corresponds with the previous description.

The second best moment of intervention is neither the phase of construction nor the phase of deconstruction, but both. By alteration of the length of the lifecycle, both the amount of construction and deconstruction moments required in a given timespan are altered. Thus by doing so, constitutes a saving in both phases. An intervention in either the phase of construction or the phase of deconstruction remains as the least effective moment of intervention.

Hierarchy of effectiveness

Figure 9 presents an overview of how the discussed elements relate to one another in determining the degree of effectiveness of interventions in addressing the depletion of resources. The main hierarchy illustrates in figure 9 is a hierarchy of variables and their influence on the degree of effectiveness. The variable ‘type of intervention’ is regarded as the most influential, followed by the ‘area of intervention’ and lastly the ‘moment of intervention’.

Addressing a system’s defects is regarded as a more effective manner to oppose a symptom, than directly addressing a symptom itself. Treatment would continue an issue in a manageable manner, whereas curing it would eradicate it altogether. An alteration of system’s behaviour is regarded as the sole manner to address a system’s defects. Thus the variable ‘type of intervention’ is regarded as the most influential, since it indicates to what extent the system’s behaviour is affected.

As mentioned the ‘area of intervention’ is based on the notion that some aspects of the issue have a more profound impact than others and the ‘moment of intervention’ can be regarded as a further specification of the area process inputs (2.2). A subhierarchy is also illustrated per variable which ranks its categorized variants from most effective (1) to least effective (3).

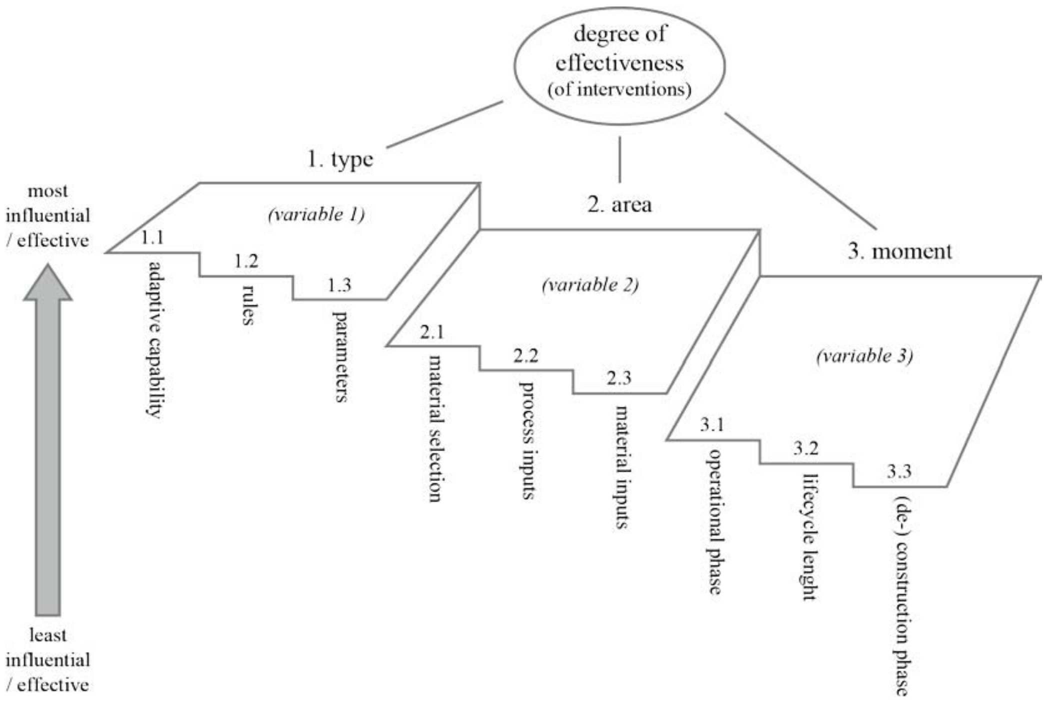

Figure 9 Hierarchy in determining the degree of effectiveness of interventions in addressing the depletion of resources

Conclusion & discussion

The question from which this study originated was whether or not the embodiment of the notion of sustainable development, present in the attitude of policy and practice, conducts genuinely and sufficiently as an antagonist of finiteness. The discussed components of the underlying rationale of the issue did not offer a conclusive substantiation to either dismiss the current measures as insufficient or embrace them as well enough. What can be concluded though, is that conventional interventions meant to oppose the prospect of finiteness are definitely not the most effective manner of endeavour conceivable.

With regard to policy and practice, it is argued that more attention is required for interventions in the system's rules and the system's adaptive capacity. Conventional measure are primarily focussed on the parameters of the system, which is regarded as the least effective variant of the most influential variable.

A lot of significance is associated with the measurability of things in today's society (Rossi, 2007). A criteria which is quite fitting with alteration in the parameters of a system. The more effective type of interventions however, are generally based on the more elusive contributions to a sustainable future. The hierarchy itself is also based on what might be described best as an 'explanation in principle' (Hayek, 1967; von Bertalanffy, 1968). A better understanding, in research, of how the more elusive improvements contribute to a sustainable future, might reduce the practical boundaries associated with its implementation.

Acknowledgements

The author thanks M. Mohammadi, M. M. T. Dominicus and J. J. N. Lichtenberg for guidance during the course of this research project. The author also thanks A. W. Vanderveen for comments and suggestions.

References

Betz, A. (1920). *Das Maximum der theoretisch möglichen Ausnützung des Windes durch Windmotoren* [The Maximum of the Theoretically Possible Exploitation of Wind by Means of a Wind Motor] (H. Hamann, J. Thayer, & A. P. Schaffarczyk, Trans.). Zeitschrift für das gesamte Turbinenwesen 26, 307-309. doi:10.1260/0309-524X.37.4.441

Black, J., Hashimzade, N., & Myles, G. (Eds.). (2012). A Dictionary of Economics: 4 ed. Oxford: Oxford University Press.

Blengini, G. A., & Di Carlo, T. (2010). *The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings*. Energy and Buildings 42, 869-880. doi:10.1016/j.enbuild.2009.12.009

Boulding, K. E. (1966). The Economics of the Coming Spaceship Earth. In H. Jarrett (Ed.), *Environmental Quality in a Growing Economy* (3-14). Baltimore, MD: Johns Hopkins University Press.

Chertow, M. R. (2000). *The IPAT Equation and Its Variants: Changing Views of Technology and Environmental Impact*. Industrial Ecology 4(4), 13-29. doi:10.1162/10881980052541927

Danger, M., Daufresne, T., Lucas, F., Pissard, S., & Lacroix, G. (2008). *Does Liebig's law of the minimum scale up from species to communities?* Oikos 117, 1741-1751. doi:10.1111/j.1600-0706.2008.16793.x

Diederen, A. (2010) *Global Resource Depletion: Managed Austerity and the Elements of Hope*. Delft: Eburon Academic Publishers.

Eekhout, M. (1997). *POPO, process organisatie voor product ontwikkeling* [POPO, process organization for product development]. Delft: Delft University Press.

Entrop, A. G., & Brouwers, H. J. H. (2010). *Assesing the sustainability of buildings using a framework of triad approaches.* Journal of Building Appraisal 5, 293-310. doi:10.1057/jba.2009.36

European Parliament. (2010). *Directive 2010/31/EU on the energy performance of buildings*. Retrieved from: http:// eur-lex.europa.eu/

Gorban, A. N., Pokidysheva, L. I., Smirnova, E. V., & Tyukina, T. A. (2011). *Law of the Minimum Paradoxes*. Bulletin of Mathematical Biology 73, 2013-2044. doi:10.1007/s11538-010-9597-1

Hayek, F. A. (1967). *Studies in Philosophy, Politics and Economics.* Chicago, IL: The University of Chicago Press.

Huesemann, M. H. (2004). *The failure of eco-efficiency to guarantee sustainability: Future challenges for industrial ecology*. Environmental Progress 23, 264-270. doi:10.1002/ep.10044

IPCC. (2014). *Climate Change 2014: Mitigation of Climate Change*. Cambridge: Cambridge University Press.

Jackson, T. (2009). *Prosperity without Growth: Economics for a Finite Planet*. London: Earthscan.

Joule, J. P. (1850). *On the Mechanical Equivalent of Heat*. Philosophical Transactions of the Royal Society of London 140, 61-82. doi:10.1098/rstl.1850.0004

Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K., Haberl, H., & Fischer-Kowalski, M. (2009). *Growth in global materials use, GDP and population during the 20th century*. Ecological Economics 68(10), 2696-2705. doi:10.1016/j.ecolecon.2009.05.007

Liu, M., Li, B., & Yao, R. (2010). *A generic model of Exergy Assessment for the Environmental Impact of Building Lifecycle*. Energy and Buildings 42, 1482-1490. doi:10.1016/j.enbuild.2010.03.018

Maslow, A. H. (1943). *A Theory of Human Motivation*. Psychological Review 50, 370-396. Retrieved from: http://search.proquest.com/

McDonough, W., & Braungart, M. (2002). *Cradle to Cradle: Remaking the Way We Make Things*. New York, NY: North Point Press.

McGill, B. (2005). *A mechanistic model of a mutualism and its ecological and evolutionary dynamics*. Ecological Modelling 187, 413-425. doi:10.1016/j.ecolmodel.2005.02.002

Meadows, D. (1999). *Leverage Points: Places to Intervene in a System*. Hartland, VT: The Sustainability Institute.

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens, W. W. (1972) *The Limits to Growth: A Report for THE CLUB OF ROME'S Project on the Predicament of Mankind*. New York, NY: Universe Books.

Meadows, D., Randers, J., & Meadows, D. (2004). *The Limits to Growth: The 30-Year Update*. White River Junction, VT: Chelsea Green Publishing Company.

MVO. (2015). *Nationale MVO Monitor* [National MVO Monitor]. Retrieved from: http:// mvonederland.nl/

Olivieri, G., Romani, A., & Neri, P. (2006). *Environmental and economic analysis of aluminium recycling through life cycle assessment*. International Journal of Sustainable Development & World Ecology 13, 269-276. doi:10.1080/13504500609469678

Ramesh, T., Prakash, R., & Shukla, K. K. (2010). *Life cycle energy analysis of buildings: An overview*. Energy and Buildings 42, 1592-1600. doi:10.1016/j.enbuild.2010.05.007

Ross, D. T. (1977). *Structured Analysis (SA): A Language for Communicating Ideas*. IEEE Transactions on Software Engineering, 16-34. doi:10.1109/TSE.1977.229900

Rossi, G. B. (2007). *Measurability*. Measurement 40, 545-562. doi:10.1007/s00153-014-0383-x

Rovers, R., Ritzen, M., & Gommans, L. (2013). *Reducing energy demand – or producing more energy? The role and impact of materials in zero or near-zero energy building & renovation*. Retrieved from: http:// www.dewijkvanmorgen.nl/

Ruimte en Mileu. (2010). *Landelijk afvalbeheerplan 2009-2021: Naar een materiaalketenbeleid* [National waste management plan 2009-2021: Towards a material chain policy] (Report no. 2). Retrieved from: http://www.lap2.nl/

Shelford, V. E. (1913). Animal Communities in Temperate America. Chicago, IL: The University of Chicago Press.

