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Retrofit de la construcción mediante paneles prefabricados: una reseña del estado del arte. Building Retrofit through prefabricated panels: an overview on the state of the art.

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***Resumen*— El objetivo principal de este paper es ofrecer una reseña del utilizo de sistemas de paneles prefabricados en el retrofit de edificios. El retrofit representa un punto focal de la eficiencia energética, considerando el gran numero de edificios existentes, privados y públicos, en Europa. La necesidad de intervención en este ámbito es enfatizada por las Directivas Europeas, y por la roadmap de Horizon 2020. Varias investigaciones y proyectos se centran en el tema de la prefabricación en el retrofit, enfatizando la importancia de esta estrategia. La reseña de el estado del arte muestra los diferentes enfoques de los paneles prefabricados: una clasificación critica de estos proyectos diferencia entre sistemas basados en grandes o pequeños paneles, sistemas de ampliación basados en paneles estructurales y sistemas parcialmente prefabricados. Esta clasificación es útil porque consiente posibles progresos en este campo, enfatizando los adventajas y desventajas de cada sistema. Los asuntos mas importantes son los de diseño, fabricación, transporte y instalación. Una reseña de estos asuntos es también provista, enfatizando los campos de innovación, y los posibles futuros desarrollos de la prefabricación en el retrofit de las construcciones.**

Palabras clave— Reconversión de edificios; paneles prefabricados; envolvente del edificio; adaptación energética.

***Abstract*- The main aim of this paper is to provide an overview of the use of prefabricated panels in external building retrofitting. Building retrofit represents a pivotal point in terms of energy efficiency, connected to the great amount of existing buildings, both public and private, all around Europe. The need of intervention is underlined by different European Directives, as well as by Horizon 2020 roadmap. Many research works and projects are focusing on the theme of prefabrication in retrofit, stressing the importance of this strategy. The review of the state of the art shows several approaches in terms of prefabricated panels: a critical classification of these projects distinguish between systems based on large and small panels, systems for extensions based on structural panels, and partially prefabricated systems. The classification is useful as it can help in understanding further development of prefabricated panels, underlining the advantages and disadvantages of the systems. The main challenges are linked to design, fabrication, transport and installation. An overview of those issues is also provided, stressing the main innovation fields to be further investigated, and the possible future developments of prefabrication in building retrofit.**

Index Terms— Building retrofit; prefabricated panels; building envelope; energy retrofit.

I. Introduction

THIS PAPER provides an overview of the use of prefabricated panels in energy eternal building retrofitting, underlining advantages and disadvantages in their use. Building retrofit represents a crucial point in terms of energy efficiency. The existing building stock, both public and private, is mainly composed by outdated and inefficient buildings. The need of intervention is underlined by the European Directives: EPBD 2002/91/EC, EED 2012/27/EU, Renewable Energy Directive 2009/28/EC and 2010/31/EU. Those directives set the requirements for renovation and retrofit operations. The challenges connected to the theme of retrofit are several, and regard the different phases of construction: design, fabrication, transport, installation and maintenance. Prefabrication could represent a primary retrofit strategy, as it could involve both façades and roofs, and could help in solving some of the limitations of traditional retrofit systems. Currently, the most part of the building renovations addresses isolated building components, such as roofs, windows or building services (Schwer, Fischer, & Geier, 2011). Single renovation measures do not allow optimal results, as new problems could arise, including local condensation or overheating (Advances in Housing Renovation - Processes, Concepts and Technologies, IEA SHC Task 37, 2011).

Prefabrication is particularly challenging, as it does not involve only technical issues. Holistic strategy could represent a solution to the local problems arising from single component based renovations (BPIE, Boosting Building Renovation: an overview of good practices, 2013). Those strategies have to meet the needs of different actors, including investors, suppliers, manufacturers and users (Cooper, 2012). Horizon 2020 roadmap underlines the economic importance of prefabrication in the field of building retrofit (Energy-efficient buildings: multi-annual roadmap for the contractual PPP under Horizon 2020, 2013).

Considering the primary role of prefabrication in retrofit, a classification of existing experiences could be useful. There have been several concepts in using prefabricated elements in Europe. Several research projects have been developed or are being developed (e.g. Osyris, Adaptiwall and EASEE) (ECTP & E2B, 2014). Other systems have been designed by architects. Each project shows its own features, linked to different contexts and conditions. The critical classification provided by this paper stresses differences and similarities and consents the identification of the main issues related to the theme of prefabrication in external building retrofit.

