AMANAC Session: how to design an adaptive wall panel for retrofitting with multiple innovative technologies

Isabel Lacave Azpeitia[1], Ana Rodriguez Pando[2], Rogier Donkervoort[3], Tim Dijkmans[4]

[1]ACCIONA Infraestructuras S.A., Madrid, Spain
e-mail: isabel.lacave.azpeitia.EXT@acciona.com
[2]ACCIONA Infraestructuras S.A., Madrid, Spain
e-mail: ana.rodriguez.pando@acciona.com
[3]Netherlands Organisation for Applied Scientific Research TNO, Delft, The Netherlands
e-mail: rogier.donkervoort@tno.nl
[4]Netherlands Organisation for Applied Scientific Research TNO, Delft, The Netherlands
e-mail: tim.dijkmans@tno.nl

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Abstract

Current solutions for highly energy-efficient retrofitting rely on thick static insulation, airtight construction and extensive ventilation systems to become independent from variable outdoor conditions. A building skin that adapts to the outdoor conditions to regulate the indoor conditions could provide an interesting alternative for current retrofitting practice. This alternative is called ADAPTIWALL and consists of three key components: (1) adaptive insulation, (2) a lightweight concrete buffer and (3) a total heat exchanger. The significant energy savings that can be achieved with such a concept have been demonstrated by simulations. The question to be answered is how this model can be translated into an actual building concept. A question made more difficult by the fact that a number of innovative technologies are to be combined to make the concept work. In this paper the design process of ADAPTIWALL will be described. In this design process a number of innovations, ranging from nano-scale to building product scale, need to be assessed, selected and integrated. This assessment is performed by considering criteria related to e.g. structural engineering, architecture, building physics material science, Life Cycle Analysis and Life Cycle Costing.

This multifaceted design challenge is initially approached by combining the knowledge of experts in the ADAPTIWALL consortium in interactive design sessions. The process will be continued by testing of material prototypes, combining prototypes into components and upscaling to a full scale panel for testing. Each phase of testing will be followed by a design stage where the optimal or most feasible solution(s) is/are selected. The solution will be improved for the next prototype stage. The results from testing will be fed back into the model to improve it and to be able to use simulations for selecting appropriate design improvements. The expected result is a working ADAPTIWALL with a validated model for design improvement.

1 Introduction

Energy-efficient refurbishment of the current building stock will be crucial in reaching the EU 2050 energy goals, considering the fact that about half of current building stock will still be operational in 2050 and approximately 85% of the dwellings were built before 1990. The European Commission stated in 2006 that in residential buildings, retrofitted wall and roof insulation offer the greatest opportunities [1].Therefore retrofitting should focus on using the building envelope to improve the indoor environment at low energy consumption. Current retrofitting solutions generally include thick insulation packages, airtight construction and consequently, additional ventilation and heat recovery systems to keep thermal comfort and indoor air quality at the desired levels, for instance when trying to reach the certification goals for a Passive House retrofit [2].

Within ADAPTIWALL (an ongoing EU FP7 project [3]) a fundamentally different, climate adaptive approach is proposed: being able to adapt properties of the envelope, such as insulation value, and taking advantage of the outdoor conditions to regulate the indoor conditions in such a way that auxiliary heating or cooling is reduced to a minimum. Within a consortium of 8 partners a building component is being developed that is aimed to deliver the required energy performance in a smarter way.

The design process of a building component that consists of a number of innovative technologies is the topic of this paper. The main challenge in the design process is the fact that the ADAPTIWALL component consists of technologies that are already innovative in their own right. Combining them into a building component is even more challenging. In order to deal with this challenge, the development of the individual technologies needs to be facilitated as freely as possible. At the same time, the overall goal of developing an integrated building component needs to be kept in mind, while considering aspects like structural engineering, architecture, building physics, material science, Life Cycle Analysis (LCA) and Life Cycle Costing (LCC).

2 ADAPTIWALL Façade System

The target group for ADAPTIWALL application consists of low-rise single and multi-family dwellings that are eligible for energy-efficiency retrofitting (built before 1990). The ADAPTIWALL concept is developed for different climate types throughout Europe, making it potentially suitable for a large market.