Stahel, W. R. (1984). The Product-Life Factor. In S. G. Orr (Ed.), *An Inquiry Into the Nature of Sustainable Societies: The Role of the Private Sector* (72-96). Houston, TX: HARC.

Stahel, W. R. (2010). *The Performance Economy: Second Edition*. London: Palgrave Macmillan.

Suh, N. P. (2005). *Complexity: Theory and Applications*. New York, NY: Oxford University Press.

United Nations. (1987). *Our Common Future, Report of the World Commission on Environment and Development*. Retrieved from: http://www.un-documents.net/

United Nations. (1992). *United Nations Framework Convention on Climate Change*. Retrieved from: http://unfccc.int/

Verhulst, P. (1838). Notice sur la loi qua la population suit dans son accroissement [A Note on the Law of Population Growth] (D. Smith, Trans.). In A. Quetelet (Ed.), *Correspondance: Mathématique et Physique* [Correspondence: Mathematical and Physics] (113-117). Brussels: Sociéte Belge de Librairie.

von Bertalanffy, L. (1968). *General System Theory: Foundations, Development, Applications*. New York, NY: George Braziler.

Annex A – laws of physics

A perception of the build and workings of the physical world is the foundation of all concepts related to the ‘proper’ use of resources. A consensus on the aforementioned perception is expressed by the common acceptance of certain physical laws. The laws of physics are regarded as indisputable with regard to the differentiation of the possible from the impossible. However, the interpretation of the physical laws with regard to the implications for the long-term future has been found to be quite unclear and controversial (Uffink, 2001).

Conservation

First of all a distinction needs to be made in ‘matter’ and ‘energy’. The term matter refers to the physical substances out of which the whole consists and the term energy refers to the dynamics associated with the interactions between these substances. It is assumed that both matter and energy can be neither created nor destroyed, change as a human perceives it occurs through reconfiguration of the universal building blocks and their relations. This notion of conservation is one with an extensive history. Even before the Common Era Empedocles expressed it by the statement ‘nothing comes to be or perishes’.

‘‘For if they died continually, no longer would they be. What could increase this whole, and from what source? How too could it be destroyed, since nothing lacks in these? But these are what there is, and running through each other they suffer change continual but always are alike.’’

(Empedocles, Janko Trans., 2004, p. 17)

The idea that matter cannot be created nor destroyed is substantiated by a single experiment performed and elaborated on by three different scientists (Spasskii, 1962). The experiment was as followed; a sealed retort containing lead is heated. In 1673 the scientist Boyle weighted the lead before and after heating, and discovered that the weight of the lead had increased. In 1756 the scientist Lomonosov weighted the retort containing lead during the heating and found that the total weight of the retort containing lead did not change. In 1774, in addition to the steps performed by Lomonosov, the scientist Lavoisier determined the change in weight of the lead and air separately and concluded that the decrease in weight of the air was equal to the increase in weight of the lead. Now assuming that weight is a proportional expression of the amount of matter we can state that the total amount of matter is conserved in chemical reactions in a closed environment.

The notion of conservation of matter is substantiated experimentally by demonstrating that no matter is inexplicably added or subtracted during chemical reactions. A similar approach in order to substantiate the notion for energy would be quite troublesome, since it is much more difficult to confine energy in an isolated environment than matter. A conducted experiment did, however, demonstrate that energy can be transformed from one type to another. In 1850 James Prescott Joule published the conducted experiment which measures the transformation of gravitational energy to thermal energy (Joule. 1850). For this experiment he places a set of paddles, connected by a string and pulley to a suspended weight, in a sealed container of water. As the weight lowered, the string turned the shaft of the paddles, rotating them in the water container. With this apparatus, illustrated in figure A1, he was able to measure the amount of heat generated by the expenditure of mechanical force represented by the fall of a weight across a certain distance.

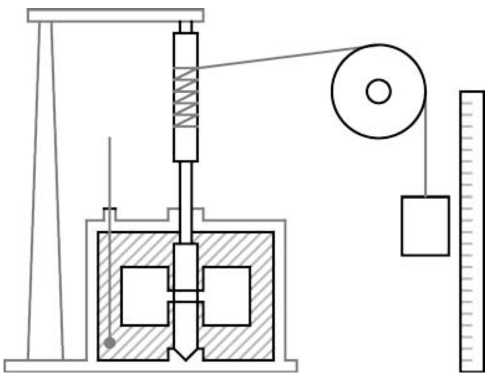

Figure A1 Illustration of Joule's apparatus

Systems of physics

The interpretation of energy and matter as something which can be neither created nor destroyed implies that the absolute quantities from which the whole consists is regarded as a fixed set condition. However, that does not necessarily mean that the same holds true for a single planet. In the field of physics a distinction is made in three different types of systems (Massoud, 2005). These systems differ on whether its boundaries allow the passing of energy and/or matter or not, as illustrated in figure A2.

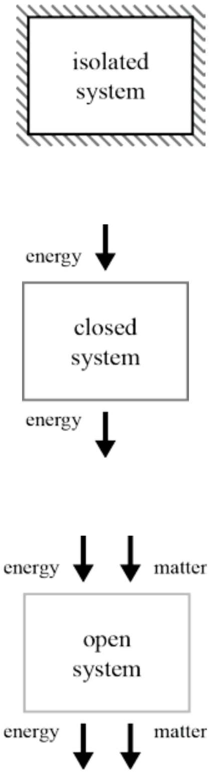

Figure A2 Systems of physics

The Earth's ecosystem in general, is regarded as a closed system, meaning that the boundaries of the system allow the transfer of energy but not of matter. The additional energy, which enters the ecosystem, originates from the energy emitted by the sun, the Earth's internal heat and the effects generated by planetary movements (Boulding, 1966). The amount of energy which is added to the Earth's ecosystem has been similar to the amount of energy which is subtracted from it, otherwise a certain balance of temperature levels would not occur.

2nd law of thermodynamics

The law of conservation is also known as the 1st law of thermodynamics. It is the 2nd law of thermodynamics, however, which is the cause of quite some controversy (Uffink, 2001). Thus the following interpretation should be regarded as a personal interpretation and not a general consensus.

The foundation of the 2nd law is the observation that when a hot reservoir and a cold reservoir are not isolated from each other, the heat will transfer from the hot to the cold reservoir until both reservoirs are of an equal temperature (Carnot, 1897). Something similar occurs in several other natural processes, for instance air moves from a higher to a lower pressure area and water falls from high to low due to the gravitational pull. These regularities are regarded as the spontaneous direction of natural processes, which moves from high to low (Scott, 2008). The opposite, a non-spontaneous process, has never been observed as a natural phenomenon. For instance, a cold reservoir which repels heat towards a warmer reservoir and thus continuously increases the temperature differences between the two. Thus it is assumed that such a natural event will not occur spontaneous.

The manner in which energy is extracted or converted occurs by intervening this flow of high to low, as illustrated in figure A3. For instance, a steam engine intervenes the flow of heat from a hot to a cold reservoir and transforms thermal energy to mechanical energy.

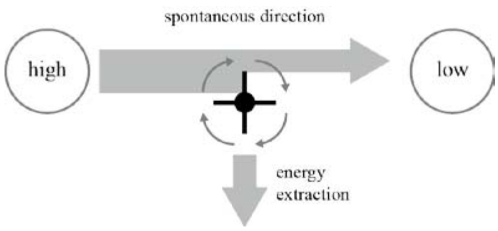

Figure A3 Principle of energy extraction

Kelvin added that it is impossible for an apparatus to extract all energy from the transfer of heat and thus preventing the colder reservoir from obtaining heat. However, he was primarily concerned with 'possibility' in the sense that it is 'available to mankind' (Uffink, 2001), thus such a statement should be adopted with caution, with regard to theoretical possibilities. Theoretically, it is assumed that since an extraction or conversion is dependent on a flow from high to low, it will not be able to extract the entire flow as energy, since it would result in a disruption of the required flow itself. An example of this is the Betz-Limit which states the maximum of the theoretically possible exploitation of wind by means of a wind motor (Betz, 2013). The Betz-Limit describes that if more than circa 59% of the kinetic energy of the passing wind particles is subtracted, it would result in a decrease of the velocity of the passing flow and with it a decrease of the absolute amount of kinetic energy which can be extracted in a given timeframe. The implications of Kelvin's addition is that in every conversion of energy the source of energy is diffused over at least two other sources.

The reason why this diffusion of energy is of such importance is that the 'height of the fall' or the difference between high and low determines the potential of a flow as a source of energy. For instance an ice cube is very useful in the summer to alter environmental temperatures to a more desired level, but during the winter it is useless in terms of work because it exhibits no deviation from the environment (Dincer, & Cengel, 2001). In general, a greater deviation from its surroundings or a greater 'height of the fall' indicates a greater potential to perform useful work (Carnot, 1897). The term 'exergy', defined as the amount of useful work that an energy source is able to perform (Rant, 1956; Diederen, 2010), was introduced in order to describe such a distinction.

The summation of the previously discussed axioms results in the theorem that the transfer or conversion of energy is always accommodated with the loss of exergy:

1. when two reservoirs which differ in 'height' are not isolated from each other, a flow will commence from high to low until both reservoirs are equal in 'height';
2. in every extraction or conversion of energy the original source of energy is diffused over at least two other sources;
3. the 'height of the fall' determines the amount of useful work that an energy source is able to perform.

The first axiom describes the spontaneous direction of natural processes which aims to nullify certain deviation in the environment. The third describes that these deviation are most valued by the social organization, since a great amount of exergy equals a great potential to perform useful work. Thus the spontaneous direction of natural processes aims to reduce exergy, the energy state which is valued most. Lastly the second axiom implies that the utilization process of these deviations cannot occur without a further diffusion of the source and thus again a loss of exergy.

The theorem as stated seems to imply some inevitable deterioration, however, two remarks should be noted. First of all the Earth's ecosystem is regarded as a closed system and the inevitable equilibrium prophesied by the 2^{nd} law of thermodynamics is only applicable for isolated systems. Secondly, the distinction in 'spontaneous' and 'non-spontaneous' is made in order to avoid the exclusion of the possible occurrence of a non-spontaneous phenomenon.

Entropy

The concept of entropy is introduced to elaborate on the relation between energy and exergy. The 1^{st} law of thermodynamics states that energy can be neither created nor destroyed and thus is regarded as a constant within an isolated system. Exergy on the other hand, is regarded as a variable and thus can be locally generated or destroyed. However, the 2^{nd} law of thermodynamics states that the loss of exergy is inevitable in every alteration of the energy states. Thus even a local generation of exergy constitutes a loss of exergy when the whole system is regarded. This relation between energy and exergy is clarified by an analogy of a tube of toothpaste, as illustrated in figure A4.

