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TES EnergyFaçade – Construction Principles

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ABSTRACT: The existing building stock needs energy efficient modernisation in order to contribute to the global climate protection objectives. Timber construction does not offer adequate, value added solutions in order to compete seriously with the market dominating systems for façade modernisation. However it has a strong potential as it supplies a prefabricated, large-format, flexible and renewables based systems for the retrofitting of the building envelope. The European research project TES EnergyFaçade developed of a defined process for modernisation from surveying up to assembly and maintenance. Additionally it examined the functional and technical requirements for the elements and provides a systemisation of the holistic task. In short TES EnergyFaçade provides an innovative and sustainable modernisation method for the timber construction sector.

KEYWORDS: Global Environment, Timber construction, Energy efficiency, Façade systems, Retrofitting, Prefabrication, Surveying, Sustainability

1 INTRODUCTION

Nowadays the building stock accounts for more than 40 percent of the primary energy demand of Europe. In Germany around 46 percent of the buildings erected between 1948 and 1978 have a heating energy demand between 150 and 300 kWh/m^2 [1]. The rate of building modernisation amounts to only 0,8 percent per year. This figure is far beyond the three percent needed, to obtain the CO_2 reduction goals according to the Kyoto protocol. Modernising the building stock is technical possible and economical viable. The reuse of the resources stored in our existing built environment is a commandment of ecologic rationality.

1.1 Modernisation of the Building Stock

How to generate fast and reasonable results for this task? The demolishing and rebuild of the building stock according to up to date standards would be an unrealistic way, only showing mid and long term results [2]. The more effective way is the retrofitting of the functional deficits of existing buildings in order to prepare them for low to moderate energy consumption. This measure will show short-term success. A prerequisite is the availability of concepts and methods for a fast and sustainable retrofitting of the urban landscape.

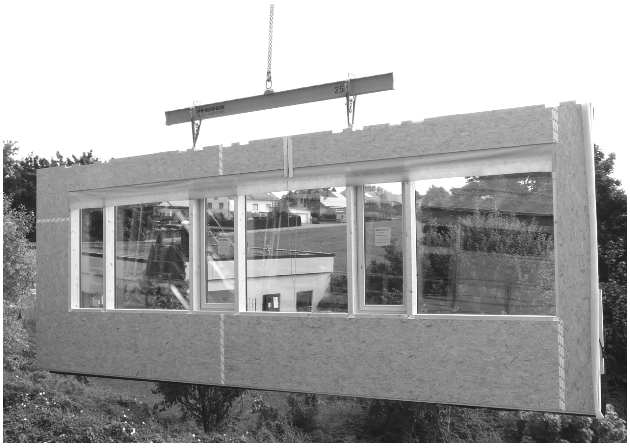

Figure 1: *Prefabricated large-format timber based element for the energy efficient modernisation.*

1.2 Energy Efficiency of the Building Stock

Efforts are forced on all levels, the political and the technological, to reduce energy consumption in the building sector to a minimum. Especially the class of buildings erected after the 2nd world war until the early 1980s indicate a high primary energy demand for operation. Several research projects have shown the possibility of a reduction of the primary energy demand of the factor 10 [3]. Undoubtedly the reduction of heat transmission through a buildings envelope is one of the strongest and most efficient measures. The amount of heat losses through the building envelope accounts for 55 - 65 % and includes the outer walls and windows, without the roof and the ground floor slab. The measures in the improvement of the envelope result in a 70 – 80 %

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reduction of the former proportion of primary energy demand [4]. Hence a modernisation of the building envelope is one of the most effective tasks when an overhaul is necessary and the energy consumption has to be cut down.

2 MODERNISATION PROCESS

Buildings from the post war era are identified for TES renovation. They fit the requirements of energy efficient renovation and need a technical overhaul.

Nevertheless most of these buildings mentioned do not have fundamental problems with the condition of their basic substance. They have technical problems in specific areas due to the end of life of single components like the building services (HVAC, electrical installations, ITC) or climate-exposed constructions like façades and roofs.

2.1 Wood a Modernisation Construction Material

The market potential for modernisation in general is demonstrated with the preceding figures of existing buildings. Subsequently the building sector and its projects are changing since several years from new building towards reconstruction and modernisation.

Sustainable and ecologic systems for the modernisation are needed urgently, because the available systems show several disadvantages.

- Low level of prefabrication,
- Time consuming construction,
- Unergonomic and high emissive work,
- Non-ecologic resources.