The ADAPTIWALL panel consists of three key components: (A) Lightweight concrete buffer, (B) Adaptive insulation and (C) Total heat exchanger (THEX). These key components are integrated into a single façade panel with a height of one storey. The panel would consist of a load bearing light weight concrete layer (A) as a core element, which is used as a buffer to store heat/cold. Adaptive insulation (B) is installed on both sides of the buffer, in order to control the heat flows to and from the buffer. The THEX (C) is incorporated in the buffer. Other parts of the façade, e.g. cladding and windows are not considered key components. However, these components influence the performance of ADAPTIWALL, and are relevant to the design process described in paragraph 3.2 of this paper.

The key components are being developed by different partners. The authors of this paper are responsible for orchestrating these parallel developments and making sure that these components become integrated into a prototype that can be manufactured, tested and monitored during the last phase of the project.

3 Architectural façade system integrated design process. Multifaceted approaches.

3.1 PREDESIGN: Theoretical design, scientific approach

As a starting point of the design process, the theoretical energy performance of the concept model was studied. Since it relies on dynamic control of the physical properties of the envelope, dynamic simulations are required. TRNSYS [4] is used to model the ADAPTIWALL component. In order to limit the complexity of the model the ADAPTIWALL component is used as the façade in a model with only one indoor space.

This one-room model (see inset in Fig. 1) is initially used to investigate the potential of ADAPTIWALL in different locations: The Netherlands, Poland, France and Spain. The one-room model is modified to represent the current local retrofitting practice in terms of R-values and U-values. From these simulations it is demonstrated that ADAPTIWALL has the potential to reduce both the heating and the cooling demand by over 90% compared to the local reference cases.

