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TES EnergyFaçade – Sustainability and Environmental Impact

Stephan Ott[1], Stefan Winter[2]

ABSTRACT:
There were two questions in the early beginning of the European Research Project TES EnergyFaçade. The first was: how to modernize existing buildings in a better, more energy efficient way. The second question was how to make a façade modernisation system more sustainable and resource efficient for a better environmental performance. The technical solutions will be presented in the paper *TES EnergyFaçade – Construction Principles* during WCTE 2010.
The problems of today's renovation processes are identified and examined with regard to the criteria of sustainability for modernisation. Furthermore every construction causes energy consumption, disposal effort and a reasonable amount of other external effects for the ecologic systems. A turnaround of the enormous demands of resources in construction business requires a more effective and future oriented concept for construction systems, their composition and life cycle. The ecologic performance of a new façade modernisation system was examined exemplary. In short this states the environmental impact of modernisation; finally parameters were identified to improve the system.

KEYWORDS: Resource Efficiency, Construction Ecology, Sustainability, Global Environment, Façade Systems, Retrofitting, Prefabrication

1 INTRODUCTION

Construction changes the environment. Therefore it is necessary today to optimise buildings at their construction, referred to cost, energy consumption and environmental impact. [1]
The life cycle principles for construction, in other words the production, use, durability and reuse of constructions, have to be developed for a future oriented building sector. Prolonging the lifespan of a product is also an economic measure to add value to construction products. The added value follows a better overall life cycle performance of the product.
In addition there is a close relation between materials used and their life cycle impact [2]. Wood and wood products for construction have an outstanding environmental profile compared to functionally equivalent products made form other raw materials [10]. The use of wood has to be forced in respect to the high resource efficiency of a renewable material. Buildings or construction products made from biotic resources show a higher ecologic quality than others [3].

Consequently the TES EnergyFaçade retrofitting system, a new building modernisation method, is introduced to satisfy these demands with a less harmful environmental impact than existing methods. The aim of TES is the develop methods for the energy efficient modernisation of the building stock with large-scale prefabricated timber based elements. Claiming low greenhouse gas emissions is a result of the main use of wood as main material source for the retrofitting system.

2 RESOURCE EFFICIENT WAY - REQUIREMENTS

2.1 Sustainability of Modernisation Systems

The application of new façade systems needs additional resources in order to eliminate existing functional and technical deficits of the building stock. In order to provide a sustainable solution the systems have to solve requirements concerning durability and life cycle issues. Accordingly another main focus is the environmental performance of a building system.
There are a few existing façade modernisation systems, which are applied in practice today. All systems show common badly scoring attributes:

- Short lifespan and high maintenance cost,
- Work intensive and time consuming,
- Unergonomic and high emissive construction,
- Non-ecologic and based on abiotic resources.

[1] Stephan Ott, Research Associate, Chair for Timber Structures and Building Construction, TU München, Arcisstraße 21, D-80333 Munich, Germany. Email: ott@bv.tum.de
[2] Stefan Winter, Professor, Chair for Timber Structures and Building Construction, TU München, Arcisstraße 21, D-80333 Munich, Germany. Email: winter@bv.tum.de

In sum they all use inefficient processes with problems in quality, waste and resource base, see Figure 1. Future oriented or sustainable systems have to avoid waste and reveal a high recycling rate.

