Evaluation of 0-materials house design

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ABSTRACT: *So far evaluation of environmental performance of buildings is unsatisfying in terms of net absolute impact reduction. Within the research Institute Built environment of Tomorrow, RiBuilT we are working on a new methodology to evaluate buildings , based on the notion that solar energy is the sole driver of the world, and the future will be (again) based on a renewable resource based society. Its better to start measuring in how far we are from a closed cycle approach with renewable materials, as in how far we have been reducing our dependence on non renewable and fossil resources. The method is called MAXergy, and the unit is Embodied land, as shortly described in a paper for PLEA 2011. [x] In this method we combine energy and materials into one indicator, without weighting factors. Which is possible with reference to the exergy (growth or decrease) in a system, which is a combined energy and mass evaluation. With this methodology we have evaluated the first buildings and building designs . This results in an overview of Embodied land, the impact related to each of the cases, and subsequently we have explored in how far the " embodied land" can be reduced by changing materials and concepts of the design. The Land embodied for materials exceeds largely the land embodied for generating (renewable) energy . The best performing design (from students thesis work), is being built in the District of Tomorrow, a demonstration and research area from the University, including the Embodied land within the plotsize. The Embodied " garden" provides space to (re-)grow the consumed resources for the building. The MAXergy method is described, and version 1.0 will be presented as open source instrument, to evaluate buildings.*

INTRODUCTION

With all environmental problems ahead of us, its no longer of any use to try to improve on our previous designs, and make a design a little less bad, but its time to define the ideal situation, and see how far we are from that. We will have to change for a renewable resources based society (again) also being known under the term of biobased society or biobased economy. We have to explore how such a building could be developed, and what the consequences will be in terms of remaining the thermodynamic quality in our systems.

So far we have evaluated buildings with tools that were not able to generate a undisputable result. All tools for instance use weighting factors, to be able to combine effects into one figure. Even LCA . However this is a subjective approach. And evaluating energy and materials impacts as two different cycles, leads to suboptimisation of systems. [1]

Based on exergy principles, -system analyses with an evaluation of the maximum to generate quality in closed cycles within that system- a combined evaluation of the materials and energy impacts can be made, with a more robust result of the real impact of our building activities .[2,3,] With this in mind, a model and tool have been developed, and some first buildings are assessed to test the tool and get some first insight in the consequences. These can set the benchmark, and show in how far other building (designs) are from that optimal situation. Every building of course has impact, however 0-impact is possible if the building (or any other activity) includes enough space and time within its responsible system borders, to level the impact by being 0-energy and 0-materials, together 0-exergy (-decrease)

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MODEL AND CALCULATION METHOD

The methodology originates from thinking about the relation between energy and mass : in a 0-energy building (that produces all energy renewable on site) the materials are the only burden to society, in resources , CO_2 etc. So how to evaluate energy performance and mass consequences together? The condition set was to avoid weighting factors as being subjective, and negotiable: a absolute evaluation of energy and mass together is needed. Involvement in research concerning exergy analyses , led to the notion that in the end its Solar radiation (and the ability to convert it into useful resources) that is the common denominator for impacts, or better, a measure for the amount of "quality generating space claimed by human demands". . [4]

With this in mind, a model and calculation method have been developed, at first assuming that in a few decades its only renewable resources that matter, whether for energy or materials, and availability of renewable is based on solar radiation conversions (as well as for food and water in fact). To convert solar radiation, space and

time is needed: a m2 land to install PV panels, to grow crops or manage forestry, with a certain production per year. (In a later stage also non-renewables are introduced)
This leads to a method, based on the effectivity of converting solar radiation in the desired form, with a common indicator chosen as Embodied land: the m2-year embodied with providing a product/building , or better to provide the function of for instance a m2 floor (by materials, energy etc) . Fig 1shows a schematic model.