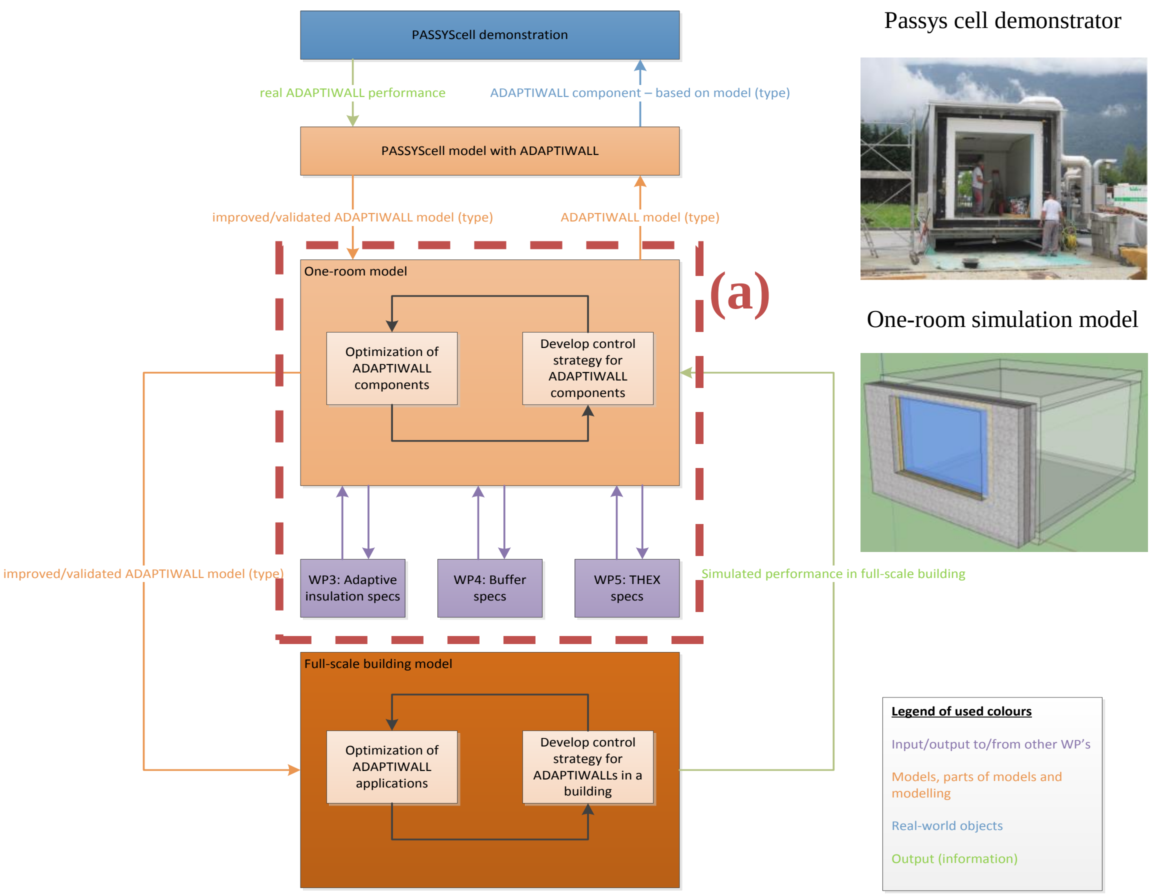

Figure 1: Relation between one-room model, component development, demonstrator and full-scale building model; box (a) contains the relation between the one-room model and the component development

These simulations are then used to specify the design challenges for ADAPTIWALL and its components [5]. Key components are each investigated by simulations based on on-going interaction with the material work packages. This process is indicated in box (a) in Fig. 1. This is an iterative process since all components affect the resulting energy savings of the whole ADAPTIWALL panel. Partners responsible for individual components also provide component properties that are deemed feasible at the time as input to the simulations. For instance, simulations are performed in order to check whether insulation with lower thermal properties than previously modelled can theoretically achieve high energy savings as well. Vice versa, the output from the simulations provides the component development with desired specifications. It is for instance found that direct transfer from solar radiation to the buffer is crucial for storing heat in the buffer. This becomes a requirement to the insulation concept.

After every design decision at any stage, the simulations are used to check whether the energy performance is still sufficient. Meanwhile, the control strategy of the ADAPTIWALL panel – when should insulation switch, when should the THEX be activated etc. – is continuously being optimized. In this process, also some sanity checking is performed when the effect of individual parts of the whole panel is assessed. For instance, the simulated energy performance of the panel was slightly improved (lower cooling demand) when there was shading on the outside of the ADAPTIWALL panel, in front of the buffer (see box in Fig. 2). This benefit is so small, that it would not make sense to install it in the actual panel because it would increase the (life cycle) costs, raise complexity and may also be undesirable from an architectural point of view.

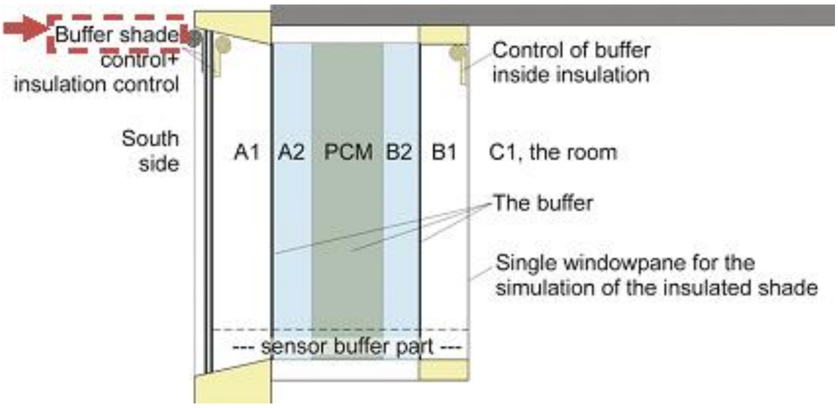

Figure 2 : Graphical representation of the parameters in the TRNSYS model

3.2 INTEGRATIVE DESIGN: Constructive design, architectural approach

Once the scientific objectives, boundaries and requirements are set, the constructive design of the panel is ready to start. In the following, the methodology to achieve a constructive design to build a full scale ADAPTIWALL panel is described.

The first step is the detailed description of the components characteristics and requirements, focused on those aspects that will affect its integration into the panel. Secondly, the identification of the interactions among these different components and its possible solutions are carried out. These lead to the definition of new boundary conditions for each of the components and, moreover, to the selection of new elements as cladding layers, connectors, etc. A specific integration workshop was held by all ADAPTIWALL project team for this purpose. Shared thoughts and points of view from the multidisciplinary team guarantee the success of the integration process.