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II. The State of the Art

Prefabrication could represent a primary retrofit approach, especially compared to traditional retrofit strategies.

Traditional retrofit (e.g. ETICS) implies wet construction, meaning that the most part of the process has to be done on-site, resulting in occupants' discomfort. Building retrofit is a complex operation that could run into unforeseen events, cost and time overruns, accidents and errors. Those features are due to the complex nature of on-site construction (Aapaoja & Haapasalo, 2014).

In this context, off-site production (i.e. prefabrication and on-site installation) could represent a safer, faster and simpler way to building retrofit and energy efficiency improvement of existing buildings.

The proposed classification of different approaches to the use of prefabrication in building retrofit considers the dimensions of the panels involved, as well as their use, in terms of building services integration and installation. The following case studies focuses on residential buildings, that represents the major part (75 %) of European building stock (BPIE, Europe's buildings under the microscope. A country-by-country review of the energy performance of buildings, 2011).

It is possible to divide the case studies in the following categories:

Systems based on large panels;
Systems based on small panels;
Systems for extensions based on structural panels;
Partially prefabricated systems.

Each of them shows advantages and disadvantages; from this point of view, the classification is particularly useful as it can help in identifying the main issues.

A. Systems based on large panels

In this section, panels with the height corresponding to a floor and variable width, often requiring a substructure are considered. Those modules include insulation, windows and building services elements. Other concepts are based on the addition of large modules on aluminum profiles deriving from standard solutions commonly used for glazed façades. Those modules usually include also building services, such as ventilation ducts and solar collectors.

1) Dieselweg, Graz (Austria)

An application of prefabricated large modules was developed in Dieselweg, Graz (Austria), and consists in modules installed on a timber substructure, mounted on-site onto the façade surface.

The substructure works as a leveling layer and the intermediate space is filled with insulation material. The module dimensions are 12 x 3 m: the dimensions were set according to intermediate floors height. The assembly is made on-site by a truck-mounted crane and additional mobile-cranes (fig. 1).

The module consists in a basic frame of timber, with a first layer of insulation and a solar comb, mounted on the outside upon a MDF board, followed by a ventilated airspace covered with a single-pane safety glass.

Fig. 1. Installation of large panels on Dieselweg building, Graz (Austria). The installation takes place by means of truck-mounted cranes and mobile cranes.

On the back of the timber frame, an OSB board completes the module. The total thickness of the module is 24 cm (Zimmermann, 2011).

2) Burse Student Hall, Wupperthal (Germany)

The Burse student residence hall in Wupperthal (Germany) is another example of large modules retrofit. The existing building was re-clad with wooden prefabricated panels including pre-assembled windows. During the refurbishment, the dilapidated façade consisting of non-load bearing slabs hanging in front of the building's shell was removed, retaining only the load-bearing structure. The building was completely fitted out with prefabricated façade elements with wooden frames and mineral fiber thermal insulation. The combination of several façade elements allows the development of an energy effective new cladding. The panels were then installed on the reinforced concrete framework. The new floor-to-ceiling triple glazed passive house windows, with wooden frames helped the renovation of the internal space and the façade articulation(Von der Energieschleuder zum Passivhaus, 2014).

Fig. 2. Schankula modules made of a timber structure and pre-assembled windows.

3) Schankula Architekten

The German architecture firm Schankula Architekten worked on the retrofit of an ex-military building, transformed in residential building. The façade has been developed through large wooden prefabricated modules, including windows (fig. 2). The assembly of the façade was carried out in few days with cranes, reducing the discomfort of the occupants. The façade, installed on the existing masonry wall, is designed in three different versions: passive façade, ventilating façade and solar-collector façade. The storey-high modules, with a thickness of 35 cm, have a width corresponding to the width of the dwelling unit (7 to 12 m) (Schankula, 2009).

4) Makartstrasse, Linz (Austria)

Makartstrasse (Linz, Austria) is a residential building that underwent refurbishment in 2006, reaching passive house standard thanks to the use of prefabricated solar walls. The building, originally erected in 1957, has a masonry wall: the new façade is made of prefabricated wooden panels, integrating the solar wall system and ventilation ducts with heat recovery. The panels are installed on the existing façade with a wooden substructure (fig. 3). The installation is carried out with truck-mounted-cranes. The existing balconies have been integrated in the new façade, increasing the living space of the building (Aschauer, 2006).

