ABSTRACT: TES EnergyFacade is introduced as an innovative prefabricated retrofit building system based on timber and other biogene building materials for the energy efficient modernisation of the building stock. The paper exemplary quantifies building stock figures ready for retrofitting in Germany and explains holistic strategies for various interventions with timber construction in the context of building structures and construction methods (e.g. concrete, brick). At the foundation of an optimised workflow, the coherence of key issues, e.g. elements, mounting methods, handling with windows and openings, are pointed out. The presentation of several built projects with specific retrofit solutions explained in detail completes the paper.

KEYWORDS: Retrofitting - potential for timber and timber building systems, Modernisation – the 2nd chance for architecture, Prefabricated timber envelope – innovative solution for modernisation

1 INTRODUCTION

A great number of buildings in Europe built from 1950-1980 has to be renovated within the next decade. Regarding this situation, the improvement of the building envelope will be a major benefit to the energy saving potentials of a building and a vital contribution to the reduction of the household’s total CO2 emissions.

This offers a great market potential for timber and timber products, if the TES method succeeds to supply appropriate timber building systems with a strong focus on the ecological improvement of an energy efficient building envelope.

TES EnergyFacade, based on an international research project in the faculties of engineering and architecture at TUM, has developed a method for the energetic renovation of the building envelope using prefabricated large-sized timber frame elements. The economical, ecological and social advantages of the system suggest a very sustainable renovation method.

The basis for the use of prefabricated retrofit building elements is a frictionless workflow.

The complexity of the retrofitting process from survey, planning, off site production and mounting on site will be explained.

TES EnergyFacade defines the process of energy efficient retrofitting with prefabricated timber façade elements. The elements combine a self-supporting structure with an infill of insulation and a panelling that can be made of a wide range of cladding materials (e.g. timber boards, timber panels, glass, tin etc.). High precision building components like windows are easy to integrate due to the modularity.

The outstanding properties of the application of TES EnergyFacade are presented:

• Precision and quality of an ecological building system
• Predictable pricing and reduction of work on-site
• Reduction of noise and disruption of the inhabitants
• Application of a great variety of cladding materials
• Integration of load bearing elements
• Integration of HVAC and solar-active components
• Spatial intervention or expansion (modules) in the same system

2 Building Stock – the potential for modernisation

Doubtless, the main task in the future for construction activity in Europe will be the modernisation of the existing real estate stock with focus on the improvement of the energy efficiency of buildings. The urge to face the consequences of the climate change through ecoefficient building methods (e.g. innovative solutions for insulation and windows) has been underlined by the publication of the fourth assessment report by the IPCC (Intergovernmental Panel on Climate Change) and the European Directive (EPBD 2002/91/EC) on the energy performance of buildings.

Buildings of the time span from 1950s to the early 1980s constitute of nearly 50 % of the German building stock and account for around 8.5 million units. This amount
illustrates the potential reducing the energy demand. The renovation rate of 0.3-0.4 % according to rough estimations and projections depicts the marginal effect of past actions and the future tasks.

The majority of residential buildings are built after the Second World War.

<table>
<thead>
<tr>
<th>Year of construction</th>
<th>Stock</th>
<th>in %</th>
<th>cumulated in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>until 1918</td>
<td>5.673.000</td>
<td>14.3%</td>
<td>14.3%</td>
</tr>
<tr>
<td>1919 - 1948</td>
<td>5.389.000</td>
<td>13.6%</td>
<td>28.0%</td>
</tr>
<tr>
<td>1949 - 1978</td>
<td>18.301.000</td>
<td>46.3%</td>
<td>74.2%</td>
</tr>
<tr>
<td>1979 - 1990</td>
<td>5.237.000</td>
<td>13.2%</td>
<td>87.5%</td>
</tr>
<tr>
<td>1991 - 1995</td>
<td>1.630.000</td>
<td>4.1%</td>
<td>91.6%</td>
</tr>
<tr>
<td>1996 - 2000</td>
<td>2.023.000</td>
<td>5.1%</td>
<td>96.7%</td>
</tr>
<tr>
<td>2001 - 2004</td>
<td>1.061.000</td>
<td>2.7%</td>
<td>99.4%</td>
</tr>
<tr>
<td>2005 later</td>
<td>237.000</td>
<td>0.6%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Sum 2006</td>
<td>39.551.000</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 1 Number of residential units, Germany 2006** (Source: www.destatis.de)

In Germany, building age classes (BAC) are defined to systemise the major changes in urbanism, typology and construction throughout the decades:

- **Building age class 1950s**
  Urbanism: developments with low density, open and green spaces nearby or inside the city centre,
  Typology: multi-storey dwellings (up to 5-6 levels) with interior staircase and seldom with outdoor corridor.
  Construction: load bearing masonry walls, floor slabs of concrete building blocks.
  Shortages: preferred building material after the war were reused bricks, concrete and plaster of poor quality, windows were wood framed without sealing and double-glazed casements.
  Energetic weak points: no insulation of the envelope, floor slabs tailed in thin outer walls, window joints in offset reveals, low U-value of window construction, poor roof construction without any insulation.