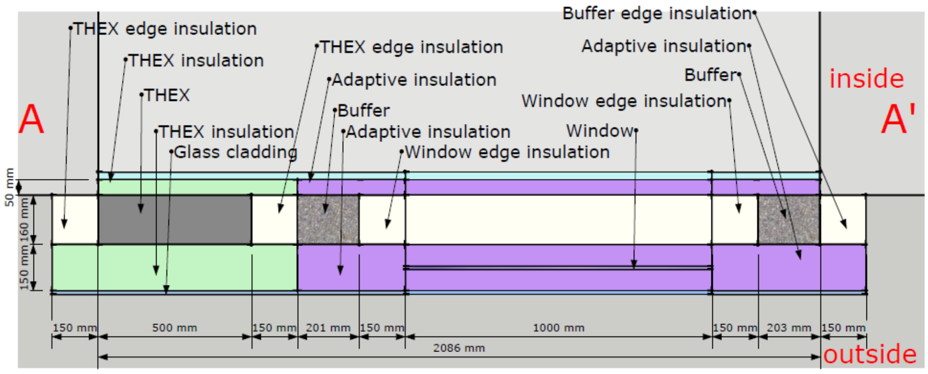

Figure 3 : Outcome of the design workshop; the basis for development of individual components

The lightweight concrete buffer is the structural layer to which all other elements are fixed. All loads must be supported by this component. Taking into account these requirements, the maximum admissible weight of the concrete and its minimum thermal inertia, establish its thickness range. Structural engineering introduces steel reinforcement. To obtain a constant thickness of the complete panel, the buffer thickness is adjusted to the THEX dimensions as it complies with the range of thickness set before.

For the adaptive insulation, material, thickness and switching system for each scenario have been defined in the previous stage. The actuators to be used and sensors to control the device are now selected and located within the panel.

The THEX has fixed dimensions due to its complex internal performance; it is placed beside the lightweight concrete panel and anchored to it by steel angles and embedded anchor rails. No external mechanical loads should be transmitted to this component. This device needs to be embedded in a thermally stable environment to guarantee its performance; therefore it’s not possible to combine the THEX with switchable insulation. Static insulation of the edges as well as plastic gaskets in the anchoring points are required. THEX must be accessible from the inside in order to allow its regular maintenance.

As a result of the interactions among the different components, new layers are introduced in the façade solution: the internal and external cladding layers. They are strongly related with the architectural approach and aesthetical solution of the panel.

Combining specifications from the design workshop, energy simulations, the development of individual components, LCC and LCA it was determined that the external cladding should be a glazing system and the internal cladding should be plasterboard. These new layers in the panel are used to confine the insulation material, when activated, in the air chamber between the buffer and the cladding.

Several solutions to connect the cladding layers and the buffer are studied. Their main constraints are: they should be introduced in the concrete panel before casting and thermal bridge through the anchoring components should be avoided to prevent undesired buffer unloading. The interaction between the cladding and the switchable insulation is focused on the air and water permeability of the cladding to prevent damages, not to interfere with switching of the mechanism and to diminish the impact of the cladding’s anchors going through the switchable insulation air cavity as it could become obstructed or divided it into compartments. For the THEX both internal and external claddings must foresee the inclusion of air in/outlets. The internal cladding must include an access door or hatch for maintenance purposes.

Finally, when all requirements, solutions and boundaries of the interaction between components have been analysed and decided the architectural design of the ADAPTIWALL panel is developed. The result is an attractive hi-tech façade solution: a glass finishing which aesthetics changes dynamically according to its energy performance needs.

Lab scale prototypes of 80x80cm are manufactured and assessed to test the design. There are three main objectives of these tests: to characterize the panel according to the local and European construction products standards; to assess the performance of the panel under real atmospheric conditions and, most of all, to verify the simulations results. Meanwhile hands-on experience is gathered through its manufacturing process, which is critical as each component will be manufactured separately and then assembled by a different partner.