Fig. 3. Installation of large panels on Makartstrasse building.

B. Systems based on small panels

In this section, small prefabricated modules are considered. Small modules are panels that can be handled by one person. In this case, they are mainly opaque panels designed to be installed on the existing façade. The main issue is the interface between panels and other façade elements (e.g. windows, openings, balconies).

1) Portuguese module

A Portuguese research team developed a module consisting in a 1 x 1 m panel, for 12 kg/m2 panel. The materials involved are agglomerated black cork insulation, XPS and aluminum finishing. The final module also integrates ventilation ducts and a smart vapor retardant. The module includes steel U-profiles where the XPS is fitted, and the aluminum finishing is shaped like a box in order to lodge the cork insulation.

Fig. 4. Installation of EASEE panels on case-study building.

The connection between modules is done through a system of pins and holes, helping the module fitting into the metal support structure.

The installation consists first in the application of the metallic support structure on the existing façade, and then the fitting of the module to the structure (Silva, Almeida, Bragança, & Mesquita, 2013).

2) EASEE module

The EASEE module was developed for the outer façade, and consists in two TRM (Textile Reinforced Mortar) plates and EPS (Expanded Polystyrene Sintered) insulation (fig. 4). This combination of materials guarantees flexibility and resistance to the panel. EPS is a light, recyclable, resistant, self-extinguishing, non-toxic and stable. The total thickness of the panel is 12 cm, and its maximum dimensions are 3,3 x 1,5 m, dependent to the formwork. The overlapping between two panels is a simple border, as it minimize fabrication, transportation and installation issues. The junction between panels consists in a two-phase solution: first, a polyethylene foam sheath and a silicone joint. The joint thickness is 1 cm, but can reach up to 1,5 cm to take up the existing façade irregularities. The TRM plate allows any kind of finishing.

The system is mounted on the existing façade through the use of steel anchor pins. Those pins allow a 5 cm air gap between the panels and the existing walls, that works as an insulating layer and does not create any moisture problem (Masera, Iannaccone, & Salvalai, 2014).

Fig. 5. Installation of tridimensional modules on Tour Bois-Le-Prêtre, Paris.

C. Systems for extensions based on structural modules

The use of structural modules consents the extension of floor area, usually involving the closing of balconies or loggias. The extension can take place also through the addition of storeys.

1) Tour Bois Le Pretre, Paris (France)

The Tour Bois Le Prêtre project, developed by Lacaton &Vassal architects, regarded a residential tower building built in 1962, and then refurbished in 2010, originally made of prefabricated structural concrete panels (fig. 5). The refurbishment project includes the demolition of the existing façades and the installation of a new transparent envelop composed of full height sliding panels with aluminum frame and insulated glass, and the consequent installation via stacking of prefabricated three-dimensional modules. These modules have an independent steel structure, a full height (276 cm), width equal to the structural span of the existing building (750 cm) and a 315 cm depth. The prefabricated modules are delivered to site yet assembled(Malighetti, 2011).

Fig. 6. Autun building module.

2) Aututn Building (France)

The Autun building, in France, is part of a research project aiming at the setting of a solution for façade renovation of collective buildings, with the goals of energy efficiency, noise protection, low disturbance of the occupants, ease of installation and high diversity of cladding and exterior finishing.

The system consists of self-supporting modules forming the façade, with a unit height equivalent to 2 stories, with intermediary uprights to ensure mechanical resistance (fig. 6). Before installing the modules, a first insulation layer is set on the façade. The modules are installed on the brackets fixed to the façade through suitable lifting equipment. The window is preassembled in the steel frame.

The installation of the air-tightness membrane has to be done on-site. The ventilation ducts can be integrated in the façade. This system is particularly interesting in case of addition of surfaces (one or two stories) to an existing building, as well as in closing balconies or loggias (Zimmermann, 2011).

D. *Partially prefabricated systems*

Those systems involve the application of prefabricated modules on the most critical parts of the façade (the window parts), and the consequent finishing of the opaque parts by means of other prefabricated panels or by means of traditional retrofit methods allowing an easier adaptation to the variabilities of existing buildings.