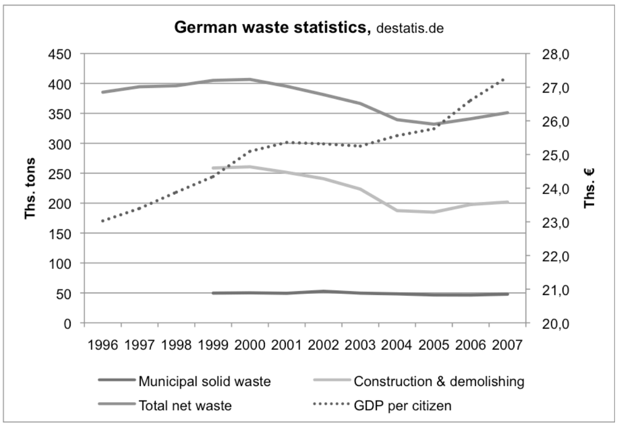

Figure 1: *Development of construction waste from 1996 to 2007 [8].*

2.1.1 Potentials of Urban Mining

A resource intensive task like building construction needs a huge amount of materials, energy and services to design, produce, maintain and finally dispose it [6]. These resources are stored in buildings for decades. In consequence future generations have to deal with the building stock and its captured values. Exactly this problem can be observed with the buildings erected after the Second World War in Europe in the 1950s to the early 1980s. Large parts of them have reached their predicted lifespan [7]. Especially the building envelope and the linings need a modernisation. The even bigger challenge is to reduce their high demand of primary energy for operation, a result of the poor construction standards of post war buildings.

Moreover the amount of post war buildings is very high and concentrated in closed urban quarters. In Germany up to 45% of the existing building stock was erected in the 1950s to the 1970s. Therefore a gentle change and preservation of historic urban situations and cultural identity is a prerequisite. Modernisation and not disposal is the sustainable answer to this task because of the values and resources waiting to be mined in buildings and urban context [5].

Table 1: *Requirements throughout the life cycle of a modernisation system.*

	Production phase	Building phase	Use / Operation phase	Disposal phase
Requirements	Technical feasible	Moderate price	Energy efficiency	Design for Disassembly
	Reasonable costs	Low emission	Less maintenance	Separation
	Production	Fast construction	Durability	Energy storage
	Process	Precision	Healthy indoor climate	Reuse
	Standardisation	High quality	User Comfort	Recycling
	Material efficiency	Zero waste		Zero waste

2.1.2 Life Cycle of the Building Envelope

The concept of life cycle describes and inherits all different stages a product or a service will run through, from raw material acquisition to the final disposal [14]. An environmental product declaration (EPD) contains information about this life cycle and describes one, several or all environmental aspects of a product. It aims at the information of customers to provide them with comparable information on environmental considerations. It thus helps to choose an appropriate product.

Lifespan is the most important factor in the whole resource efficiency discussion of a product itself. The higher the lifespan the lower is the environmental impact per time unit.

However a simple stretch of the timeline should be examined carefully because of the limited durability of constructions or products in general. Otherwise the probability of a system breakdown will rise.

2.2 Modernisation of the Building Envelope

A modernisation is a complex process, which has to be implemented together with the system of an existing building. The retrofit of a system has to take care of the actual requirements defined by the stock and sets new conditions for the future. Finally the whole building performance has to reach the predicted sustainability benchmarks of the modernisation concept.

2.2.1 Functional Deficit

Existing buildings show a long list of functional deficits especially in the building skin. Most of them have to do with topics related to building physics. It is a consequence of the poor construction standards and the early phase of industrialisation in the building sector.

There are general problems with low heat resistance and missing heat protection of the outer walls or façades. The low heat resistance in combination with old, damaged rain protection layers leads to moisture problems inside the outer wall construction.

Modernising façades have to solve the problems of building physics. A second skin can provide this very efficiently, without severe interventions in the existing structure.

2.2.2 Technical Deficit

In the first industrialisation wave of the building sector new functional structures and constructions emerge. Prefabricated concrete elements were joined on site. Façades show the typical grid of the structure and joints of the elements. These gaps between constructions were closed with flexible sealant on-site.

Nowadays construction joints and gaps are often damaged and sources of leakages. They lead to a high level of infiltration of air. In consequence there is heat and moisture transport through this leakages that leads to a further damage of the gap and the adjacent elements.

The building envelope consists of subassemblies like windows, doors etc. The thermal quality of frames and glasses do not meet the requirements of today's building regulations. Furthermore they are heavily stressed mechanical and therefore show considerable shorter life cycles than other parts of a construction.