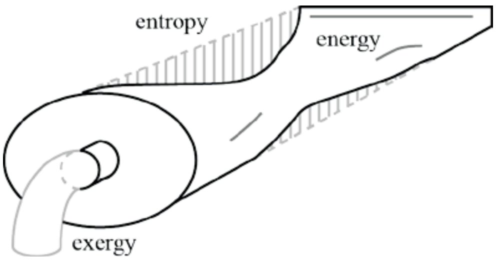

Figure A4 Entropy, exergy and energy - toothpaste analogy

The presence of the tube itself is constant and represents the amount of energy. The amount of exergy is represented by the paste, which can be increased locally by adjusting the depression of the tube, but can only be decreased with regard to the whole tube. The concept of entropy is represented by the space left due to the compressions of the tube. When al exergy is depleted entropy is at a maximum state, which is referred to as the system's equilibrium (von Bertalanffy, 1968).

Probability

The concept of entropy is often entangled with both energy and matter, since matter also exhibits a unidirectional nature of processes. The unidirectional nature of non-human alteration to configurations of matter, is clarified by the example of a salt and pepper box (Diederen, 2010). If we would imagine a little box which contains a layer of salt grains and a layer of pepper powder, perfectly separated on top of each other, the box would be very ordered. If this situation would occur it would take almost no effort to mix the layers of salt and pepper, simply shaking the little box or even small vibrations from movement around the box would lead to a state of a mixture of the salt and pepper layers. Now if we would want to recover the condition of the box from a mixed state to a perfect separation of salt and pepper, this would require a lot of effort. Instead of the previous spontaneous direction, this tendency is referred to as the probable direction, as illustrated in figure A5

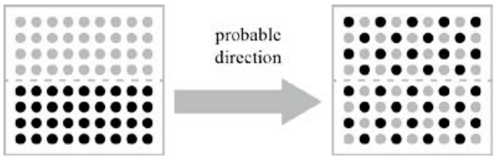

Figure A5 Probable direction of configurations of matter

A 'random event' is defined as an event which has an outcome that is unknown prior to its occurrence (Black, Hashimzade, & Myles, 2012). The amount of factors influencing the final result of a random event are too numerous to take into account. However, if one turns to a long sequence of repetitions of such an event the average results demonstrate stability, despite the 'irregular' behaviour of a single event (Borovkov, 2013). This is the premise on which probability theory is based. Figure A6 illustrates an example to support this phenomenon, the graph displays the relative frequencies corresponding to the outcome sequence 'h-t-t-h-t-t-h-h-h-t-h-h-t' in a coin tossing experiment, in which 'h' stand for 'heads' and 't' stands for 'tails'.

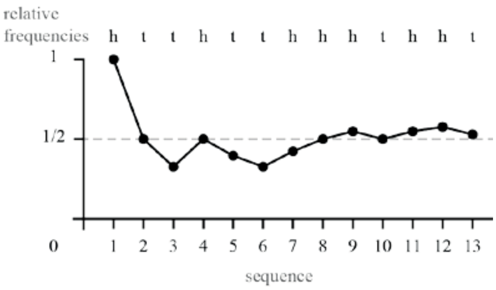

Figure A6 Relative frequencies coin tossing experiment, adopted from (Borovkov, 2013, p. xv)

The phenomenon illustrated in the example of the salt and pepper box occurs because a state which is regarded as ordered or concentrated is less probable than a state which is regarded as disordered or diffused. Figure 7A illustrates why a state which is regarded as ordered is less probable than a state which is regarded as disordered. The figure displays all possible configurations of four separate 'particles' spread over two squares, square 'a' and square 'b'.

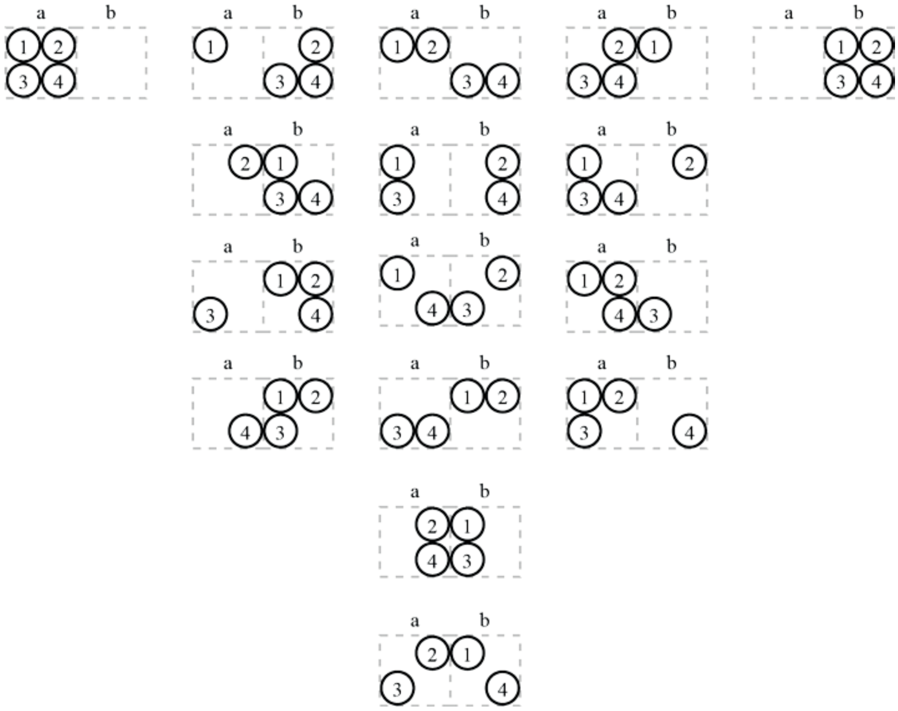

Figure A7 Probability of disorder over order

Each possible configuration has an equal chance of occurrence since the spread is regarded as a random event. There are only two possible configurations which are regarded as 'most concentrated', all particles placed in square 'a' or all particles placed in square 'b', while there are six possible configurations which are regarded as 'most diffused', two particles placed in both square 'a' and square 'b'.

References

Betz, A. (1920). *Das Maximum der theoretisch möglichen Ausnützung des Windes durch Windmotoren* [The Maximum of the Theoretically Possible Exploitation of Wind by Means of a Wind Motor] (H. Hamann, J. Thayer, & A. P. Schaffarczyk, Trans.). Zeitschrift für das gesamte Turbinenwesen 26, 307-309. doi:10.1260/0309-524X.37.4.441

Black, J., Hashimzade, N., & Myles, G. (Eds.). (2012). A Dictionary of Economics: 4 ed. Oxford: Oxford University Press.

Borovkov, A. A. (2013). *Probability Theory*. Springer. doi:10.1007/978-1-4471-5201-9

Boulding, K. E. (1966). The Economics of the Coming Spaceship Earth. In H. Jarrett (Ed.), *Environmental Quality in a Growing Economy* (3-14). Baltimore, MD: Johns Hopkins University Press.

Carnot, N. L. S. (1897). Reflections on the Motive Power of Heat, and on Machines Fitted to Develop that Power. In R. H. Thurston (Ed.), *Reflections on the Motive Power of Heat* (37-126). New York, NY: John Willey & Sons.

Diederen, A. (2010) *Global Resource Depletion: Managed Austerity and the Elements of Hope*. Delft: Eburon Academic Publishers.

Dincer, I., & Cengel, Y. A. (2001). *Energy, Entropy and Exergy Concepts and Their Roles in Thermal Engineering*. Entropy 3, 116-149. doi:10.3390/e3030116

Janko, R. (2004). *Empedocles, On Nature I 233-364: A New Reconstruction of P. Strasb. Gr. Inv. 1665-6*. Zeitschrift für Papyrologie und Epigraphik 150, 1-26.

Joule, J. P. (1850). *On the Mechanical Equivalent of Heat*. Philosophical Transactions of the Royal Society of London 140, 61-82. doi:10.1098/rstl.1850.0004

Massoud, M. (2005). *Engineering Thermofluids: Thermodynamics, Fluid Mechanics and Heat Transfer*. Springer

Rant, Z. (1956). *Exergie, ein neues Wort für 'Technische Arbeitsfähigkeit'* Forschung im Ingenieurwesen 22, 36-37. doi:10.1007/BF02592661

Scott, C. B. (2008). *A Primer for the Exercise and Nutrition Sciences: Thermodynamics, Bioenergetics, Metabolism.* Humana Press. doi:10.1007/978-1-60327-383-1

Spasskii, B. I. (1962). *M. V. Lomonosov and the Development of Physics*. Soviet Physics Uspekhi 75, 397-401. doi:10.1070/PU1962v004n06ABEH003388

Uffink, J. (2001). *Bluff Your Way in the Second Law of Thermodynamics*. Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics 32, 305-394. doi:10.1016/S1355-2198(01)00016-8

von Bertalanffy, L. (1968). *General System Theory: Foundations, Development, Applications.* New York, NY: George Braziler.

Annex B – A systems approach

A systems approach is regarded as a method of deducting reality into a model by identifying the primary relations and involved elements which govern the whole or parts of the manifestation, in which a system is defined as ‘‘sets of elements standing in interaction’’ (von Bertalanffy, 1968). The hierarchical order present in any system is illustrated in figure B1. An element is a smallest subdivision which is acknowledged by the system, it can, for instance, be an individual human being or even one cell out of which a human body consists. A component is a configuration of elements which interact with each other. Sequentially a system is a configuration of components which interact with each other, or, as previously defined, sets of elements standing in interaction. The addition of the terms subcomponent or subsystem are often considered as useful since the boundaries of both component and system are somewhat arbitrary.

Generalization

Due to the systematic nature of the systems approach it is also regarded as a useful tool in the act of generalization, in which it displays lots of similarities with axiomatic design. The most important terms in axiomatic design are as followed (Suh, 2005):

- Axiom: Self-evident truth or fundamental truth for which there are no counter-examples or exceptions. An axiom cannot be derived from other laws or principles of nature. Axioms are valid only within the bounds established by the definitions of the key terms.

- Theorem: A proposition that is not self-evident but that can be proven from accepted premises or axioms and so is established as a law or principle.

- Corollary: Inference derived from axioms or from propositions (theorems) that follow from axioms or from other propositions that have been proven.

In order to establish a theorem all related axioms should have originated within the same boundaries in which they are valid. The alternative is an act of generalization in which a known axiom is transferred from one boundary to another, as illustrated in figure B2. Generalization is based on the comprehension of the difference between both boundaries referred to as ‘system a’ and ‘system b’. In addition, an understanding of the effect of system a on the regarded axiom is required in order to deduct how the axiom will behave in an alteration of the system.