1) *Swiss module*

An example of this strategy is provided by a Swiss project. This project developed a façade and roof construction module, with internal ventilation ducts for external retrofitting of the existing building envelope, aiming at the reduction of energy consumption. The prefabricated module includes components such as windows, ventilation ducts, blinds, thermal insulation, solar energy systems and other utility services. The dimensions of the modules were set considering transportation limits, possible façade arrangements and factory-processing sizes.

The so called “base module 4.1” is a small size module (2,8 x 2,8 m), highly standardized. This module includes a window, and it can be applied to a full vertical line of existing openings (fig. 7). The remaining opaque façade sections can be cladded in the usual way, using standard façade systems, or prefabricated modules.

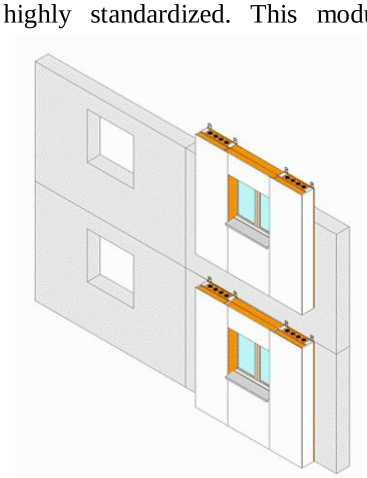

Fig. 7. Installation of the module on the windows area.

The thickness of the module depends on the diameter of the integrated ventilation ducts (20 cm or 22 cm). The size of the opening in the module is adaptable to the clear opening in the existing wall. The modules are fixed to the existing walls though metal flats and metal brackets, by means of cantilevered platforms. The module frame is made of timber. The insulation used for the module can be mineral wool, foam or vacuum insulation panels.

The tolerance area between the modules is filled with compressible insulation (Zimmermann, 2011).

III. IDENTIFICATION OF MAIN ISSUES

The case studies analysis allows an evaluation of the most critical points related to the retrofit through prefabricated panels. Each strategy presents advantages and disadvantages, and could be suitable for a limited amount of buildings.

A. *Dimensional adaptability*

Dimensional adaptability is among the most demanding and significant challenges. The chosen system should adapt to different boundary conditions from a dimensional point of view. None of the presented cases solves completely this problem. Large panels solutions usually have a height equal to the floor height. It is true that not all the buildings have the same floor height, but depending on some factors such as year of construction, it is possible to identify recurring heights. None of the analyzed cases, however, shows any explications about how the horizontal dimension has (or has not) been optimized.

Large modules are not flexible, so they require very high quality data of the façade, such as 3D laser scanning. From those data, the module is designed and then produced to fit, resulting in a “custom-tailored” solution, that cannot be applied to different buildings with different geometrical conditions. Smaller panels are easier to manage in terms of geometrical adaptation, as they cover less surface and it is more likeable to find a modular dimension suitable for different buildings. On the other hand, smaller modules mean a higher amount of connections and joints.

B. *Façade morphology adaptation*

Building retrofit has to cope with extremely different façade morphologies. Even if it is possible to take into account only one typology and limit the consideration to a restricted period of construction, the variability of façade elements is still very high. Decorative elements, frames, different claddings (both regular, i.e. plaster, and irregular, i.e. bricks, concrete, stone, wood), represent an important issue to consider when designing elements to be set on an existing façade.

The most part of the presented cases results in an addition strategy, rather than a replacement, with the exception of Burse Student Hall. That façade was dilapidated, therefore the architect decided for its demolition. Usually, the prefabricated panels are mounted on the existing façade.

The main problem linked to the existing façade is the unavoidable presence of irregularities, that can be partially absorbed by means of a substructure and soft insulation, especially in case of large modules. Large modules result in an easier integration with building services and openings, as they usually present pre-assembled windows. Small modules, on the other hand, imply an higher level of attention and care in the installation phase, especially in the connection between windows and modules.

Balconies and loggias are usually thermal weak points, lacking of thermal break. The prevailing strategy is their closing, consenting a better energy efficiency and a higher market value, due to the increase of floor surface of the building.

The majority of presented case studies does not cope with problems other than balconies and windows, leaving some questions still open.

Considering the existing façade, there is still an important ambiguity connected to its structural resistance. None of the presented systems has investigated how the existing and new parts are reacting, from a structural point of view. This aspect could represent a critical point, due to the notable dimension and weight of the panels, especially referring to horizontal forces.