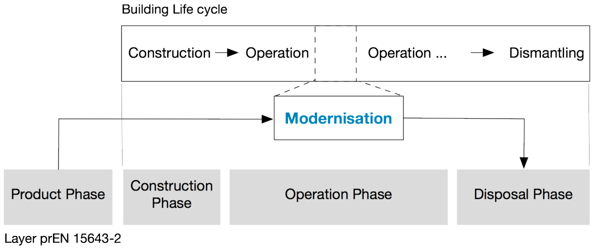

Figure 2: *Modernisation in building life cycle.*

2.2.3 Energy Efficiency

Energy efficiency is closely related to the operation phase of a building. The requirements of energy efficiency and technical solutions in short:

- Low heat transmission through the building skin,
- Minimized thermal bridges, either geometric or construction related flaws,
- Wind tight building skin (prevents the cooling of the insulation layer)
- Airtight inner layer prevents heat convection and moisture transport inside the outer leaf.
- Compact hull leads to a low heat transmission area.

Life cycle examinations of buildings normally put the emphasis on the operation not on the erection phase, due to the long life span of buildings in general. Thus the energy consumption during the use of the building seems to be the most critical part.

A change of the heating concept will change the ratio of primary energy demand in all phases. For example a passive or net zero energy house, as a future oriented operation concept, reduces primary energy demand to a minimum.

Consequently the material flow also needs to be reduced to a sustainable level. One path is to substitute conventional construction materials by intelligent products from renewable resources. Another contribution could be the reuse of dismantled construction material and of entire buildings by their modernisation.

2.2.4 Other Deficits

Quarters from the 1950s and 60s with her used look and patinated façades, combined with an old-fashioned appearance easily drift into urban problem zones.

A bad condition and a shabby look force this process, because they scare possible inhabitants off. Thus it leads to problems in the urban context with high fluctuation and related social problems.

Therefore TES EnergyFaçade offers a second chance for architecture with an urban and sustainable modernisation solution [9].

2.2.5 Resource Efficient Solutions for Modernisation

Solutions for the deficits in modernisation are technology dependent on one hand and material dependent on the other hand.

An increased use of materials from renewable resources improves the ecologic quality during the product phase see Figure 2. This has distinctive consequences for the disposal phase. Biotic material can be recycled more easily and with a fraction of the energy demand of abiotic material. Another possibility is the use of the biotic material as an almost carbon neutral fuel after it is disposed.

The building phase gains from a proper and efficient use of materials. The basis for a high durability lies in a good process quality. All this prerequisites can be fulfilled in a much easier way in controlled and conditioned work environments. Prefabricated products show higher quality ratings in the whole construction industry than on-site manufactured assemblies.

The operation phase is indicated as an energy-consuming phase. In this phase the correct application of intelligent systems can help to reduce the consumption.

Another issue is maintenance during operation. Intelligent systems have modular concepts for the ease of upgrade. A more specific task is the design of a comprehensive hierarchy in layering that supports separation, repair and improvement of parts on the outer side.

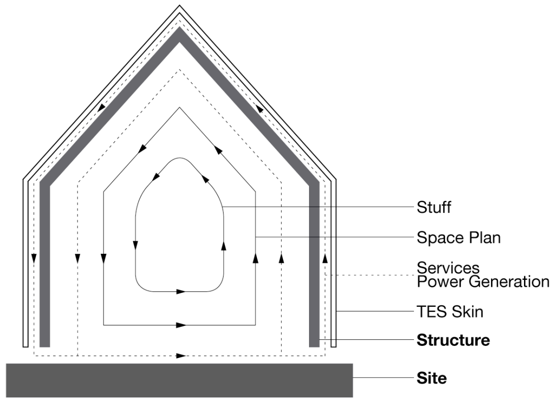

Figure 3: *Hierarchy of composition of layers. Layers on the borders are easier to change or improve, based on Kibert 2002.*

2.2.6 Social and Economic Aspects

Methods of improving a building envelope are used in common practice today; originate in construction methods for new buildings. These are only limited applicable to the set task of retrofitting existing buildings see Figure 4.