- **1960s**
  Urbanism: densified large development areas, closed spaces, located in outskirts.
  Typology: medium to large scale housing complexes, apartments with large floor space.
  Construction: simple compound or monolithic structures, intensified use of concrete, large facade openings, structured façades and additional loggias and balconies, availability of industrial facade systems, timber and metal window frames with single glazing.
  Shortages: poor building and construction standards, low quality construction.
  Energetic weak points: facade openings and construction, missing insulation layer.

- **1970s**
  Urbanism: high density, large development areas with green spaces.
  Typology: high rise buildings, large scale housing complexes, smaller floor space.
  Construction: intensively prefabricated, structural optimized, high quality concrete structures, concrete skeleton frames, layered and structured façades, façade claddings and curtain wall façades with material mix or sandwich construction, single layer glazing.
  Shortages: poor building standards and construction, problematic and leaking joints, technical defects of façades, problems of mass production and material quality, economy of materials.
  Energetic weak points: missing or minimized insulation, massive thermal bridges by cantilevering building parts in façades, poor energetic quality of façades and windows.

Residential areas from the 1950’s to 1980’s are often in the need of urban improvement, due to technical, architectural and social aspects. Building modernisation as a holistic intervention offers a 2nd chance for architecture and urban renewal, including infill development. Due to natural decay, a great number of multiple dwelling units in Europe from this time have reached a point where renovation within the next decade is necessary.

Regarding this situation, the improvement of the insulation level and the air tightness of the building envelope will be a major benefit to the saving potentials of the energy consumption of a building and a vital contribution to the reduction of the global CO2 stock along with an increase of the value of our building stock.

From the residents point of view a reduced building time on-site with less disturbance and the improvement of the living comfort is a desirable effect.

The common renovation practice used in some European countries (e.g. plastered foam composite insulation systems) can be characterised as follows: craftsmen like, non ergonomic procedures, utilisation of pollutive and resource intensive insulation and construction materials, tailoring and processing on site with high dust and noise emissions, great off cuts and inefficiency, disturbance of neighbourhood. A professional planned and industrialised retrofitting process from survey, planning, off-site fabrication and on-site assembly is no common practice. The application of prefabricated systems and sustainable raw materials are marginal exceptions to the rule.

A responsible and economical management of resources is an obvious and necessary task for the future.

Our holistic understanding of ‘energy efficiency’ not only focuses on primary energy demand for the operation of a building but also respects the resources for the realisation of a modernisation project. Large quantities of material flow, mostly common in traditional construction industry, result in environmental problems. Additionally the lack of resources will force economic problems in the near future, as seen in the oil and steel market in the first decade of the 21st century.
3 TES EnergyFacade

TES EnergyFacade (Timber based element systems for improving the energy efficiency of the building envelope) was a nationally funded research project under the first ERA-Net WoodWisdom-Net call with research and SME partners from Finland, Germany and Norway.

TES EnergyFacade defines the basics of a prefabricated timber construction system for the energy efficient retrofitting of the building envelope. The elements combine a self-supporting structure with an infill of insulation and a panelling offering the possibility to utilise a great variety of cladding materials (e.g. timber panels, sawn boards, tin, plaster etc.).

TES EnergyFacade advances the energetic modernisation of the building envelope using prefabricated large-sized timber framed elements. The economical, ecological and social advantages of the system compared to conventional renovation methods suggest a very sustainable renovation method. The professional participants (planners, surveyors, carpenters) are responsible for a specified task within the digital workflow as state of the art in survey, planning and production. The process provides a consistent structure along the workflow chain: digital measurement – planning – off-site fabrication – on-site assembly.

Key results of the TES Energy Facade project are:
- Definition of an optimised building process based on a frictionless digital workflow from survey, planning, off-site fabrication and on-site assembly [2]
- Systematisation of requirements for the modernisation of large buildings
- Definition of basic construction system with a detail catalogue for prefabricated timber based façade elements

Building with wood and prefabricated timber elements offers various solutions for energy efficient building modernisation. The building stock as a resource for the densification of our urban city structures offers a large potential for innovation modernisation methods.

Building structure:
TES EnergyFacade [3] as a prefabricated timber building system for façade modernisations is characterized by precision and velocity of building processes on site. Based on the premise of an advanced level of prefabrication of large scale elements, different options to react to the existing building geometry are possible: from a high insulated wall panel up to the addition of complete space modules for extensions. The level of prefabrication is determined by the configuration of load bearing elements (i.e. post, beam, plate), insulation and air- and wind tight layers: from single elements up to finished wall or roof panels with cladding, integrated windows, sun shading device, HVAC services or solar collectors. The basic orientation is a horizontal, vertical or space element:

![Figure 5 Basic orientation of TES elements](image)

Façade details and element layers that are proven in regular wood construction of new buildings are adapted and provide the necessary function of building physics. The correct connection to the existing structure and geometry of a building determines the requirements of fire safety, air and wind tightness and sound protection. A cavity free construction is premise to prevent from uncontrollable convection and fire spread.