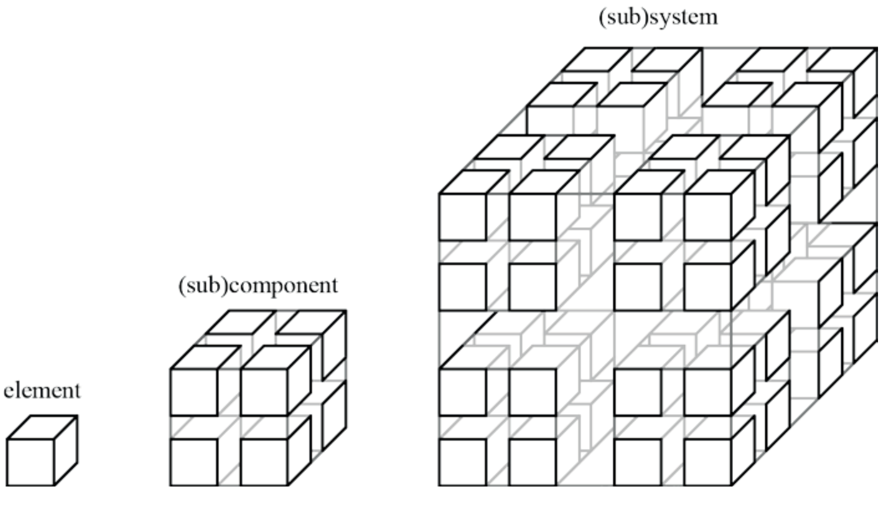

Figure B1 Hierarchical order in systems

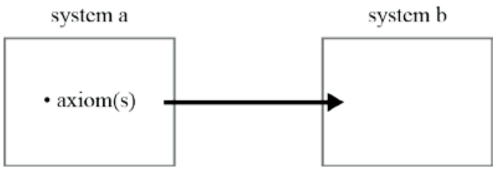

Figure B2 The act of generalization

The result of an act of generalization cannot be regarded as reliable as the axiom itself. Such deduction is not without its uncertainties, similar to the increasing uncertainty in the hierarchy of axiom-theorem-corollary. Thus it is of great importance to remain conscious about the reliability of both the assumptions and the line of reasoning.

Complexity and complicatedness

In most of the regarded literature systems are defined as either simple, complicated or complex (Grabowski & Strzalka, 2008; Boccara, 2010; Efatmaneshnik, Nilchiani, & Heydari, 2012). In this interpretation the terminology is applied to express a degree of difficulty associated with the full comprehension of the related system.

''While many systems may be quite complicated, they are not necessarily considered to be complex. Today, most authors agree on the essential properties a system has to possess to be called complex'' (Boccara, 2010).

Boulding, however, described a hierarchy of levels of increasing complexity, in which every system has a certain degree of complexity (Boulding, 1956). The author does, however, agree with the distinction in complicated and complex, but not as categories in systems but as gradient characteristics, as in the case of Boulding's level of complexity.

Three different kinds of distinction can be made when dealing with complexes of elements (von Bertalanffy, 1968);

1. according to their number;
2. according to their species;
3. according to the relations of elements.

Figure B3 illustrates the three distinctions by visualizing two possible complexes per kind of distinction.

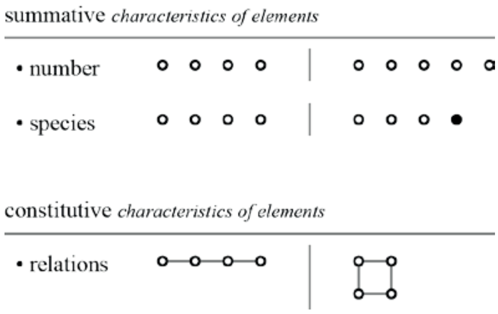

Figure B3 Summative and constitutive, adopted from (von Bertalanffy, 1968, p. 54)

The distinctions in both number and species are regarded as the summative characteristics of elements. Summative characteristics of an element are those which are the same within and outside the complex; they may therefore be obtained by means of summation of characteristics and behaviour of elements as known in isolation (von Bertalanffy, 1968).

The distinctions in the relations are regarded as the constitutive characteristics of elements. Constitutive characteristics are those which are dependent on the specific relations within the complex; for understanding such characteristics we therefore must know not only the parts, but also the relations (von Bertalanffy, 1968). "The whole is more than the sum of parts" means simply that constitutive characteristics are not explainable from the characteristics of isolated parts. The characteristics of the complex, therefore, compared to those of the elements, appear as "new" or "emergent" (von Bertalanffy, 1968).

In the regarded literature, no concrete definitions have been found for the terms complicated and complex. However, the distinction in summative and constitutive characteristics exhibits a lot of similarities with the found distinctions between a complicated system and a complex system. Thus by maintaining a similar division, the level of complicatedness is regarded as a measure of quantity, which is determined by a system's summative characteristics. The level of complexity is regarded as a measure of unpredictability, which is determined by a system's constitutive characteristics and which also matches with Boulding's hierarchy of levels of increasing complexity in systems.

Hierarchy of increasing complexity

The hierarchy of complexity in systems is distinguished in nine levels (Boulding, 1956), as illustrated in figure B4. This complexity increases gradually and is of an accumulative nature, thus the complexity of each level bears among others the complexity of the previous. Each level of system complexity is 'nicknamed' by a generally well-known system of its category. The difference between each level will be briefly elaborated on. The second level, nicknamed 'clockworks', differs from the first as it refers to dynamic systems instead of static systems. Thus the addition of dynamics constitutes the first step of increased complexity. The second step of increasing complexity constitutes the interpretation of information. The concept of the third level, nicknamed 'thermostat', is illustrated in figure B4. The thermostat is a control mechanism and as such it is, unlike the clockworks level, able to maintain any given equilibrium. In order to do so the system requires the ability to observe and interpret the difference between the perceived state and the desired state. With this information it is able to control in- and/or outflow until the discrepancy is zero.

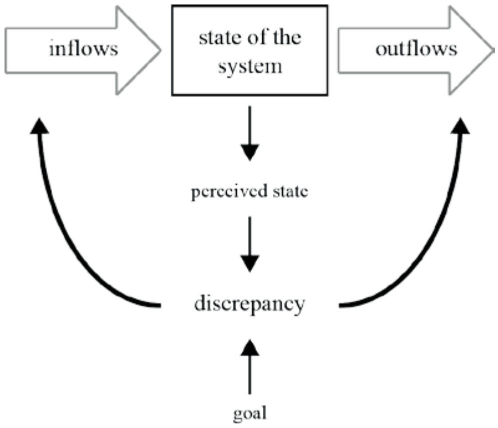

Figure B4 Thermostat - the interpretation of information, adopted from (Meadows, 1999, p. 4)

The fourth level exhibits the added ability of self-reproduction and of self-maintenance of structure in the midst of a throughput of material and energy. The fourth level is where 'life', represented as a system, differentiates itself from 'not-life', in which both the added characteristics are essential. The fifth level, nicknamed 'plant', differs from the previous as it consists of differentiated and mutually dependent parts. This level adds a 'division of labour'. The next level, the 'animal' level, exhibits the added complexity of a knowledge structure which intervenes between the receptors and effectors, as illustrated in figure B5.

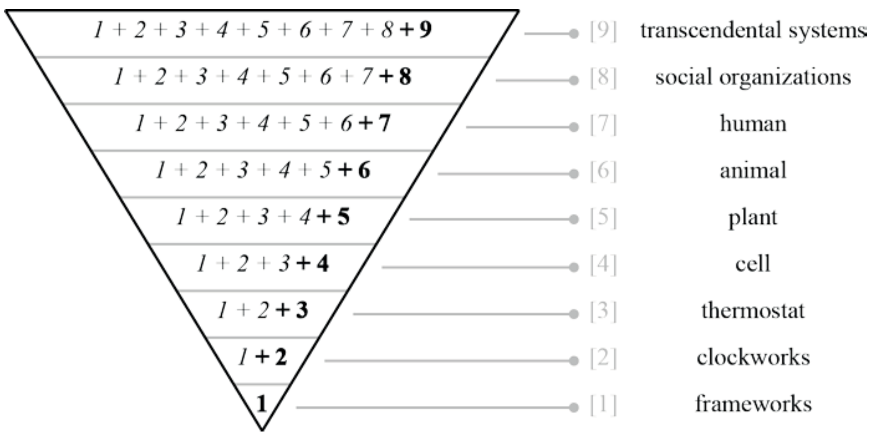

Figure B3 Hierarchy of increasing complexity

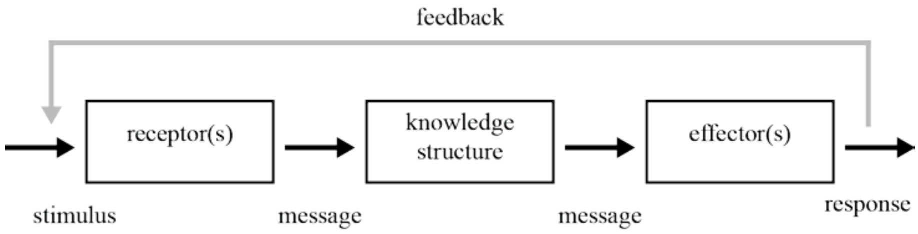

Figure B5 Intervention of the knowledge structure, based on (von Bertalanffy, 1968, p. 43)

In this complexity behaviour is no longer regarded as a direct response to a specific stimulus, but to 'image' or knowledge structure or view of the environment as a whole. The knowledge structure act as a sort of control apparatus in order to reflect new inputs of information with that which is already known before a proper response is chosen. The knowledge structure is of course still established based on the stimulus received by the receptors, however, the relation between the receipt of information and the building up of an image however is exceedingly complex.

The step of the sixth to the seventh level primarily includes the transformation of self-awareness to self-consciousness. 'He not only knows, but knows that he knows' (Boulding, 1956). This self-reflexive quality is connected to an elaborate image of time and relationship and the ability to produce, absorb, and interpret symbols.

The final step which will be elaborated on is the increased complexity of the social organization, being considered as a system, as opposed to an individual human being. The eight level brings with it the additional complexity of the interrelation between the 'role' and the individual of system's differentiated parts. A system of a social organization consist of several individuals which have been given a certain 'role' within the system. The referred to interrelation should been seen as followed: a square person in a round role may become a little rounder, but he also makes the role squarer.

Generalization of the law of the minimum

The axiom known as the law of the minimum was introduced in the field of ecology (van der Ploeg, Böhm, & Kirkham, 1999), stating that the rate of growth of a plant, the size to which it grows, and its overall health depend on the amount of the scarcest of its essential nutrients that is available to it (Park, & Allaby, 2013). In time, the concept has been broadened into a more generally applicable law stating that at any giving time growth of an organismic system is limited by the amount of the essential element most closely approaching the critical necessary minimum (Danger, Daufresne, Lucas, Pissard, & Lacroix, 2008; Diederen, 2010; Gorban, Pokidysheva, Smirnova, & Tyukina, 2011; Park, & Allaby, 2013).

Figure B6 illustrates how the system in which the original axiom is regarded as valid differs from the system to which it is often generalized to, both in terms of complexity and complicatedness.