The special conditions of the stock like unsatisfying documentation of the geometric situation, poor construction details and very often an inhabited situation need an innovative modernisation system. The Integration of the system in a defined process solves these restrictions. TES EnergyFaçade introduces such a modernisation system. It is based on a prefabricated timber element system, which combines several advantages:

- The building processes are continuously planned and referenced internally.
- The precision and quality of the elements is high
- Functional and technical requirements of the building envelope are improved
- Erection time and hence the disturbance of neighbours are reduced to a high degree
- The façade cladding offers a wide variety of material and design opportunities
- Solar components and building services can be integrated easily
- Excellent LCA due to good material quality
- Less externalised costs

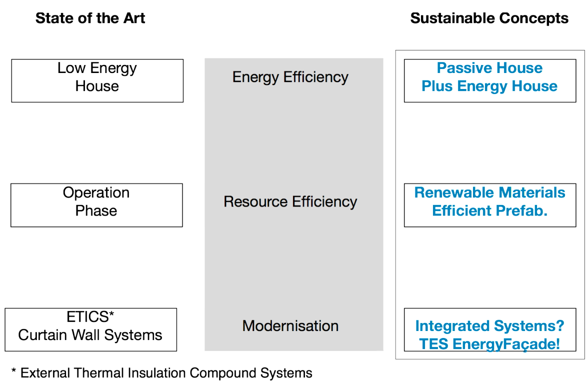

Figure 4: *Sustainable Construction in Modernisation*

3 SUSTAINABILITY BENCHMARKS

3.1 AVAILABLE SYSTEMS

In a first approach, the performance of a TES EnergyFaçade was examined within existing sustainability certification systems. There are 1st and 2nd generation evaluation systems for the sustainability of buildings. They all have a catalogue of criteria derived from the three main pillars of sustainability and the principles of sustainable development first mentioned in the *Brundtland-Report* [4]. The three dimensions, social, economical and ecological aspects establish the theoretical construct of sustainability. They have to be fulfilled to get a positive result for the single task and a good overall rating. The central prerequisite is the observation of all three dimensions over the life cycle of a building.

3.1.1 LEED System

One of the first generation systems that came to market was *Leadership in Energy and Environmental Design* (LEED). Benchmarking is done mostly by qualitative evaluation and credits for all criteria from the field of *green building*. The internal hierarchy does not stick as close to the three dimensions of sustainability. However the defined criteria are also found in second-generation systems.

3.1.2 German DGNB System

The *German Certificate for Sustainable Building* or Deutsches Gütesiegel Nachhaltiges Bauen (DGNB) is one of the 2nd generation systems. Its structure is according to the three dimensions and follows the scope of international standardisation efforts. Therefore the DGNB system is compatible with upcoming European standards of sustainable building, which are under approval.

3.2 European Standards TC 350

The *TC 350* represents the European branch of the international *ISO/TC 59/CS 17 „Sustainability in Building Construction"* standardisation development committee.

The new prEN 15643 is based on the three dimensions of sustainability as well but widens the perspective by the integration of further aspects like functionality, technical quality, and process or planning quality [16]. These additional aspects follow an idea of early quality planning in the construction process when a high influence on the whole building concept is possible at moderate costs.

For the development of TES the focus is on the dimension of ecology, because there are methods available in order to benchmark the performance. The most important instrument is the calculation of *life cycle assessment* (LCA) of a building or its construction elements.

Relevant for the LCA of TES EnergyFaçade are described in prEN 15643-2, the *Framework for the assessment of environmental performance* [17]. The restriction to the product phase set the basis for a universal applicable and comparable product system. Hence the *cradle to gate* dimension is very important in the development process of a new façade system. It allows planners a statement on the ecologic quality of the façade construction on basis of a functional unit. Building owners get comparable declarations on a system and its alternatives in the decision process.