However the timber construction sector, with his very ecologic raw material does not have an innovative solution until now. There are some conventional systems called external thermal insulation compound systems (ETICS), which are also available based on wooden materials. Still the main share of timber workshops is the insulation and lining of roof structures in a traditional manner.

2.1.1 Wood and Timber systems

In new construction timber based systems are leading the passive and plus energy house market with high efficient products. They are all based on prefabricated, large format elements made from cross-laminated timber plates (CLT) or timber framework structures. A unique system of quality control in timber construction industry provides clients with durable solutions and added values like a good sustainability and an outstanding ecologic performance.

The TES EnergyFaçade research project sets the goal to transfer the advantages of innovative, prefabricated timber construction into the modernisation of the building stock. In this development a systematic and optimised digital workflow from survey, planning, implementation and maintenance are combined in a holistic modernisation process.

2.2 Prefabrication

The time consuming process of modernisation in general needs an improvement. The methods of prefabrication effect the reduction of unproductive construction time on-site. In contrast to conventional retrofitting scenarios the planning and preparation off-site takes a bigger range of time.

Therefore the planning of a modernisation needs a very good preparation based on reliable data from the condition and geometric situation of a modernisation object. The data flow from the survey; to the planning up to the prefabrication is coordinated with the requirements of the digital process chain. A successful, experienced and cooperating construction team requires an architect, engineer, surveyor and a timber workshop [7].

Consequently the advantages are:

- Planning and production process of a professional team,
- Short erection time and low disturbance,
- Quality approved building system.

2.3 Survey and Digital Workflow

Due to the lack of adequate documentation of the as-built/as-maintained condition of existing buildings, retrofitting work today often suffer from estimation errors, inaccurate bids, design and fabrication mistakes, expensive field rework, etc.

The second vital issue is that TES is a prefabricated renovation method and needs CAD/CAM models for production. Combining the conditions of an existing object with new adapted and industrially manufactured parts lead to the paradigm of reverse engineering (RE) [5]. Abella et al. describes it as "… *the basic concept of producing a part based on an original or physical model without the use of an engineering drawing*".

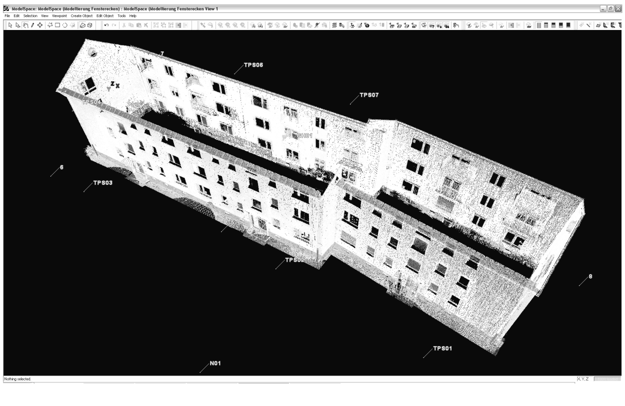

Figure 2: *3D image or point cloud of a façade scan with a 3D laser scanner.*

2.3.1 Surveying Methods

Methods to gather RE data are used in the automotive development or systems engineering and many other fields. Several measuring methods for prefabrication in construction business are evaluated in recent research projects concerning tailor made vacuum insulation panels [6]. The measuring methods are based on remote sensing technologies applied by surveyors. Nowadays the most common close range surveying technologies, used in the building sector are tacheometry, photogrammetry and 3D laser scanning [7].

All methods derive 3D polar coordinates from measuring devices, either directly or with additional software, like photogrammetry. The amount of coordinates defines the resolution and indirectly the geometric precision of the survey. Methods like 3D laser scanning generate hundreds of thousands up to millions of measuring points in high density, during seconds, of one object. Therefore the resulting point cloud is called 3D image of the measured object see Figure 2.

***Figure 3:** Rectified measuring image (left) and wireframe model with DTM analysis of the façade topography.*

2.3.2 Surveying Content

A 3D image should consist of a reference grid and a local coordinate system for each façade with a common horizon level. The overall dimensions of the building as well as edges and heights have to be measured. The openings of the façade should be taken with highest precision. Moreover floor heights for correct positioning of fixation and joints of doors or other openings extended to floor level are necessary compare Figure 4.

Finally the surface model of the façade topography is analysed (useful only with 3D laser scanning data) for adaption of elements to façade unevenness.

Additionally a rough 3D image can be taken of the surrounding for logistics, supply, storage, crane and assembly simulation.