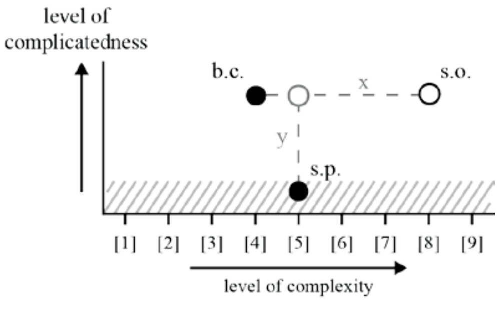

Figure B6 Generalization of the law of the minimum

The original axiom is the result of observing a single plant (s.p.) which generalization aims to clarify the workings of the social organization (s.o.). The difference between both systems in terms of complexity is illustrated by 'x'. 'y' illustrates the difference of between both systems in terms of complicatedness. A study with bacterial communities (b.c.) has concluded that bacteria communities, unlike single species, are likely to be co-limited over wide ranges of supplied nutrient ratios (Danger et al., 2008). Such studies can substantiated the line of reasoning made to generalize to higher levels of complicatedness. However, the lower level of complexity associated with the studied system should be regarded. For instance, the time requested to adjust to resource ratios in communities of higher complexity is likely to be longer and may more easily exceed the rates of change of resource supplies in comparison with communities of bacteria (Danger et al., 2008).

Still, system of higher complexity also display 'effects of adaptation' (Gorban et al., 2011). The nature of the effects might differ for systems of various complexity, it is however quite presumable that the potential of adaptation increases with a higher complexity.

A last point of attention which should be noted with regard to the act of generalization, is illustrated in figure B6 by the addition of a grey hatch. Naturally when an axiom is observed for a specific species, it does not ensure the same hold true for a different species. The grey hatch aims to emphasise these irregularities, since such a case exhibits no difference in either the levels of complexity as the levels of complicatedness. The grey hatch only covers the bottom of the graph since an irregularity of a single species is much more common than the irregularity of a specific combination of species. Thus an increased level of complicatedness diminishes the attention which this point requires.

References

Boccara, N. (2010). *Modeling Complex Systems*. Springer Science+Business Media, LLC. doi:10.1007/978-1-4419-6562-2

Boulding, K. E. (1956). *General Systems Theory – The Skeleton of Science*. Management Science 2(3), 197-208. doi:10.1287/mnsc.2.3.197

Danger, M., Daufresne, T., Lucas, F., Pissard, S., & Lacroix, G. (2008). *Does Liebig's law of the minimum scale up from species to communities?* Oikos 117, 1741-1751. doi:10.1111/j.1600-0706.2008.16793.x

Diederen, A. (2010) *Global Resource Depletion: Managed Austerity and the Elements of Hope*. Delft: Eburon Academic Publishers.

Efatmaneshnik, M., Nilchiani, R., & Heydari, B. (2012). *From Complicated to Complex Uncertainties in System of Systems*. 2012 IEEE International Systems Conference, Vancouver. doi:10.1109/SysCon.2012.6189537

Gorban, A. N., Pokidysheva, L. I., Smirnova, E. V., & Tyukina, T. A. (2011). *Law of the Minimum Paradoxes*. Bulletin of Mathematical Biology 73, 2013-2044. doi:10.1007/s11538-010-9597-1

Grabowski, F., & Strzalka, D. (2008). *Simple, Complicated and Complex Systems – The Brief Introduction*. 2008 IEEE Conference on Human System Interaction, Kraków. doi:10.1109/HSI.2008.4581503

Meadows, D. (1999). *Leverage Points: Places to Intervene in a System*. Hartland, VT: The Sustainability Institute.

Park, C., & Allaby, M. (Eds.). (2013). A Dictionary of Environment and Conservation: 2 ed. Oxford: Oxford University Press.

Suh, N. P. (2005). *Complexity: Theory and Applications*. New York, NY: Oxford University Press.

van der Ploeg, R. R., Böhm, W. & Kirkham, M. B. (1999). *On the Origin of the Theory of Mineral Nutrition of Plants and the Law of the Minimum*. Soil Science Society of America Journal 36, 1055-1062. doi:10.2136/sssaj1999.6351055x

von Bertalanffy, L. (1968). *General System Theory: Foundations, Development, Applications*. New York, NY: George Braziler.

Annex C – Ecosystem and civilization

The primary system of interest in this study is the ecosystem and specifically how its subsystem 'the social organization' interacts with its other subsystems (figure C1). The term 'ecosystem' was introduced as a union of the known term 'biome', the whole complex of organisms inhabiting a given region, and the whole complex of physical factors, which form what is called the environment of the biome (Tansley, 1935). This definition underlines the importance of not only the interaction between organisms but also the interaction between the organic and inorganic.

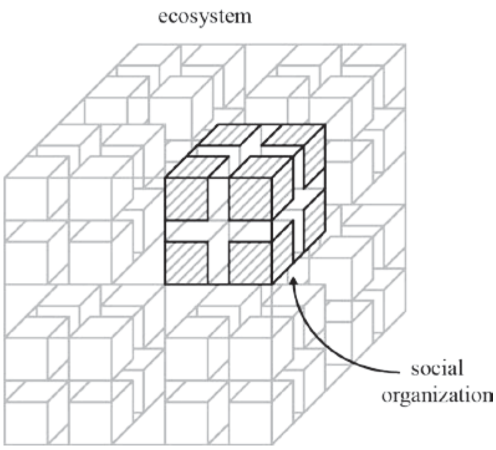

Figure C1 Social organization as a subsystem of the ecosystem

Through observation of a system, for a certain period of time, one is able to notice a behavioural pattern, which is defined as the 'function' or 'purpose' of a system (Meadows, 2009). The 'function' of the ecosystem is the gradual attainment of a more complete dynamic equilibrium, which degree of perfection is measured by its stability (Tansley, 1935). Characteristic for each organismic subsystem of the ecosystem, whether on the scale of a single organism or a whole complex, is the dominant importance of some form of 'metabolism', described as the property of self-maintenance of structure in the midst of a throughput of material and energy (Boulding, 1956). The act of metabolism alters the state of all elements involved and through the summation of all these alterations the ecosystem seeks stability, hence the dynamic nature of the equilibrium of the ecosystem. A stock is an expression of quantity (Meadows, 2009), it is regarded as an amount of a resource (matter or energy) in a particular state. Since metabolism alters the state of elements, it simultaneously alters the stocks. If the amount of elements in a particular state resulting from metabolic processes is lower than the amount being altered into another state by metabolic processes the stock decreases and vice versa the stock increases. As shown in figure C2 the stock acts as a buffer capacity which enables temporary deviations. Alterations and structural deviations in stocks provide insight in the stability of the ecosystem.

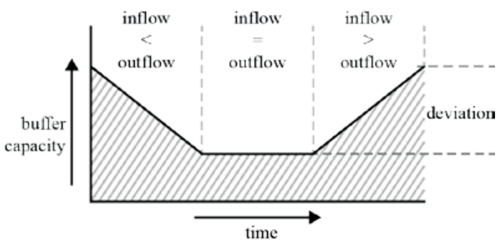

Figure C2 Stock as a buffer capacity

Cowboy or spaceman

Kenneth E. Boulding described in the work 'The Economics of the Coming Spaceship Earth' the difference between a civilization based on an open system or on a closed system, similar to those known in physics;

''For the sake of picturesqueness, I am tempted to call the open economy the "cowboy economy," the cowboy being symbolic of the illimitable plains and also associated with reckless, exploitative, romantic, and violent behaviour, which is characteristic of open societies. The closed economy of the future might similarly be called the "spaceman" economy, in which the Earth has become a single spaceship, without unlimited reservoirs of anything, either for extraction or for pollution, and in which, therefore, man must find his place in a cyclical ecological system which is capable of continuous reproduction of material form even though it cannot escape having inputs of energy.'' (Boulding, 1966)

An organismic system is by definition an open system as it requires some form of metabolism for its continuation. The ecosystem on the other hand, establishes something equal to a closed system by the composition of open systems in a concatenation without a beginning or end, also referred to as a cyclical system.

However, the fundamental difference between both of Boulding's economies is not the concatenation of which the whole consists, but whether the primary focus is the system's throughput or the system's stock.

Waves of change

In the work of Alvin Toffler (Toffler, 1980) civilization is described by the discontinuities in history, simplified in the great revolutions, the waves of changes. His work describes the transitions of the agriculture revolution, the industrial revolution and the third wave of change not commonly named yet. Each individual is seen as a follower of a certain wave and with each revolution a new wave inevitably conquers the vast majority and thus gains those followers. But with the coming of a new wave civilization is split into followers of different waves, this naturally generates conflict and tension. Civilization represented by the most dominant movement of that time can be divided in the primal, agricultural, industrial and the not yet commonly named civilization.

Figure C3 illustrates a timeline in which the waves of change are expressed by the changing percentage of followers associated by the different movements. The winding line placed over the timeline represents the degree to which the behaviour and values of the social organization correspond with either the cowboy or spaceman economy.

In a hierarchy of systems, the social organization is regarded as a component of the ecosystem, in turn, the human individual is regarded as a component of the social organization or an element of the ecosystem. The social organization is the intermediate between the system as a whole, which is closely affiliated with the spaceman economy (closed system), and the element, its smallest part which is oppositely affiliated with the cowboy economy (open system).

Human history starts in the primal civilization in which human individuals acted as hunters and gatherers using the environment to support their metabolism which maintains itself in in a continuous inflow and outflow. Followers of the primal movement where not bond to a single location. If a certain environment could not provide all what was necessary, a new environment would be found to replace it. Although this lifestyle causes conflict with the nature of the environment, human civilization in general was too small in comparison to the ecosystem for it to cause real damage.

With the coming of the first wave, the agricultural revolution, people decided to settle in single locations. They learned to supply their metabolism from a single piece of land. A better understanding of the environment was a necessity in order for people to remain in a single location, because settling means facing the consequences of own wrongdoing towards the little land which supplies your living.

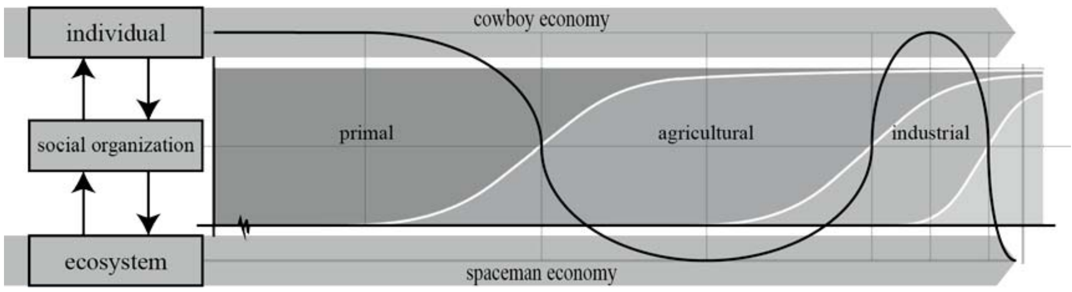

Figure C3 Waves of changes in relation to affiliation with cowboy or spaceman behaviour and values

At this time transportation was limited so this could not provide a substitute supply. Also if someone would measure the success or wealth of a certain individual, the amount of land would be dominant. In order words stock and not throughput was the measure of success.

The second revolution provided civilization with industrialism. It recreated a functioning open society in a much greater scale. Industrialism brought civilization the introduction of nations, in some cases just straight lines drawn on a map which separated pieces of land into independently functioning nations. With nationalism concern would be limited to the area between these lines on the map. Industrialism also removed existing dimensional constrains with a vast improvement of transportation possibilities. Thirdly industrialism brought superiority in regard to nature and to other races. The evolution theory of Darwin was misused to justify certain behaviour.