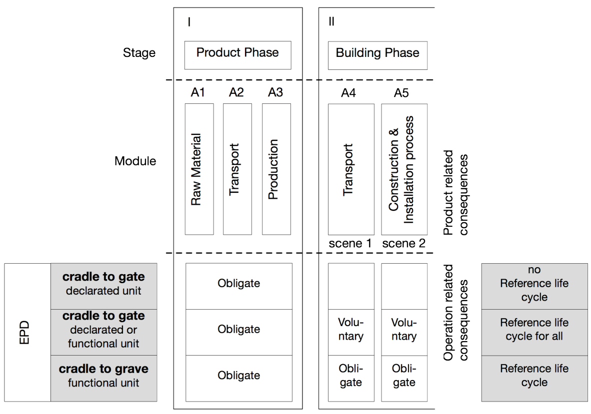

***Figure 5:** Cradle to gate for the product phase according to prEN 15643-2.*

3.3 Sustainability Criteria

Basic preliminaries are the criteria according to the *Guideline to Sustainable Building* published by the German Federal Ministry of Construction (BMVBS) [7]. The life cycle is the most significant aspect of a sustainable valuation. Its value can be expressed in mean product life of an object or the entire *life cycle in years*.

Other important values are *life cycle costs* and maintenance, *dismantling* of a construction and finally their *recycling* or disposal. A further issue is the *energy efficiency* of a building demonstrating its low primary energy demand. In addition *average prices* of the construction examples, based on mean values from a building element catalogue, illustrate the investment costs.

Additional parameters are derived from sustainability assessment frameworks. The selected ones represent all three dimensions of sustainability:

- Fast building process, less emissions (economical, social),
- Precision and quality (economical),
- Variation of cladding (cultural, social),
- Integration of building services (technical),
- Use of few abiotic and much biotic resources (ecological).

Qualitative criteria have to be defined clear and explicit in order to avoid the influence of the questioner. What objectively formulated questions lead to an objective indication of the modernisation system or process characteristics? The following list of stakeholder requirements correlates with the selected parameters from sustainability assessment, which are shown above:

- No spatial restrictions during construction,
- Environment friendly measures,
- Minimized disturbance (spatial, optical, etc.),
- Speed, time span of modernisation,
- Durability, low maintenance effort.

The evaluation is a qualitative approach showing a linear relation between the selected characteristics of sustainability (without weighted parameters) in Table 2. The selected façade systems are mostly external insulation thermal system. Additional systems are outer leafs with insulation and claddings of brick wall or sheet metal. The chosen TES EnergyFaçade was taken from the monitoring project of Realschule Buchloe. Its system details are described in section 4. The strong focus on environment friendly products and the positive social and economic aspect in the life cycle of the product are evident throughout all parameters. The sum of the parameters A_{sust} provides a high value for pollutant and inflexible systems and a low value for sustainable systems like the TES EnergyFaçade.
Results of parameter analysis of the TES EnergyFaçade show very good values due to its sustainable and ecologic performance.

***Table 2:** Sustainability parameter. Range from 1 (good), 2 (neutral) to 3 (bad).*

	Lifespan [years]	System price [€/m2]	R-values [m^2K/W]	Recycling [1/100]	Fast Constr.	Precision & Quality	Variation Cladding	Multi-funct. envelop	Low Abiotic Res.	High Biotic Res.	Sum A_{sust}
E. PS	25	80	5,556	0	3	3	3	3	3	3	18
E. MW	25	110	5,882	0,3	3	3	3	3	3	3	18
E. WF	25	100	5,000	0,9	3	3	3	3	1	1	14
E. CS	25	130	4,545	0,5	3	3	3	3	3	3	18
Brick	80	200	3,030	0,3	3	3	3	3	3	3	18
Metal	25	250	5,263	0,5	3	3	2	2	3	3	16
TES	50	230	12,500	0,95	1	1	1	1	1	1	6