C. *Fixing system*

The different dimensions and weight of the panels strongly influence the fixing systems. As stated before, in some cases the use of a substructure is provided, that could also be useful in absorbing part of the façade irregularities. The corresponding gap is usually filled with soft insulation. Small modules are sometimes fixed to a substructure, or directly installed on the façade by means of steel pins or anchors.

Besides fixing, the junction between elements represents another crucial point. There are two main strategies: a first concept could be the design of a special connection (such as a tongue-and-groove joint), in order to reduce on-site work. This approach shows some limitations, because it results in a more complex manufacturing and create some weak point in the panels. The small parts, realized to consent a snap-fit of the elements, can be damaged during transport and installation.

The other strategy implies the on-site management of the connection between panels. A level edge choice consents in fact higher flexibility, especially in edges junction. The lack of overlapping makes water resistance and air tightness more difficult to obtain. The façade has to be waterproof and the envelope should constitute an airtight layer.

In many cases, however, there is still an essential observation lacking: the intermountability. Maintenance is usually not considered. It is important to consider additional tolerances to allow an easier assembly and expansion due to temperature variations.

IV. Future developments

The classification of case studies and consequently the identification of main issues connected to the theme has been particularly useful as it can help considering outcomes and future developments.

A. *Is prefabrication a viable strategy?*

This question is crucial: the advantages deriving from using prefabricated systems instead of on-site construction has been analyzed and underlined. However, prefabrication could be intended as one possible solution, but not the only one. On-site construction could be a better solution for some cases. Many works have focused on how to evaluate prefabrication and on-site construction (O'Connor, O'Brien, & Choi, 2014)(Pan, Gibb, & Dainty, 2008). What emerges from those studies is that it strongly depends from the considered Country and the boundary conditions. It is not possible, by now, to evaluate which, between prefabrication or on-site construction, is the best strategy. There are many factors to be considered and each of them has a different weight (Jonsson, 2015).

Prefabrication has an influence in many different phases of the construction process, and therefore requires different actors and skills. For this reason, the evaluation of the best strategy for building retrofit could derive from cooperation between the actors involved in the process (Bertelsen, 2005).

B. *Quality of the results*

In terms of quality, it is interesting to underline how all the projects shown have reached a combination of goals.

Besides general improvement of energy efficiency performance, the interventions testify also an evident enhancement of architectural quality.

In addition, the choice of closing loggias and balconies meant an extension of floor surface or built volume. The combination of those effects results in a consequent increase in the building value.

C. *Economic implications*

In terms of market efficiency, there have been no documented diffusion of any of the products developed. The lack of flexibility makes them incapable to fit to the heterogeneous conditions of the existing building stock. As stated before, the experimental solutions have been applied on demonstration buildings characterized by simple plans and simple façades.

By now, the market of prefabricated panels for retrofit seems to be promising but lacks of manufacturers’ willing to develop them. This effect is due to the lack of request from the users, that is connected to a general lack of understanding of the benefits linked to the use of those systems.

Referring to the Boston Growth-Share matrix, it is possible to see prefabricated panels as question marks. They have great potential, but with a low market share by now. Question marks have potential to gain market share and therefore become stars and eventually cash cows (fig. 8).

D. Materials and manufacturing

In order to consent a wider diffusion and an industrial production process of those systems, it is necessary to focus on critical issues still to be solved. The fixing system and structure is a primary element to be investigated.

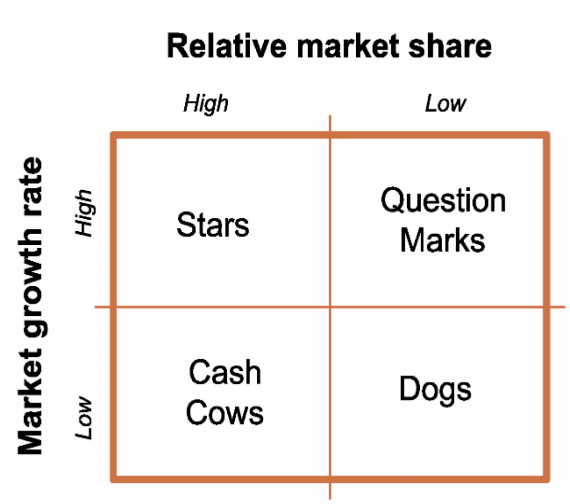

Fig. 8. Growth-Market Share Matrix.