''It was only a short leap to the idea that whole societies evolve according to the same laws of selection. Following this reasoning industrialism was a higher stage of evolution than the non-industrial cultures that surrounded it.'' (Toffler, 1980)

Superiority justified the exploitation of nature and others. These three elements where the foundation of the functioning open system civilization of industrialism. The only concern was the nation and the improvement of transportation generated possibilities to import necessities and export unwanted consequences. The desired throughput, the continuous inflow and outflow, was made possible. Superiority brought the necessary justification to sustain such a constant exploitation of others.

Mystery of Rapa Nui

The agriculture revolution is regarded as the first transition in which the social organization moved from a more open to a more closed system. As opposed to the current situation, in general, this transition was not imposed by a necessity, in which the deterioration of the ecosystem threatens the current way of life. However, what occurred at the island of Rapa Nui in this period of time does seem similar to the current necessity of a transition.

What exactly happened on the island of Rapa Nui before the coming of the European colonists is still a mystery but there is enough evidence to support certain hypotheses. Evidence suggests that when the first Polynesian settlers arrived 70% of the island was covered with dense woodland, centuries later when the colonists discovered Rapa Nui they described it as a treeless landscape (Mieth & Bork, 2009). Two different chronologies of the Rapanui history are hypothesized, which are labelled by Hunt (Hunt, 2006) as the popular view and the revised chronology. Which hypothesis is the correct representation of the islands history is of no importance to this study, it is the interaction of an influential civilization with its environment in both scenarios which creates a better understanding of the interaction of the social organization with the ecosystem.

The first scenario, or the popular view of Rapa Nui's history, describes a civilization with no regard for its environment, which ignores the signals provided by the ecosystem and continues its ways unchanged. Inevitably the island is unable to support the continued growth of population and the devastating lifestyle of its inhabitants. As a result the collapse of civilization, hunger, war and even cannibalism until the population is decimated to a number the severely degraded environment is able to handle.

The second scenario, or the revised chronology of Rapa Nui's history, describes a similar growing civilization which exploits the palm trees among others for the creation and transportation of the massive Ahu and Moai statues. The difference between the two is that in the second scenario the civilization eventually responded to the signals provided by the environment. Although a lot of the woodland was already destroyed, in the end civilization found its balance with the island. A cultural change was made and the Rapanui stopped with the creation of statues. Grasses where grown to replace wood as a resource for fire and with smart use of stones soil erosion, due to the loss of vegetation, was retained.

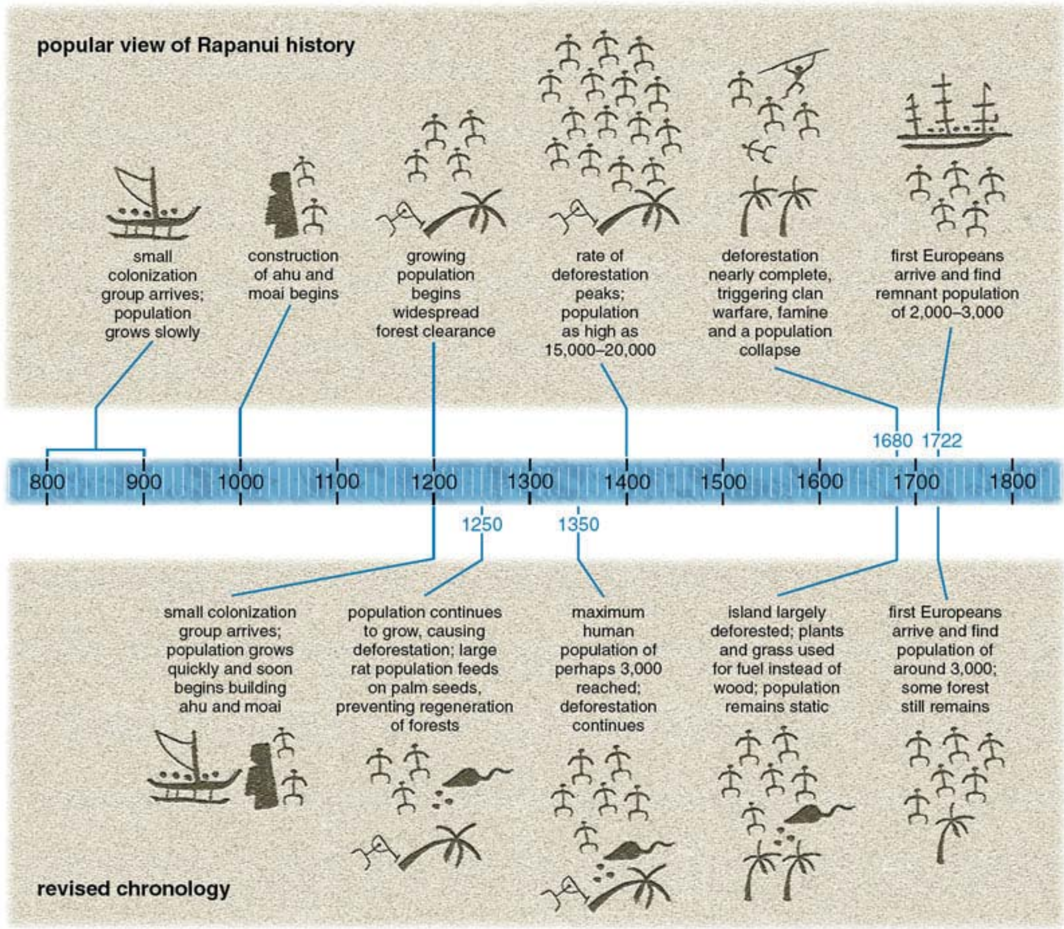

Figure C4 Comparison of two possible chronologies of the Rapanui history, adopted from (Hunt, 2006, p. 418)

But probably the most important implemented change was the stop of population growth at a level which can be supported by the Island of Rapa Nui. A visual comparison of both chronologies of the Rapanui history is illustrated in figure C4.

The result of both scenarios at the time the Europeans arrived seems similar, the woodland was decimated and populations where of equal size, but they could not be more different. The second scenario described a civilization which had found a balance with its environment, the woodland might have been nearly destroyed in the process but with this new found balance a future could be sustained. In the first scenario civilization was merely confronted with the limitation of the environment but still lacked knowledge of how to sustain a future.

Unfortunately the future of this civilization was not determined by their past actions but by the interference of the Europeans which brought conflict, decease and enslavement to the Rapanui.

References

Boulding, K. E. (1956). *General Systems Theory – The Skeleton of Science*. Management Science 2(3), 197-208. doi:10.1287/mnsc.2.3.197

Boulding, K. E. (1966). The Economics of the Coming Spaceship Earth. In H. Jarrett (Ed.), *Environmental Quality in a Growing Economy* (3-14). Baltimore, MD: Johns Hopkins University Press.

Hunt, T. L. (2006). *Rethinking the Fall of Easter Island: New evidence points to an alternative explanation for a civilization's collapse.* American Scientist 94, 412-419.

Meadows, D. H. (2009). *Thinking in Systems: A Primer*. London: Earthscan.

Mieth, A., & Bork, H. (2010). *Humans, climate or introduced rats: which is to blame for the woodland destruction on prehistoric Rapa Nui (Easter Island)?* Journal of Archaeological Science 37, 417-426. doi:10.1016/j.jas.2009.10.006

Tansley, A. G. (1935). *The Use and Abuse of Vegetational Concepts and Terms*. Ecology 16, 284-307. doi:10.2307/1930070

Toffler, A. (1980). *The Third Wave*. London: Pan Books Ltd.

Annex D – Materials

It is estimated that there are between 40 000 and 80 000 different materials, from which products can be assembled (Ashby, Bréchet, Cebon, & Salvo, 2004). The general classification of materials is illustrated in figure D1 (Czichos, 2006). In this classification materials are differentiated based on their origin: natural origin or synthetically processed and manufactured. In addition, materials are grouped into inorganic and organic materials. Composites are combinations of materials assembled together to obtain properties superior to those of their single components.

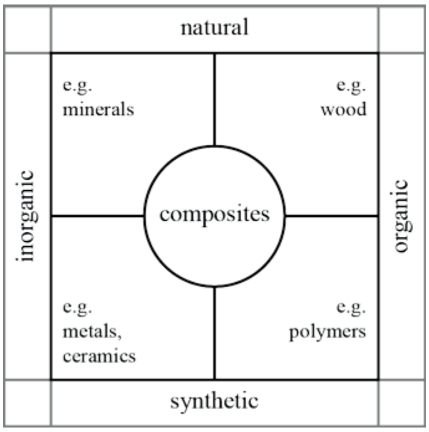

Figure D1 Classification of materials, adopted from (Czichos, 2006, p. 2)

(In-) organic

The organic materials, as opposed to the inorganic, are or once were living matter, as such both renewal and decay are characteristic of their configuration.

Renewal can be regarded as a form of self-reproduction either of the entity or the components, in which for instance growth is regarded as self-reproduction of the components. The phenomenon of reproduction is one which is initiated on a 'parent' basis. In the example of seed dispersal (self-reproduction of the entity) a parent plant or tree disperses its seeds which will later grow independently once arrived in a proper environment which conditions allow the growth of a plant or tree. In regards to other organisms, like animals, the 'initiation' period might require a greater timespan due to the fact that the 'new born' is unable to satisfy its necessity for metabolism independently from its parent. But in both cases reproduction is initiated on a parent basis eventually resulting in a new organism which is only dependent on a proper environment to satisfy its necessity for metabolism.

Decay occurs as a consequence either due to an inability to suffice the necessity for metabolism or due to the decline of the ability of self-maintenance. During the process of decay the materials is disintegrated into smaller components which act as nutrients in other processes of metabolism. The main cause of decay of organic materials used in products is, for instance, lumber which is separated from its roots and soil in order to be part of a product configuration and thus has lost the ability to muster the essentials required for its metabolism.

Renewables

The category of organic materials requires a further differentiation based on the rate of renewal, as illustrated in figure D2.

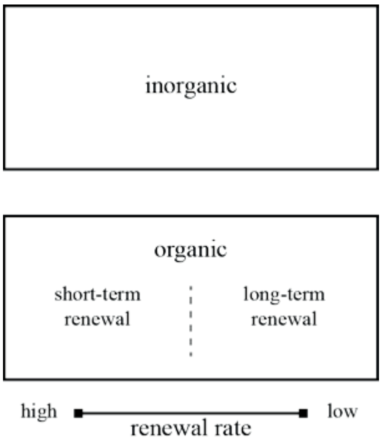

Figure D2 Differentiation on renewal rate

The renewal rate is defined as a quantity which is able to renew itself (grow back) in a certain period of time. Even crude oil is of organic origin, however, the quantity which is able to renew itself in the lifetime of a generation is seemingly insignificant. Thus often when one refers to renewable materials, the reference is intended to the organic resources which exhibit short-term renewal.

Reserves

Another difference between the organic (short-term renewal) and inorganic resources is the importance of the notion 'reserves'. The absolute resource stock can be divided in stock which is already exploited, accessible stock and non-accessible stock, as illustrated in figure D3.