Abbr.: E. (ETICS), PS (polystyrene), MW (mineral wool), WF (wood fibre), CS (calcium silicate)

3.4 Sustainability Functions

Subsequently a linear function of the sum A_{sust} with the different parameters demonstrates the performance of each façade system. $f_n = A_{sust} / Parameter_n$

The function of heat resistance shows a good performance of most of the systems in Table 1, except of the ones showing low heat resistance, like brick leaf systems. This factor has to be handled with care because it is only a construction element declaration

and cannot be used as an overall primary energy demand parameter of a building.
The high value of the price function of TES is interesting. From a short-term investment point of view it is a bad value. However this value is related to the sustainable values of TES EnergyFaçade and therefore it is a very positive result. It expresses also that the environmental costs for a building product are internalised. Otherwise the costs are externalised to society or into the future.

Finally a simulation proofs the robustness of the factors as well as the parameters. The simulation indicates to which degree the performance of a façade system has to be improved in order to reach the quality of TES EnergyFaçade. All sustainability parameters of the existing systems need improvement as well as the life span of the systems. This is illustrated with an ecofriendly product like a wood fibre based ETIC system. Its overall performance is quite good but it shows a shortcoming in life span.

***Table 3:** Functions of sustainability parameters and simulation of robustness.*

	Lifespan factor	Heat Resist.	Recycling	Price	SIM Life	SIM Energy	SIM Recycling	SIM Price
ETICS PS	1,389	0,309	0,000	4,444	15,000	4,500	18,000	15,913
ETICS MW	1,389	0,327	0,017	6,111	15,000	5,250	16,105	15,130
ETICS WF	1,786	0,357	0,064	7,143	11,000	-1,000	8,316	11,391
ETICS CS	1,389	0,253	0,028	7,222	15,000	1,500	14,842	14,609
Brick Leaf	4,444	0,168	0,017	11,111	8,400	-6,750	16,105	12,783
Metal Leaf	1,563	0,329	0,031	15,625	13,000	1,750	12,842	9,478
TES EnergyFaçade	8,333	2,083	0,158	38,333	0,000	0,000	0,000	0,000

Abbr.: PS (polystyrene), MW (mineral wool), WF (wood fibre), CS (calcium silicate)

4 LIFE CYCLE ASSESSMENT

„*... LCA gets more and more attention by industry and authorities as one important tool for e.g., Integrated Product Policy (IPP), Technology Assessment (TA) or Design for the Environment (DfE).*“ This citation from Frischknecht et al. underlines the need of life cycle assessement of new construction systems, especially when they are used in the field of energy efficiency and modernisation [12].

LCA of TES EnergyFaçade was done with the data of a real project. This modernisation project was a school building in Buchloe (RSB), 50 km south of Augsburg, Germany. It was planned by e3-Architekten. One of the small and medium enterprises (SME) of the TES EnergyFaçade research project, Ambros Holzbau, won the public tendering of the façade retrofitting.
The school is a building from the early 1980s, erected as a concrete skeleton structure with a hybrid façade of concrete and aluminium-glass elements. The school had a heating energy demand, which was around 170 kWh/m^{2}a and is now reduced by factor 10, to around 17 kWh/m^{2}a, which is almost passive house standard. The existing façade layers were disposed and replaced by highly insulated, prefabricated timber elements and three-layer insulation windows.
The wall elements are supported by steel brackets, which were doweled into the concrete slabs of the existing floors. The fire safety concept according to the Bavarian building regulations demands non-combustible insulation and outer panelling of the elements, because the school is in building class 5. The visible façade cladding layer, made of horizontal wooden planks, is a special construction, which needed an approval.