Materials used are also an interesting field. The most part of the projects uses steel or timber. The possibility to integrate light materials, such as textile, could be interesting and could help in coping with different issues. The use of textile in prefabricated panels has been limited until now to cladding. Patented existing systems are used as an external envelope, without thermal insulation.

In addition, in terms of substructure, plastics could play an interesting role as lightweight option.

Dimensional variability and manufacturing tolerances require the adoption of production systems based on mass customization and on precise adaptation of retrofit solutions. In this sense, robotic and additive manufacturing (3D printing) could help overcoming some of the barriers preventing the widespread diffusion of prefabricated systems for retrofit.

V. Conclusions

Building envelope represents a critical element to reach the 2050 decarbonisation goal, as it represents the main part of the building thermal loads. The improvement of the energy performance, aesthetics, acoustic and lighting comfort, together with the quality of indoor environment represent the main targets connected to building envelope. In this context, prefabrication could become a primary tool in building retrofitting.

The proposed classification of case studies related to use of prefabricated panels in external building retrofit has helped in identifying some of the main issues and barriers connected to the theme. Prefabrication could play a primary role in the field of retrofit, becoming an excellent strategy instead of traditional retrofit (e.g. ETICS systems), that has already shown its limits. The use of prefabricated panels on large scale should be evaluated in terms of adaptability, both linked to the dimensions of the panels and to the existing building stock façade morphology.

Prefabrication is strongly linked to manufacturing; therefore, the development of prefabricated systems has to be carried out in strong collaboration to manufacturers.

References

Aapaoja, A., & Haapasalo, H. (2014). The Challenges of Standardization of Products and Processes in Construction. Proceedings of the 22nd Annual Conference of the International Group for Lean (pp. 983-993). Oslo: Akademika forlag.

Advances in Housing Renovation - Processes, Concepts and Technologies, IEA SHC Task 37. (2011). Herkel, S.; Kagerer, F.

Aschauer, J. (2006). Makartstrasse Linz: a new quality of living - Passive House retrofitting of an apartment building. Responsive building elements and integrated building concepts.

Bertelsen, S. (2005). Modularisation: a third approach to making construction lean? 13th International Group for Lean Construction Conference: Proceedings, (pp. 81-88). Sydney.

BPIE. (2011). Europe's buildings under the microscope. A country-by-country review of the energy performance of buildings. Buildings Performance Institute Europe.

BPIE. (2013). Boosting Building Renovation: an overview of good practices.

Commission, E. (2013). Energy-efficient buildings: multi-annual roadmap for the contractual PPP under Horizon 2020.

Cooper, P. D. (2012). Existing building retrofits: Methodology and state-of-the-art. Energy and Builings, 889-902.

ECTP, & E2B. (2014). Energy-efficient Buildings - EeB PPP Project Review.

Jonsson, H. (2015). Production System Classification Matrix: Matching Product Standardization and Production-System Design. Journal of Construction Engineering and Management .

Malighetti, L. (2011). Refurbishment Bois-Le-Pretre tower in Paris. Arketipo - n. 67, 92-103.

Masera, G., Iannaccone, G., & Salvalai, G. (2014). Retrofitting the existing envelope of residential buildings: Innovative technologies, performance assessment and design methods. Advanced Building Skins - Conference Proceedings of the 9th ENERGY FORUM, (pp. 987 - 994). Bressanone.

O'Connor, J., O'Brien, W., & Choi, J. (2014). Critical success factors and enablers for optimum and maximum industrial modularization. Journal of Construction Engineering and Management, 140(6).

Pan, W., Gibb, A., & Dainty, A. (2008). A decision support matrix for build system selection in housing construction. International Journal for Housing Science and Its Applications(32 (1)), 61-79.

Schankula, A. (2009). Aktive Hulle. Fassadentechnik .

Schwer, P., Fischer, R., & Geier, S. (2011). Retrofit Strategies Design Guide. EMPA - Building Science and Technology Lab.

Silva, P., Almeida, M., Bragança, L., & Mesquita, V. (2013). Development of prefabricated retrofit module towards Nearly Zero Energy Buildings. Build (56), 115-125.

Von der Energieschleuder zum Passivhaus. (2014). EnEv im Bestand, 14 - 21.

Zimmermann, M. (2011). ECBCS Project Summary Report: Annex 50 Prefabricated Systems for Low Energy Renovation of Residential Buildings . EMPA - Building Science and Technology Lab.