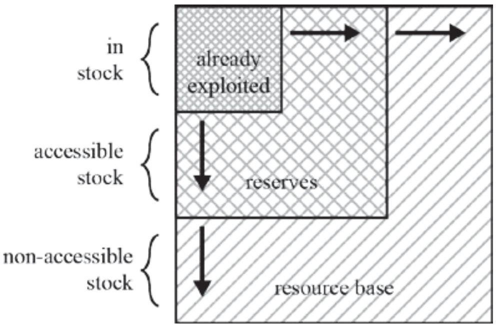

Figure D3 Difference between reserves and resource base, adopted from (Ashby, 2012, p. 33)

The reserves are synonymous to the stock regarded as accessible. This accessibility is based on the feasibility of extraction, both in economic and technological terms.

The distribution of resources and the configuration in which they occur is regarded as a random event (for elaboration see Annex A). However, the intrinsic characteristic of parent-based renewal of organic materials affects the probability of distribution.

''*Despite the evident importance of their dispersal, most seeds fall near their parents. Genetic markers confirm that the vast majority of the offspring of one common European cherry species end up within 10 meters (m) of the tree that produced them, while a minority travel much further.*'' (Howe & Miriti, 2004)

The segregation of reserves from the resource base is primarily based on a quality difference in various sources. However, due to the nature of renewal (either of the entity or the components), short-term renewal organic material will not exhibit a similar quality difference of sources, as the distribution is not regarded similarly, as a random event. Figure D4 illustrates the adjusted workings of the (short-term renewal) organic resource base, in which the characteristics of renewal and decay have been added.

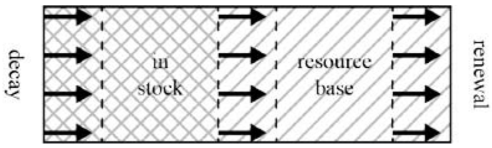

Figure D4 Workings of the (short-term renewal) organic resource base

References

Ashby, M. F. (2012). *Materials and the Environment: Eco-Informed Material Choice, Second Edition*. Butterworth-Heinemann. doi:10.1016/B978-0-12-385971-6.00016-6

Ashby, M. F., Bréchet, Y. J. M., Cebon, D., & Salvo, L. (2004). *Selection strategies for materials and processes*. Materials & 25, 51-67. doi:10.1016/S0261-3069(03)00159-6

Czichos, H. (2006). Materials and Their Characteristics: Overview. In H. Czichos, T. Saito, & L. Smith (Ed.), *Springer Handbook of Materials Measurement Methods* (95-102). Springer Science+Business Media, Inc.

Howe, H. F., & Miritti, M. N. (2004). *When Seed Dispersal Matters*. BioScience 54, 651-660. doi:10.1641/0006-568(2004)054[0651:WSDM]2.0.CO;2

Annex E – ‘Learning-by-doing’

‘‘Everything you see or hear or experience in any way at all is specific to you. You create a universe by perceiving it, so everything in the universe you perceive is specific to you.’’ (Adams, 2009)

In a game, at least in the type of game I am referring to, you are presented with a situation inspired by real-life. The player is informed of a set of rules which consist of the possibilities and clear causalities concerned with those possibilities. The goal, clear winning conditions, are also provided. In essence a game is a complete model in which purpose, elements and relations are prior deducted, in which only the task of devising an optimal strategy remains.

As such, a game educates on two aspects. First of all it is a great tool of communicating one’s perception of the workings of the situation it is inspired on. It may be limited by its simplification, however, its ability to transfer understanding exceeds that of the written word. In addition, such a game educates on devising an optimal strategy to deal with the issue or task presented.

This annex will proceed with an elaboration of the well-known board game ‘the Settlers of Catan’. It is argued that the aforementioned game presents a dated perception on how resource should be managed in relation to the workings of underlying physical boundaries. The concept of the ‘the Settlers of Catan’ will be improved, based on more accurate perception of the workings of resource use, by a step-by-step alteration of the rules in order to enable its use as an educational tool.

Game overview

Let’s starts with the overview (Teuber, n.d.) of the original game. Figure E1 illustrates some of the game’s key aspects.

1 The island of Catan consists of a random assembly of 19 terrain hexagons surrounded by the ocean. Your goal is to colonize the island and expand your territory to become the largest and most glorious in Catan.

2 There are five productive terrain types and one desert on Catan. Each terrain type produces a different type of resource card. The desert produces nothing.

3 You begin the game with two settlements and two roads. Each settlement is worth 1 victory point. You therefore start the game with 2 victory points! The first player to acquire 10 victory points on his/her turn wins the game.

4 To gain more victory points, you must build new roads and settlements or upgrade settlements into cities. Each city is worth 2 victory points. To build or upgrade, you need to acquire resources.

5 How do you acquire resources? It’s simple. Each turn, a dice roll determines which terrain hexagon (indicated by the numbered markers) will produce resources. If, for example an ‘8’ is rolled, the terrain hexagons containing the ‘8’ will produce resources.

6 You only collect resources if you own a settlement or a city adjacent to a terrain hexagon producing a resource. Since settlements and cities usually border on 2-3 terrain types, the can ‘harvest’ up to 3 different resources based on the dice roll.

7 Since you rarely have settlements everywhere as the game starts or progresses, you may have to do without certain resources. This is tough, for building requires specific resource combinations. For this reason, you can trade with other players. Make them an offer! A successful trade might yield a big building!

8 You can only build a new settlement on an unoccupied intersection if you have a road leading to that intersection and the nearest settlement is at least two intersections away.

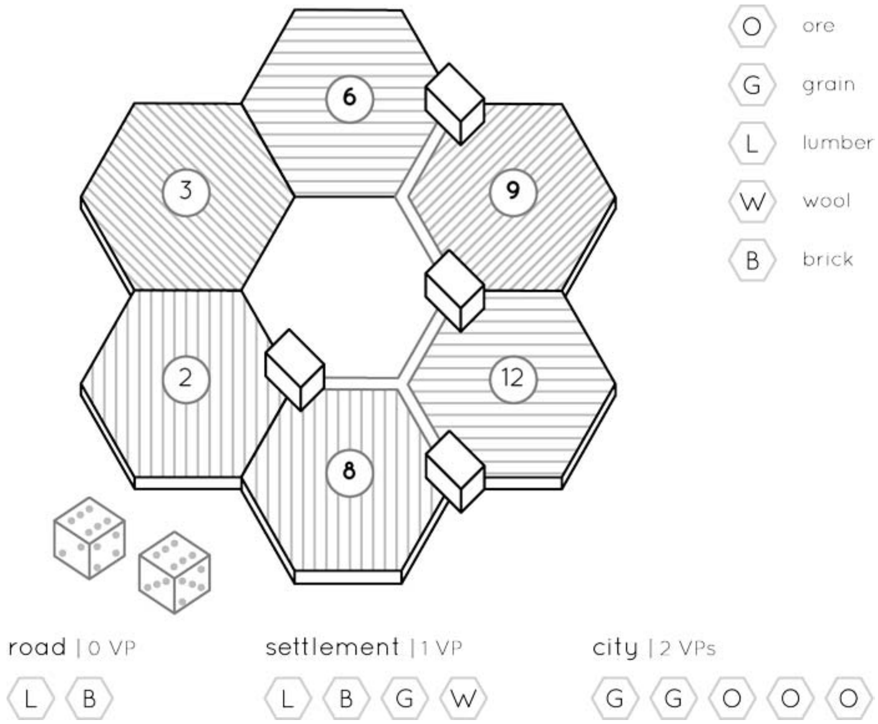

Figure E1 The Settlers of Catan - key aspects

VPs

As mentioned in the game's overview the goal is to 'expand your territory' to become the 'largest' and thus 'most glorious'. A winning formula towards this goal is easily deducted; exponential growth, more settlements results into more resources which in turn enables more settlements and so on. Such a simple winning formula can only set foot in a world of abundancy, in which the sole hindrance of ever greater growth is the current state of technology itself. Whether in the work of Toffler (Toffler, 1980), who applied the term 'maximization' or in 'the Limits to Growth' (Meadows, Randers, & Meadows, 2004), which used the term 'exponential growth', it can be both seen as characteristic of the industrial revolution and sequentially the source of our current resource related problems. Nevertheless the new game will retain the same goal. The educational message focusses on how to play the game, not which goal to pursue.

Figure E2 illustrates the 'adjusted' characteristics of the items (roads, settlements, etc.) which will be elaborated on one by one in the following segment.

The original game includes a distinction in 'items' in relation to the goal, 'roads' unlike 'settlements' and 'cities' do not contribute to the amount of 'victory points'. Roads are a necessity, since new settlements can only be built on a location connected with a road to a previous settlement, however, they do not contribute directly to the goal of 10 victory points. The improvement version will retain this distinction in items which contribute directly or indirectly to the goal.

The items which contribute directly to the amount of victory points are referred to as consumer (c.) products, those which do not are referred to as process facilitating (pf.) products. Due to the simplified nature of the game the 'settlements' and 'cities' fulfils both roles, they offer shelter for the colonialists but also enable resource production and thus are regarded as items which contribute to the amount of VPs. The roads, receivers and furnaces are regarded as process facilitating products and thus do not result in an increase of the VPs. The added items, receiver and furnace, will be explained later on.

	road	settlement	city	receiver	furnace
VP(s)	0 VP	1 VP	2 VP	0 VP	0 VP
resource configuration	L B	L B G W	G G O O O	B G O	L B W
(dis)assembly cost	E	E	E E	E	E
production gain	-	?	? ?	E E	E E E E
production cost	-	E	E E	-	L or G G
maintenance cost	1/4 E 1/6 L	1/4 E 1/6 L 1/4 G 1/4 W	2/4 E 2/4 G	1/4 E 1/4 G	1/4 E 1/6 L 1/4 W

Figure E2 The improved 'items' overview

Resources

''How do you acquire resources? It's simple. Each turn, a dice roll determines which terrain hexagon will product resources.'' (Teuber, n.d.)

Acquiring resources may not be as simple as presented. The law of conservation, a well-known axiom in physics, excludes the possibility of 'resource production'. Thus the terrain hexagons should not be able to simply generate resources, when a resource is extracted from a source, a part of it should physically move to the extractor. To enable the implementation of this change the one-piece hexagon needs to be divided, as shown in figure E3.

In the original game acquired resources were expressed by cards, when a certain resource was acquired the player received a card from the 'resource bank'. When an item was built the required resource cards were returned to the 'resource bank', the amount of cards of which the resource bank consist were of such proportions that they did not allow depletion.