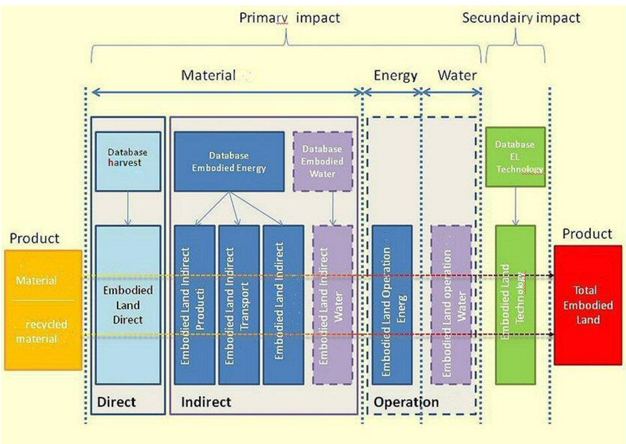


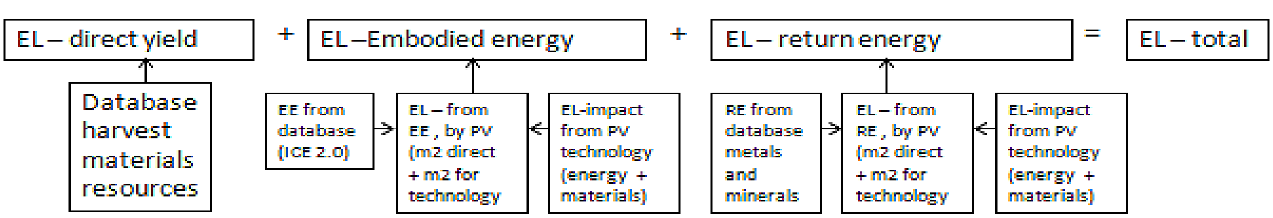
Figure 1:The Model as basis for calculations

Everything is based on solar radiation conversion and the space time involved, as follows:

- to grow renewable materials , in tons per hectare per year. (Own database development) this is used to calculate the total hectares needed to provide the construction materials, in ha-year
- Secondly the embodied energy to harvest , transport and process, in kWh. The kWh are assumed to be provided by Solar conversion devices, and can be recalculated for m2-year need. (We use an average production per m2 (ha) per year for our region for the technology chosen (and ICE database for Embodied energy)[5]
- Thirdly the operational energy of the m2 floor,, again in kWh, and transferred to ha-year need in solar energy.

This gives a total of ha-year, embodied to the building. Land to be reserved to produce or compensate the demand. This can be provided in one year or for instance in x years, depending lifetime commitment. In that case the ha-year is divided by say 50, reducing the land area, but enhancing the time occupied. (see fig2 for the model)
This is the basis. A few additions have to be made. Renewable energy needs storage , to be available 24 hours. We have calculated the extra land-production needed to secure continuous supply, including storage energy and materials demand. (which increased land need for direct solar energy by around a factor 4). Other supply routes are under calculation , like biomass energy (which includes storage by definition, but most likely increases Embodied Land in most cases).

Questions remaining are that for the moment we still have a lot of fossil fuels involved, and a lot of non renewable materials, how to deal with these issues in a calculation, as well as with recycling?
-fossil fuels are in fact renewable energy, though with a long geological cycle. This can be calculated and the solar radiation-biomass-sedimentation-cooking and pressurizing route over 65 million years and global surface leads to a effective production of around 0,0006 kWh-electric per year per hectare. (or 0,0017 kWh-e /ha-year , average for all fossil fuels)[6]
So called ‘non renewable’ materials are calculated by 2 characteristics: embodied energy (to be expressed in m2-year solar energy in stead of fossil fuels,) , and most important: they are depleted. In a Exergy system analyses, to restore quality in the system, (compensate entropy and avoid equilibrium) they have to be renewed as well. And it should be calculated how much space-time is involved in restoring the quality in the system. In fact: counting land to regrow renewable material (trees for instance) is also a form of restoring quality. To have equal conditions the non renewable should have the same



Simplified model calculating Embodied Land –for each resource. For energy generation based on multi-crystalline PV, including storage. (but could be replaced by for instance biomass energy) . Operational energy is to be added similarly, as EL for OE, direct PV surface plus technology related EL.

Figure 2 simplified model EL calculation

Figure 3: The 3 analyzed buildings: left winning student design (dark area is Solar amorf covered façade); in the middle a Dutch average row house ; and on the right a new 5 storey wood and strawbale house (with wood façade).

approach in calculation.