4.1 Basic Wall Element

The Buchloe school modernisation project provides data from a realistic building site. This data was compiled and fed into the life cycle assessment software *LEGEP* [19]. The life cycle analysis software was especially developed for the use in architectural planning and serves as an integrated construction specification and calculation tool.

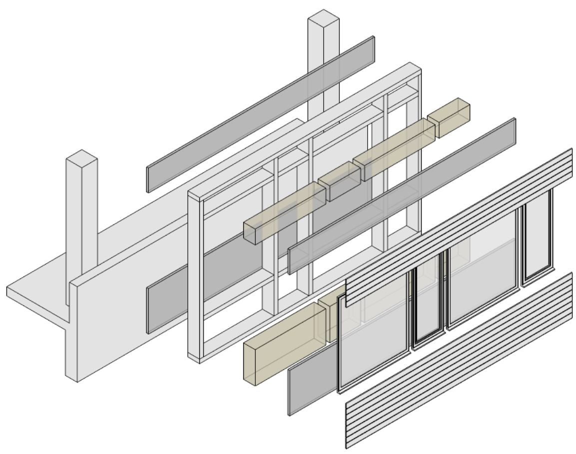

***Figure 6:** Wall explosion drawing of RSB. Layer from outside: cladding larch oil impregnated, windows 3-layer IG, gypsum fibre board, mineral wool 300 mm, timber frame spruce 300 mm, OSB board.*

4.2 Functional Unit and System Boundary

TES EnergyFaçade is a construction element; therefore it has to be described within a functional unit. The unit has to fulfil the requirements mentioned in 2.2. and following paragraphs. For this reason it is composed from several individual components. The functional unit consists of the basic timber framed core with the insulation and the functional panelling layers. Additionally the cladding layer of the visible façade surface comes along. Further parts like an adaption layer; the anchoring construction and flashings are added to the life cycle inventory proportional to their share of a large-scale element. The functional unit and its system borders are represented in Figure 7.

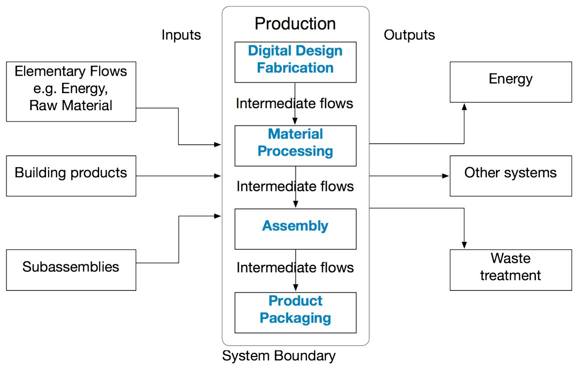

***Figure 7:** System boundary of a TES EnergyFaçade product system.*

The description of the subassemblies is done in the LCA software-tool. A fully described TES element in the database contains all materials inherited in the construction. It equals the functional unit of the façade system.
The database also serves as the life cycle inventory of the functional unit. All materials are quantified with their specific environmental qualities. The characteristic material values are provided by the *ecoinvent* database and environmental product declarations (EPD), which are underlying the formal structure of the element description [11]. All calculation was done without maintenance, disposal and reuse, in order to get the *cradle to gate* values for the façade system for further improvement. The other important parameters have to be calculated within an entire modernisation project as pointed out in section 3.

4.3 Impact Assessment

Two different façade compositions were simulated with *LEGEP* and then compared, see Table 4 and Table 5. In a third simulation, the first element was calculated again with *Ecosoft WBF* [20]. This was done as a kind of cross check with the first results, see Table 6. Cross checks with other LCA software will not show exactly the same indicator values, because of several influences e.g., different LCA databases. Finally the additional results will give hints on the probability of the results.