Two options for bringing in insulations can be differentiated:
• filling insulation in the production process off-site
• filling insulation on-site

Regarding the second option, extra time on-site as well as more effort for the wind tight closing of the filling holes has to be considered.

![Figure 6 Basic TES element](image)

Exemplary window connection
If the existing window is replaced, the new window is positioned within the self supporting frame of the TES element. The interior reveal is covered with a wood or gypsum board, the connection window frame – existing wall has to be sealed with suitable tapes.

![Figure 7 Exemplary window in TES element](image)

Basic element, layer hierarchy:
1 – Cladding
2 – Insulation, Framework
3 – Smoothing layer
4 – Structure (existing)
Amongst fulfilling building regulations, economical and technical goals, the modernisation of a façade always changes the appearance and visibility of a building. This is a chance, to improve the architecture with high quality solutions.

4 Demonstration Projects

Experiences were made in demonstration projects during the planning and construction process. The projects are undergoing monitoring in order to learn about the effects, behaviour and condition of the construction after a modernisation with TES elements. Most important experiences at this stage:

1. Survey
The measuring methods are based on remote sensing technologies applied by surveyors who delivered precise data of the existing building. The most important tasks are the predefinition of all points to be measured and a common interpretation of the results in a team of surveyors, planners and carpenters.

2. Planning
The issue of fire safety of the whole building has to be considered seriously at the very beginning of the planning stage. The validity of today’s building regulations has to be checked carefully and measures (e.g. additional fire doors, stairs etc.) have to be realized.

2. On-site mounting
The situation of the site (access, space etc.) determines the logistics of transportation and mounting. The level of prefabrication depends on the geometry of the buildings. The seize and the weight of elements with insulation, windows and glazing has to be considered, as the possibility of crane positions and lifting processes on-site are a determining factor.

RISOR TECHNICAL COLLEGE, NORWAY 2009
Owner Aust-Agder county
Location Risør, Norway
Architect Arkitektstudio AS
Contractor Trebyggeriet AS
Construction mid 1960’s
Modernisation 2009
Storeys 2
Heat Energy demand kWh/m²a (before/after) 325,0/ 49,0

As the Norwegian pilot project, Risør Technical College was retrofitted with new facades and improved roof insulation. Due to this intervention the heat energy demand for the school building was drastically reduced.

REALSCHULE BUCHLOE, GERMANY 2009
Owner Landkreis Ostallgäu
Location Kersteinstraße 2, D - Buchloe
Architect e3 architekten, D - Marktoberdorf
Contractor Josef Ambros GmbH
Construction 1980
Modernisation 2009
Floor area net 8.903 m²
Volume 27.822 m³
Surface 5.688 m²
Storeys 3
Energy demand kWh/m²a (before/after)
Primary energy demand 125,0 / 17,0
Heat energy demand 89,9 / 16,0
U-values W/m²K
Wall 1,34 / 0,1
Roof 0,35 / 0,15

Figure 8 Risør College, new façade 2009
Figure 9 Façade detail: rough sawn timber board, coated with silicate paint
Figure 10 Realschule Buchloe, 2009
The school building is a concrete skeleton structure with a non-load-bearing façade that was replaced by prefabricated TES elements.

**Figure 11 Realschule Buchloe, removal of precast concrete façade**

The work was done during school holidays in 2009 to minimise the disturbance for the user. Metalworkers and carpenters worked hand in hand to remove the existing steel façade and mount the TES elements at the same time.

**Figure 10 Realschule Buchloe, Mounting**

Other projects in progress based on the TES method:

- GWG München, Kaufmann Lichtblau Architekten
  The project is a typical residential building of the 1950’s which does not suit today’s social and technical needs. The building is extended by an additional storey; the floor plans are changed as the staircase is replaced by an external elevator and staircase tower. The project is currently under construction.

- WBG Augsburg, lattkearchitekten, bauart Ingenieure
  The project is a six-storey residential apartment block, built 1960. The task is to retrofit bathrooms, façade and the HVAC technique with residents living on site. The project is in a planning stage.

5 CONCLUSIONS

Retrofitting with prefabricated elements offers the second chance for architecture! The concept (as well as the projects) shows a wide range of varieties of the sustainable and durable timber construction system.

The TES method provides the basis for the further development of a prefabricated timber building system for the energy efficient building modernisation based on the experience and competence of the timber construction sector. Retrofitting systems with value-adding attributes (i.e. elements with integrated components) and customised process solutions from design to production will provide the answer to a new, industrialised holistic and cost-efficient retrofit system.

The properties of TES are convincing:
- Precision and quality of an ecological building system
- Predictable pricing and reduction of work on-site
- Reduction of noise and disruption of the inhabitants
- Application of a great variety of cladding materials
- Integration of load bearing elements
- Integration of HVAC and solar-active components

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REFERENCES