For most minerals a renewable route is available: lime stone is produced by for instance seashells ( ) as the most effective route known for the moment. (they grow in Dutch sea waters at around 245 kg/ha-year) . Similar for Gypsum , which can be regained by evaporation from seawater. [7]
For metals its more demanding. In the end exergy-loss leads to entropy, and for most metals this is the state of being dissolved in seawater (oxidation, runoff to rivers, ending in sea). The reproduction of concentrated metal from seawater (the energy involved) is used as the "embodied return energy", translated again in (renewable energy) embodied land in ha-year. (Several other mechanisms have been explored, but the seawater route seems the most effective, although further research could reveal better options) [8]
Recycling can reduce the "embodied land". Analyses learns however that this is not a free ride: if the first time use is not compensated with controlled re-growth or return-routes, the burden is still the same as new. If it's a renewable material, the time of previous use has to be known, in order to calculate previously compensated re-growth in time and land. So far we have excluded recycling from calculations, in new versions this should be further detailed and added.

BUILDINGS ANALYSED

Using this model a first calculation tool has been developed, and is used now to run test cases for the Embodied Land performance (see fig 3). The first buildings we calculated was the winning design for one of the buildings in "the District of Tomorrow". [9] The District is a real life built environment, in which we construct buildings designed by students, and use these buildings as laboratory. Both technical, as for their use: One building is designed as living working space, another as apartments for elderly people with technology to stay in their own house as long as possible, and a third one will be used for start up companies by graduated students. The last one was the design that was first calculated. The students did not have to calculate the Embodied Land. Based on some first experience with the method, we defined performance based indicators, for easy design structuring. We use this to test if easy indicators can bring designers close to the optimum result. We calculated the Embodied Land parallel and in the background.:
The main (resource related) requirements (performance indicators) for the design were :

- 0-energy or better,
- Installation-poor design (building integrated solutions preferred)
- Less then 750 kg/m2
- 100% made of renewable materials

In fact the two material related indicators are similar to the energy approach : reduction (in kg, compared to kWh-quantity based) and 100% renewables (compare 100% renewable energy – quality based)

The result recalculated for the total Embodied Land based for the winning student design (nr1) is 2508 ha-year . (table 1a) This is to be interpreted as the total land in time needed to compensate for the use of resources, materials and energy. The ha-year need can be provided in one year, in that case the yield of 2508 ha in one year is enough. Or it can be provided in 10 year: 250,8 ha, or in 100 year: 25,08 ha for 100 years will do.

Useful Floor space of the building is 266 m2, so it can be normalized as 9,43 ha-year / m2 floor. Of course this includes minerals and metals as well, (though not –yet- recycling) which counts for the biggest part in the EL. The fraction renewable material is 82 % and non renewable 18 %. Resulting in 2444 ha-year for the non renewable metals and minerals part , and the EL is 64 ha-year, for the 82% or regrowable materials fraction. If we normalize the latter, then its 0,24 ha/m2 floor.

Table 1a and 1b: Embodied Land impact for different buildings(totals) and EL for Energy related impact

	EL tot*	EL/m2fl	EL ren only	EL ren/ m2fl
	Hayear	Hayear/ m2fl	Ha-year	Hayear/ m2fl
Design1	2508	9,43	64	0,24
D1 no shellsand	2466	9,3	21,7	0,08
D1 no shells + no alu	**1494**	**5,62**	**21,6**	**0,08**
NL-ref-new	*1028**	9,3	na	na
Ijburg2	2630*	9,83	11**	0,04**

	Emb Energy	EE/m2fl	Operat. Energy	OE/m2fl
	M2year	M2year /m2fl	M2year	M2year/m 2fl
Design1	2470	9,29	142	0,53
D1 no shellsand	-	-	-	-
D1 no shells + no alu	-	-	-	-
NL-ref-new	*1497**	13,49	257	2,32
Ijburg2	2013*	7,54	60	0,23

*Incomparable between different buildings due to different m2's of floor =total impact in EL
** this is for only 43 % of Renewable materials fraction

It was concluded that the students made a few strange choices, and for a mature design a few adaptations were made: as for instance the design had included soil improvement, by replacing a huge volume with shell-sand. Now the yield of shells and crushed to sand (which give better humidity control around the foundation) is only 245 kg/ha-year. The students were supported in making a few adaptations: If we replace this with normal sand and adapt the foundation somewhat, the result both in construction as in performance is more acceptable, and the EL for the renewable fraction reduces from 64 to to 21,7 hayear or 0,08 ha-year/m2 floor.