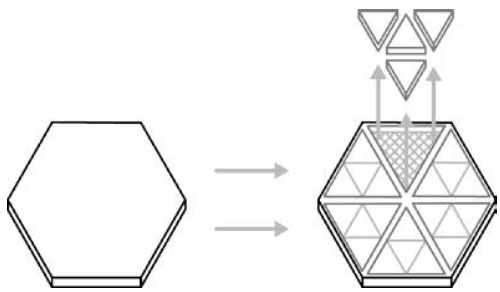

Figure E3 Partition of terrain hexagon

This axiom of physics affects both the sources as the items, the sources due to the fact that matter cannot be created and the items due to the fact that matter cannot be destroyed. A product is not merely 'bought' with a shopping list of materials, it is assembled by a distinct configuration of selected materials. Figure E4 illustrates the change of appearance of the items (roads, settlements, etc.) in the improved version. The new items are represented by a translucent object in which the required combination of resources can be set. The translucent object represents an immaterial vessel of knowledge, which configures selected materials in improbable arrangements, objects of human knowledge (Boulding, 1966).

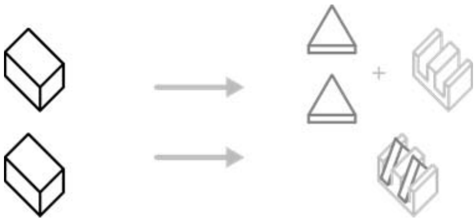

Figure E4 Items – configurations of resources

'Cost'

Due to the implementation of the conservation law the original 'cost' has been taken out of the equation. The knowledge of a product being a specific configuration instead of an item which is paid for with a list of resources enables a certain reversibility, in which resources can be reconfigured to new products. A process or action without a certain 'cost' seems to collide with our perception of reality, one cannot gain something for nothing.

Thus the concept of 'energy' is introduced in order to replace this initial cost. As illustrated in figure E2, each action requires the payment of energy, including the assembly and disassembly of items. This still allows the reconfiguration of items into different items, or the repositioning of items by disassembling and reassembling on an alternative location, however, not without some form of payment.

Two new items are introduced in order to generate the required energy costs: the receiver, and the furnace. The receiver represents an energy generator which is independent of resource inputs in order to enable its operation, for instance, a solar panel. The furnace represents an energy generator which is dependent of resource inputs in order to enable its operation, for instance, a coal plant. Energy, despite its necessity for the functioning of numerous products, is not regarded as a direct contribution towards the material well-being, therefore both the receiver and the furnace are regarded as process facilitating products and thus do not contribute to the amount of 'victory points'.

The act of production will also include the cost of energy. The extraction of resources will require energy and as mentioned the furnace requires a material input in order to enable its burning process.

Temporality

'The only constant is change' is a well-known expression which is somehow derived from the words of Heraclitus, an ancient Greek philosopher. Presumably the originally expression was applied by Heraclitus to describe a world order consisting of a constant process of change of the things that constitute it, specifically in the interchange of opposites (Vieira, 2013). Nowadays the expression is applied in all sorts of matters as an indication of the temporality of things.

In the domain of product development the distinction in 'functional' and 'technical' lifespan is often applied in regards to this temporality (Gijsbers, 2011). The technical performance is regarded as something which naturally degrades over time and thus eventually a product will be unable to perform the performance for which it was assembled, ushering the end of the technical lifespan. The degradation can be explained due to all external forces to which a configuration is exposed to, which tend to have an eroding effect on it. The functional lifespan is related to the period in which a product is suited to the demands of the users. The demands of the user are also regarded as constantly changing, thus if the performance delivered by the product remains similar it will eventually be insufficient to meet the demands of the user.

In the improved version an item is regarded similar to an organism, as a system which is able to maintain its technical performance and adapt to the users changing demands by reconfiguration and replacement of the decayed organic materials applied in it. As long as this 'maintenance cost' is continuously fulfilled the product will be 'unaffected' by change, if not it will be regarded as out of commission. Thus both a maintenance cost of an input of energy, to compensate for necessary reconfiguration, and of an input of organic materials, to compensate for the phenomenon of decay, is required. Unfortunately current state of technology has proven to be insufficient in order to retrieve all resources applied in a product configuration to its previous state once it's assembled. Thus the maintenance cost of constant reconfiguration should also include a compensation for insufficient recycling, however, this is not implemented as such in figure E2.

Source quality

The original 'the Settlers of Catan' has already incorporated a system to distinguish in different source qualities. Each turn the summation of the result of two dice rolls will determine which terrain hexagon(s), indicated by the numbered markers, will 'produce resources'. The probability that for instance a '2' is rolled is approximately 3% while the probability that a '6' is rolled is around 14%, thus the amount of resources that a terrain hexagon with a more 'probable' number is able to 'produce' in the same timeframe is greater. A source of lesser quality, thus in a more diffuse state, not only experiences a lower extraction speed but also a higher input 'cost' for an equal amount of resources. This is incorporated by 'paying' for 'possible extraction'.

Extraction 'cost' and extraction speed need to be treated in a similar fashion in order to incorporate a proper distinction between source qualities. In the original game the cost of a settlement is equal despite the quality of the source it is adjacent to. If we were to incorporate an 'operational cost' it should also be independent of the source quality and should be paid, for instance, once a turn despite whether the source 'delivers' or not. If so the amount of resources that a terrain hexagon with a more 'probable' number is able to 'produce' in the same timeframe is greater for the same 'cost'.

Abundancy & scarcity

The original Settlers of Catan incorporated a diversity in quantity of sources, hence the playing board consist of 19 hexagon it is not even possible to play with an equal amount of each of the five sources. In order to gain a better understanding of abundancy and scarcity the inequality needs to be enlarged for which the current 19 terrain hexagons do not suffice.

First of all the hexagon source which is divided into six triangles which each are further dived into four smaller triangles will no longer necessarily represent a single source. The six triangles which form a single hexagon will each represent a separate source, resulting in 114 sources instead of the previous 19, increasing the possibility for inequality in regards to resource amounts. A roll of the dice still determines of which hexagon resources may be extracted, but if more than one type is present in a single hexagon the 'extractor' is allowed to choose which resource to extract. To avoid a multitude of possible decisions with each dice roll a settlement or city is only allowed to extract from the 'main-triangles' directly surrounding it, as illustrated in figure E5.

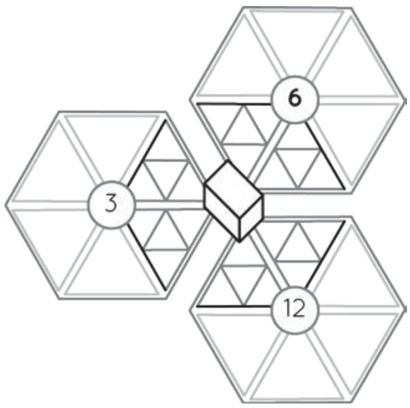

Figure E5 Area of possible extraction

Organic & inorganic

Ore, grain, lumber, wool and brick are the different resource incorporated in the Settlers of Catan. As mentioned in annex D, resources can be classified as either organic or inorganic.

The renewal rate, however, is also of importance to classify organic resources on quality as potential sources of energy. For most organic resources, or at least for most plants, the light emitted by the sun is an essential inflow in the metabolic process. Inherent to their expansion is the storage of energy into chemical bonds. A source of which long-term renewal is characteristic requires a longer period of time in which to carry out its metabolic process in order to reach a similar renewal as a source would of which short-term renewal is characteristic. The difference can either be explained by a slower metabolic process or a relative greater requirement of inflow. Assuming the latter as at least part of the explanation it can be stated that sources with a lower renewal rate possess a greater concentration in its energy storage and thus is regarded as a higher quality of energy source.

In summation - the improved overview

1 The island of Catan consists of a random assembly of 19 terrain hexagons, each composed out of six main-triangles, thus 114 partitions in total. Your goal is to colonize the island and expand your territory to become the largest and most glorious in Catan.

2 There are five terrain types each associated with the presence of a particular resource. The resources ore and brick are classified as inorganic resources and the resources grain, lumber and wool are classified as organic.

3 You begin the game with two settlements, two roads and either a furnace or a receiver. Each settlement is worth 1 victory point. You therefore start the game with 2 victory points! The first player to acquire 10 victory points on his/her turn wins the game.

4 To gain more victory points, you must build and maintain settlements and cities. Each operating settlement is worth 1 victory point and each operating city is worth 2 victory point. In order to build, rebuild and maintain, you need to acquire resources and generate enough energy.

5 How do you obtain energy? At the beginning of each player's turn all his or her operating receivers will generate a fixed amount of energy. In addition, he or she can chose to active operating furnaces to generate more energy at the expense of acquired resources.

5 How do you acquire resources? It's simple. Each turn, a dice roll determines which terrain hexagon (indicated by the numbered markers) will enable resource extraction. If, for example an '8' is rolled, the terrain hexagons containing the '8' will enable extraction of its resources.

6 You only collect resources if you own an operating settlement or city adjacent to a terrain hexagon enabling the extraction of resources.

In addition you are only able to collect resources from the 'main-triangles' surrounding the settlement or city, as illustrated in figure E5.

7 However, you only collect resources if you have chosen to apply the adjacent settlements and/or cities for resource extraction (which requires a payment of energy).

A round consist out of one turn for each player. A dice is rolled during each of these turns. A player determines in each of his or her turn which settlements and/or cities to apply for resource extraction during the following round.

8 Each main-triangle contains 4 resources. You are only able to extract resources from a source which is not yet depleted.

9 The sources of organic resources exhibit renewal with a rate specific per resource type (grain, lumber or wool). A source will cease its renewal when it is fully depleted.

10 A player needs to fulfil the required maintenance cost for each of his or her items (settlements, cities, road, receivers and furnaces). Failing to do so will result in an item which is regarded as out-of-commission and thus will not operate or contribute to the amount of VPs.

11 Since you rarely have settlements everywhere as the game starts or progresses, you may have to do without certain resources. This is tough, for building requires specific resource combinations. For this reason, you can trade with other players. Make them an offer! A successful trade might yield a big building!

12 You can only build a new settlement, receiver, furnace or city on an unoccupied intersection if you have a road leading to that intersection.

13 During your turn you are able to disassemble any item, simply in order to move it or to collect the resources it contains for different purposes. A disassembly is only possible if the required energy cost is fulfilled and if it does not disrupt the sole road leading to an item.

References

Adams, D. (2009). *Mostly Harmless*. London: Pan Books.

Boulding, K. E. (1966). The Economics of the Coming Spaceship Earth. In H. Jarrett (Ed.), *Environmental Quality in a Growing Economy* (3-14). Baltimore, MD: Johns Hopkins University Press.

Gijsbers, R. (2011). *Aanpasbaarheid van de draagstructuur: Veranderbaarheid van de drager op basis van gebruikerseisen in het kader van Slimbouwen* [Adaptability of the building structure: Changeability of the support based on user requirements in the context of Slimbouwen]. Eindhoven: Universiteitsdrukkerij Technische Universiteit Eindhoven.

Meadows, D., Randers, J., & Meadows, D. (2004). *The Limits to Growth: The 30-Year Update*. White River Junction, VT: Chelsea Green Publishing Company.

Teuber, K. (n.d.). *The Settlers of Catan: Game Rules & Almanac*. Mayfair Games, Inc.

Toffler, A. (1980). *The Third Wave*. London: Pan Books Ltd.

Vieira, C. (2013). *HERACLITUS' BOW COMPOSITION*. The Classical Quarterly 63, 473-490. doi:10.1017/S0009838813000037