The survey precision for a proper prefabrication process is defined by 1δ = 10 mm for geometric edges and discreet points. The surface deviation should be even more precise with 1δ = 8 mm [7].

2.3.3 3D Image and 3D Model

After measuring, the gathered data or the 3D image have to be processed into a 3D model for the use in planning. This is the most time consuming task whereas the measuring campaign on-site is done much faster.

Appearance and content of the models vary on the demands of the construction team members. A wireframe model of the edge geometry for example is a very abstract result of the measuring but common to most CAD users. Additionally digital terrain models (DTM) of the façade topography are added to this geometry dataset see Figure 3.

Hence new developments and advanced capability of CAD tools in working with 3D images or point cloud data will provide enhanced modelling within the cloud in the near future. These methods will be described in detail in the TES EnergyFaçade research report.

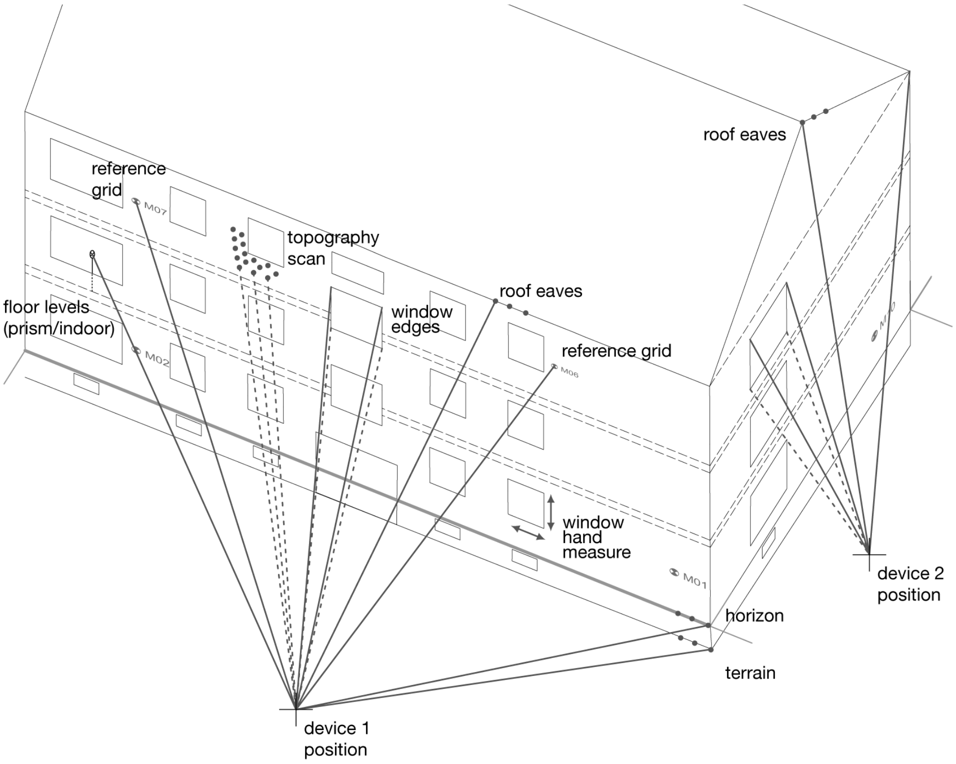

***Figure 4:** Obligate measuring points and reference system for an entire façade model.*

3 FUNCTIONAL AND TECHNICAL REQUIREMENTS

The task of functionality is to fulfil the users demands for thermal, acoustic and visual comfort and health in general. The social components are complementary to the technical concepts of modernisation.

3.1 Energy Efficiency

Properties of existing buildings concerning hygrothermal (heat, air, moisture), acoustical and lighting support the modernisation concept. All building components with possible hazards have to be investigated to ensure a high quality and the projected durability of a new TES EnergyFaçade.

3.1.1 Heat transmission and Heat bridges

Survey of the physical condition of the existing envelope of the building is the basis for the improvement of hygrothermal properties. The material, its properties and condition, e.g. moisture, cracks, leakages and construction details of the envelope have to be surveyed and documented. This documentation is the basis for the selection of an appropriate repair solution.

TES EnergyFaçade stratifies a closed, exterior insulation layer in front of the existing structure without thermal bridges.

Additional insulation on the outside allows the drying of moisture of wet existing interior walls.