The grand total is still high , this relates to the use of aluminum and steel. Students included 300 kg of aluminum, the highest impact resource (from embodied energy and ' return" energy, see table 2) , which could be easily replaced by alternatives. If the (300kg) aluminum is replaced by for instance steel (and the shell sand replaced) the grand total of the final design becomes 1494 ha-year, or 5,6 ha-year/m2floor. (300 kg aluminum is there for responsible for about 1000 ha-year of the result! Of course: with energy generated form solar energy m2's, and regain from seawater included) Further improvement can be made to reduce the significant amount of structural steel in the design. But with these small adaptations we have set this design as the standard to calculate with.

Table 2 shows some typical values for the materials here mentioned: aluminum steel, wood and sea shells. (yield , embodied energy, return energy)

Table 2: specific data for different materials ; EE and RE based on Solarbased production of energy

	Yield per ha	Specific EL	Embodied energy*	EL specific, Emb energy	'Return' energy**	EL Specific return energy
	kg/ hayear	M2year/ kg	MJ/kg	M2year/kg	Mj/kg	M2year/kg
Wood -fir	3000	3,2	5,4	-	-	-
Iron	90.000	0,00011	25	0,077	2.648.230	8184
Aluminium	18.602	0,00054	218	0,67	9.000.000	27815
Shells	245	40,8	-	-	-	-

*ICE 2.0 database Bath university: averages
** re-calculated from seawater extraction, Bardy 2010

Suppose we will compensate the impact for this design of 1494 ha-year on a 50 year basis , then we need around 30 hectares reserved to produce in total . If we only review the renewable fraction its around 0,43 ha, on a 50 year basis. (82 % of total)

EMBODIED LAND AND ENERGY

Interesting is also to see the relation with energy. The total for embodied energy is 0,2470 ha-year , and for operational energy (of this low demand 0-energy building) is only 0,0142 hayear(142 m2year). Of course the last one is on a yearly basis. (not to be divided by 50 in case of 50 years lifetime). It takes about 20 years for the operational energy to become of higher impact as the embodied energy. (see table 1b)

However its obvious that the materials impact is far more important: for only renewables it was already 21,7 ha-year for the final design, and for the total it was 1494…

OTHER BUILDINGS COMPARED

We also compared the design with two other buildings: A Dutch standard reference house (brick based), and a commercial house from partly wood and straw bales. The grand total is the factual impact of the building ie the design. However this can not be used to benchmark buildings, unless they deliver the same amount of functional use, or m2 useful floor. So we have to use the hayear/m2fl indicator. And we can only compare the totals/m2 as a whole, since breaking down the data is good for the projects evaluation, but leaves out many differences and therefore becomes incomparable.

Where the final student design had 5,62 ha-year/m2 floor, the NL-ref house had 9,3 ha-year per m2 floor. Which was however lower as expected. The reference house turned out to have no aluminum and hardly any structural steel incorporated. Therefore the embodied energy was lower (0,1497 hayear) . The operational energy higher since only built according to the current regulation (0,0257) this means that in 6 year operational energy will take over as most impact energy part. This also shows that creating 0-energy houses, the impact of embodied energy becomes significant higher.
The second comparison was made with the wood straw bale building IJburg 2. This had 9,83 ha-year/m2 Embodied Land. So nearly twice as much as our design 1. This was due to also a low fraction of steel and no aluminum, but with a foundation on poles from concrete. Therefore the fraction of renewable material was only 43 %. The EL of that fraction only was 0,04 ha-year/m2 floor: which makes sense: its about half as for design 1, with about twice as much renewable material fraction. The calculation method seems workable, as a first impression.

A 100% BIOBASED BUILDING

The quest for the demonstration project based on design 1, now called " Maxergy house" , is to construct this from 100 % biobased materials, and to set a benchmark for space-time impact of a building, for improved method and calculations . This leaves us with quest to find alternatives for all steel based components, and also for parts so far from " non-renewable origin"
The remaining 18 % consists of mainly finishing and

Figure 4:The buildings products that require a biobased alternative science processes.