***Table 4:** Life cycle impact of façade system 1 for school Buchloe.*

Name	Amount [m2]	Mass [kg]	GWP [kg CO2-Äq]	Abiotic Res. [kg Sb-Äq]	PEren [MJ]	PEnr [MJ]
GE 1-7 MW	1.059,74	102.583,00	-63.107,56	330,44	1.999.123,72	771.364,02
V1 GLASS	169,95	7.214,00	7.954,40	83,74	60.252,83	190.849,27
V2 GLASS fixed	785,01	33.320,00	36.741,90	386,81	278.311,69	881.545,09
V3 GLASS comp.	58,76	1.775,00	922,99	7,86	1.068,47	17.202,72
Steel bracket	465,00	26.505,00	41.080,10	266,61	41.824,36	486.387,95

Abbr.: GE (general element), GWP (global warming potential), PEren (primary energy renewable), PEnr (primary energy not renewable)

***Table 5:** Life cycle impact of alternative façade construction (cellulose insulation) for school Buchloe.*

Name	Amount [m2]	Mass [kg]	GWP [kg CO2-Äq]	Abiotic Res. [kg Sb-Äq]	PEren [MJ]	PEnr [MJ]
GE 1-7 Cellulose	1.059,74	106.822,00	-71.084,98	817,10	1.971.735,05	646.936,01

4.3.1 Façade System 1

The system one indicates the results of the built-in façade elements with mineral wool insulation. Composition of the entire basic element in the first line is according to Figure 6, without the glazing. Additionally there are other elements with window openings and doors. The basic element with the closed surface and the timber cladding shows very good results for all *Life cycle impact assessment* (LCIA) indicators.
A high Bonus for *global warming potential* (GWP) and *primary energy renewable* (PEren) can be recognized.

Whereas the elements with the glazing are exceptional bad, due to its large area and the 3-layered passive house of glazing system with a timber frame and an outer leaf from aluminium.
Another bad performing indicator result from the steel parts of the fixation. Its GWP is exceptional high due to the high amount of energy needed for production. Additionally the fixation variety seems not to be the most effective one. One reason is probably caused by the high weight of the elements together with the heavy glazing.

4.3.2 Alternative Solution Façade System 2

The simulation of a second façade system was done with another insulation layer made of cellulose fibre instead of mineral wool. The results show that the element weight is minimal higher (4 %), and heat conductivity is also higher due to the slightly worse thermal conductivity of λ = 0,040 W/mK instead of mineral wool's λ of 0,035 W/mK.
However the overall performance shows almost equal figures, but the ecologic indicator for a basic element is better due to the renewable source of the insulation material.

4.3.3 System 1 – Alternative Calculation

The LCIA simulated with *Ecosoft WBF* provides sufficient and similar results of the ecologic indicators. In consequence the LCA of the façade elements tends to be robust. The figures cannot be compared exactly with the *LEGEP* result because of the reasons mentioned above.

Table 6: *Buchloe façade LCA indicators calculated with Ecosoft.*

specific Mass [kg/m2]	GWP [kg CO2-Äq]	PEren [MJ]	PEnr [MJ]
99,29	-61,51	1102,45	1575,16

5 CONCLUSIONS

The influence of sustainability parameters on the quality of a façade system for modernisation can be demonstrated well. The TES EnergyFaçade is a sustainable solution due to its positive characteristics. Namely the life cycle and the high use of biotic resources attend to low environmental impact. In a further step a more differentiated and weighted examination of sustainability parameters is necessary. This should lead to a better knowledge of the cost parameters and a reduction of the overall costs, but this can only be done in relation to the life cycle. Hence TES is a good example for a new modernisation product determined to the field of industrial ecology.
The results of the LCA clarify the environmental performance of TES and give valuable hints on improvement potentials. The key parameters for better ecologic benchmarks are an improved fixation technology as well as a reduction of the overall material use of the system. The share of openings in the façade can only be judged in the context of the architectural and functional requirements of a specific building. However they contribute an important share to ecologic indicators decreasing the performance. Therefore this influence should be taken into consideration but in a very careful way, when optimisation is the goal.

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