3.1.2 Air and Wind Tightness

To prevent heat air and moisture leakage into the outer wall construction, the inner layer has to be airtight. This could be the existing, e.g. continuously plastered wall. Skeleton structures with visible interior TES walls need an additional vapour proof layer on their interior side. Gaps between element boundaries and between elements and existing walls have to be closed airtight. Air exchange rates are $n_{50} \leq 3$ (or 1,5) h^{-1} (German EnEV 2009 without / with mechanical ventilation). The passive house requires a much higher air tightness of $n_{50} \leq 0{,}6\ h^{-1}$. Wind tightness of the outer hull protects the insulation layer and the interior space from infiltration with cold air.

3.2 Adaption Layer

The gap between the uneven existing construction and the rear side of the TES element has to be filled with an adaption layer. No uncontrolled hollows or spaces are allowed for the composition of all layers, existing and new ones. Other parts of building physics like fire safety and acoustics have equal prerequisites. Furthermore the adaption layer allows a direct thermal coupling of the existing inner shell with the new TES EnergyFaçade. This prevents suppresses thermal induced air movement in the gap. An entire filling with an insulation material is a sufficient construction see the greyed layer in Figure 6.

3.3 Fire Safety

TES elements are defined as non-load bearing wall elements that are adapted to load bearing, non-combustible mineral wall structures. TES elements have to follow the requirements as structural elements. In difference the cladding or visible façade layer on top of the structural element is classified according to the combustibility for the material.

3.3.1 Basic Element

TES elements applied in building class 4 and 5, according to the German design building regulation (Musterbauordnung), have to fulfil the requirements of fire safety of structural elements. Therefore they are classified as EI30 (EN 13501) or in Germany as W30-B (DIN 4102).

For buildings up to seven meters height of the top floor level (class 3), there are no restrictions for the structural elements of the façade see [8].

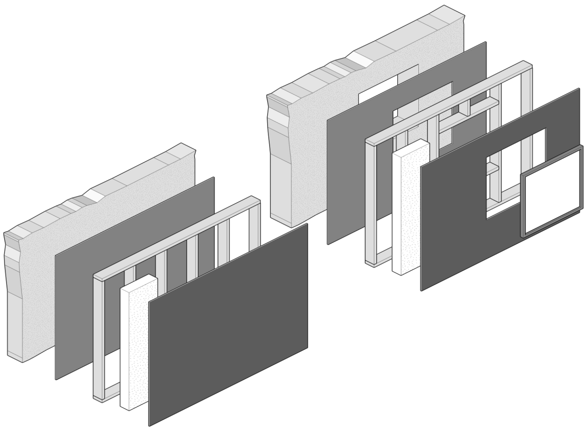

***Figure 5:** Basic element composition with a core of timber frame, filled with insulation and panelling, optional integrated window (right).*

3.3.2 Cladding

The TES cladding layer has to fulfil the requirements of the different building classes. Up to building class 3 combustible materials are allowed where in classes 4 and 5 cladding material has to be difficult-combustible and at least class C- or B-s2,d0.

Timber or other combustible façade materials are applicable but need special constructions and additional approval.

Using combustible ventilated gaps the cladding have to be supplied with a storey wise separation either by suitable fire stops or with a horizontal separating construction.

3.4 Acoustics

Façades and outer walls have to fulfil the belongings of sound protection of airborne sound as well as structure sound. Flanking sound is the most critical transmission path for TES elements (DIN 4109, EN 12354).

Decoupling of the existing construction from the new element by means of an adaption gap, which is filled with an adaption layer of an absorptive and soft material is necessary. Decoupling of supports (brackets) should be done with sound insulating elastomeric supports. Finally decoupling of linear joints by separating the elements with noise absorbent material is needed.

3.5 Structural Conditions

TES elements are self-supporting structural elements mounted in front of or in-between the existing structure. The fixation depends on the structural system of the modernisation object. Solutions range from single mounted and stapled versions up to hanging elements.

3.5.1 Existing Construction

The existing construction typology and the structural system differentiate between a monolithic outer wall and a skeleton structure with an additional closing layer.

In the first type, window openings are just holes in the monolithic wall. In the second type openings show all possible sizes from a single window to continuous ribbon windows or full size glazing.

Like geometric uncertain situations, the structural conditions also need entire survey due to the lack of reliable documentation.

The load bearing capacity of existing structures has to be examined thoroughly. All possible load-bearing locations need material and construction testing. A useful method for construction verification is tension force testing of a sufficient number of anchoring.

3.5.2 Elements Stability

An assembly of storey high elements has no specific transport and mounting condition. However vertical oriented elements, covering two or more storeys, have to be transported horizontally and turned on-site into vertical condition. Elements stability and mounting condition whilst the gyration has to be considered in detail. It may be critical e.g. when windows are installed already.