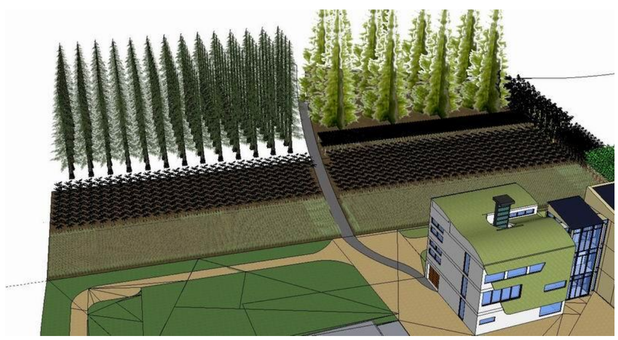
decoration materials. A list is provided in fig 4 . The biobased materials industry in the Netherlands (and beyond) is challenged to provide us with product alternatives for the listed items. We have organized a meeting with the industry to explore the possibilities. It has come out that they can deliver a lot of base materials and half products, but that finished products for the building industry are still lacking: there has been hardly any demand so far, and most effort goes to either bio-.energy products of medical industry and nano-

However some niche production have already been identified. A German firm seems to have screws based on biopolymers available, a Dutch firm has already developed prototypes for bathroom and kitchen equippement. Some of the industries have proposed to make some prototypes for the electronic installations like, piping and switches. By January 2013 construction starts, and the end result can be evaluated, in terms of how high the percentage will be.

THE 0-MATERIALS BUILDING-GARDEN

Apart from the combined energy mass evaluation in terms of Embodied land, the building will also be a 100% renewable material based building. However, renewable materials are only to be called renewable if they are

Figure 5:The design with 0-materialsproduction garden



renewed : We have to secure that process, otherwise its a free ride without knowing the consequences (or for instance tropical forest reduction) . In this case we plan to regrow the materials on site, included in the building plot. (fig 5)
This way creating the same position as a 0-energy building: a building that use little material, and (re-) producing the demand on site.
A garden is designed to provide these materials, for demonstration purposes on a 50 year lifetime/ regrowing basis. We estimate that , based on the 0,43 ha we need (for 82 % of the materials in a 50 year cycle) that with the alternatives for the remaining 18% added, we can do with around 0,5 hectare of land (1 soccer field) . see illustration. The crops included several wood/tree species, hemp and flax fields, beet root and sugar roots, bamboo, and several other small parts to be determined by the available new products from industry.

0-EXERGY BUILDING

Since we include the energy and mass production within our building plot size, the whole will maintain quality within its own system borders, and a such can be also qualified as a 0-exergy building: one that generates its own resources, and maintains a constant exergy level, or better : one that avoids increase in entropy. Water will be included as well, however we have not yet included food for the inhabitants. That's why we speak of a 0-exergy *building*, . including food would create a " 0-exergy *household* site". (terms to be improved…) .

CONCLUSIONS.

We now have some first indications and references of the Embodied Land impact of buildings: that is the impact of energy and materials combined, without weighting factors, in one absolute figure. This is the true establishment of closing cycles in some resources, and the space time impact these represent.

Some first conclusions are possible: that in a world based on renewable sources materials have a much higher impact as energy has. And in our cases the impact of installations , the material part , mainly being metals, have not yet been included.

The 5,62 hayear per m2 floor for the 82 % of renewable material, still seems like a high figure: further optimizations have to be made. One possible improvement is to reduce the insulation level, and a large amount of materials to be harvested (hemp, flax) and in return increase the space need for energy production, which seems more efficient land-time use, and can reduce the total need (in land) .

Consequences on a global scale: We have not yet extrapolated these data to a global scale: How much overshoot do we create at this moment with our construction following this methodology. A first impression is that this is immense. You can also reverse the question: How much land is there per capita, and how much functionality can be created per hayear per capita . This would be the honest approach to level welfare in the world.

Of course, this is a first time exercise , and many elements can be improved. For instance, the database of crop yields, which also differ of course per region and or climate area. Allocation is also part of discussion, not only with us, but in many research fields of biobased approaches. The return route energy causes much debate, and maybe a more efficient approach is possible. And so far we have calculated with all energy based on PV generation (with storage impacts included) but other routes can be studied: like the Hydrogen route or the direct biomass route (which includes storage by definition) .

We hope to have all our data on line by the time of the conference, and explore the possibility to have this operated as open source, so that the capacity to develop the approach is hugely increased.

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