3.5.3 Fixation

Monolithic structures allow fixation all over the wall whereas skeleton structures normally just have floor slabs as continuous load bearing structure. An additional foundation may be useful in case of construction work for sealing or insulating old basement walls. The load bearing systems used for outer leaf brick wall façades are also suited for the fixation of TES elements.

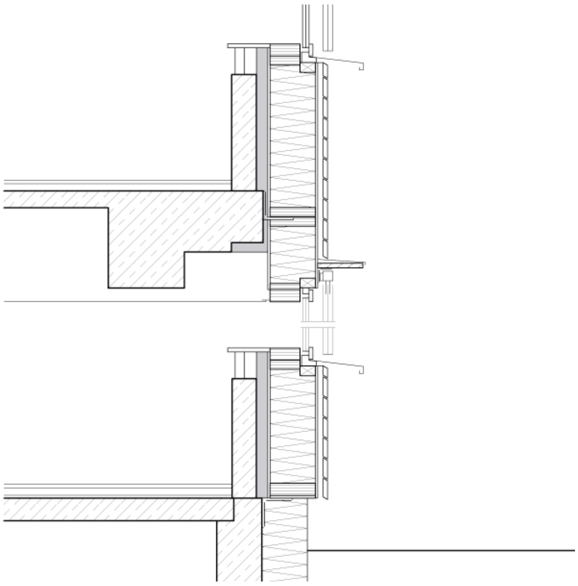

***Figure 6:** Section through existing concrete structure (left) and a new, prefabricated TES EnergyFaçade element. Adaption layer fills the gap (grey).*

4 TES ENERGYFAÇADE ELEMENTS

4.1 Material and Environmental Impact

Environmental performance of TES can be measured with LCA calculation en detail. Some parameters for the selection of ecofriendly materials are:

- Low or negative GWP per m^2 of ≤ +5 kg CO_2equiv of an entire closed element without cladding,
- Higher amount of PEren than PEnr (primary energy renewable and not renewable),
- Modularity and Durability,
- Increased ratio of biotic instead of abiotic resources.

4.2 Degree of Prefabrication

The degree of prefabrication seems to be the impetus, which enables a strong persistence on quality and therefore durability of the offered solution. Most of the production and building processes are belonging to a controlled work setting.

An additional proceeding could be the use of *ready-made elements* with a slightly higher amount of adjustment work on-site. Ready-made elements designate to prefabricated subassemblies in predefined dimensions. The dimensions are derived from typical grid dimension of existing buildings. The time gain probably will not be as high as with large-format prefabricated elements, but there is an inferior requirement of process know-how of the builders.

There is also the fact that smaller buildings with smaller façade areas need economic incentives to choose a high quality method. In sum timber workshops can focus on good quality work without handling all services needed for the top level technology.

In the end there have to be efforts in a further development of high-technology solutions with, e.g.

buildings services or solar components integrated in the TES EnergyFaçade.

4.3 Composition and Size

TES elements are mass customized on basis of precise surveying. Restrictions come from production and transport limitations. Therefore dimensions depend individually on several modernisation object parameters like functional distribution, construction grids, structural axis, floor heights, binding joist, ring beam etc.

Size should be as large as it can be handled in the context, in order to reduce joints and reduce assembly time.

The core TES Element is self-supporting and consists of a structural core in analogy to a timber frame construction. The compartments are filled with insulation. The front and rear sides are panelled with functional layers. They provide all closings qualities required by building physics as well as structural stability.

An advantage of TES seems to be its outstanding variability of cladding materials. There is a wide range from timber panels and cement-bound boards to plastered surfaces or even glass or metal layers.

5 CONCLUSIONS

Without a defined process a complex task like a modernisation is not possible, neither in sufficient quality nor in an adequate speed. Both are added values of prefabricated timber systems used today with great success for energy efficient, healthy and ecologic homes.

Which system offers the better solution for the industrialised modernisation? Is it the ready-made approach that is medium sized or the strategy of prefabricated large-scale elements integrated with added-value components? The low-tech but not no-tech oriented way of the use of ready-made wood products in modernisation could be a viable alternative. This alternative also deserves further research because it promises a high market penetration with wood in the building stock.

Finally another potential lies in the added value of integrated façade systems. The new building skin provides not only a simple insulation system. Rather it could be a system containing also the building services that provides power, integrates routing of electricity, heating and ventilation.

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