Once the lab scale prototypes are manufactured, many lessons learnt regarding assembly procedures and auxiliary elements can improve the initial design. ADAPTIWALL panel is now ready for a full scale demonstration. The Passys cell demonstration facilities (see inset in Fig. 1) are located in Chambéry (France). The panels will be integrated on two 6m² demonstration facades both facing south. Two scenarios will be compared with different internal conditions and control strategies. Though the scale of the Passys cell (approximately 2.45 high and 2.50 width internal dimensions) is not that of a real facade, they are no longer prototypes but fully performing installations including a monitored HVAC system to control the interior environment of the cells. The testing facility provides many of the architectural constraints and boundary conditions of that in a real building. Remarkable issues to be resolved at this stage are the integration of a window and the anchoring to the existing structure.

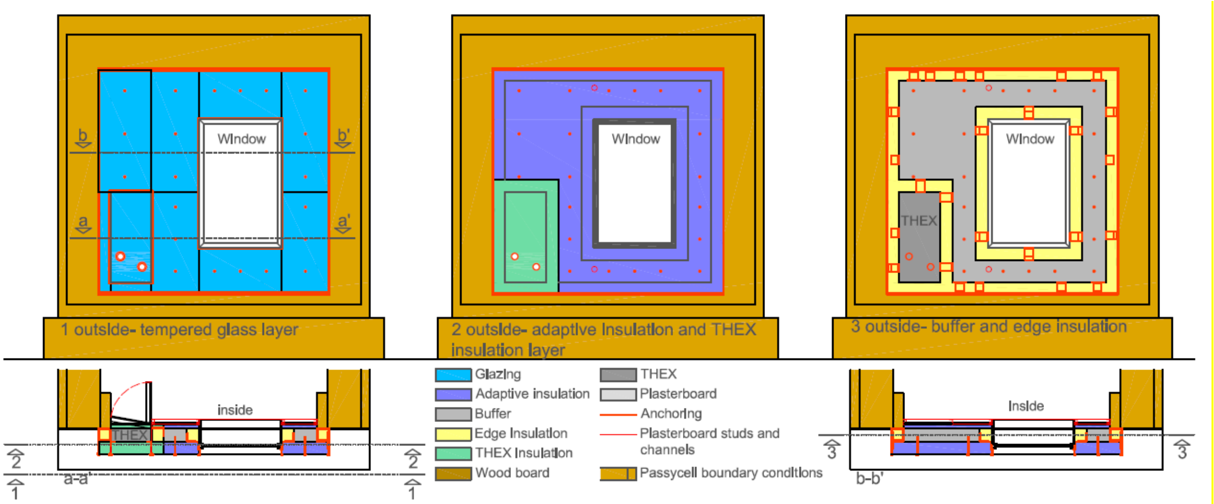

Figure 4 : Detailed design in progress for the Passycell demontrator

Window size (1.0m width 1.56m height) was previously determined by the Dutch case study and considered in the one room simulations, maintaining the same open-closed ratio. The window properties were determined as well by the energy simulations aiming for a U-value of 0.7 W/m^{2}K for the window assembly. Window frame anchoring to buffer is resolved in a similar way as the one for the THEX by means of steel angles and embedded anchor rails. These anchoring elements make different positions of the window possible. Since the adaptive insulation is switchable the optimal position comprises the buffer and the light trespassing. Window sill must provide drainage and together with its head and reveals warranty air and water tightness. The edge of the lightweight concrete buffer has to be thermally insulated to avoid the undesirable transmission of heat to other elements, such as the window frame or the slab edge. The target properties of this insulation have been determined through energy simulations. Anchoring is also located on the edge of the buffer; edge insulation must provide access to anchoring during assembly.

For the external and internal cladding layers that were ideally positioned on each side of the adaptive insulation layers, supporting structure has to be provided minimizing thermal bridges and interferences with the functionalities of the adaptive insulation system. For the internal plasterboard a shaftwall system has been considered to avoid chamber compartments caused by the supporting structure. External cladding must provide water and air tightness, glass bolted fittings and window frames were assessed considering different glass dimensions and specifications to minimize thermal bridges and shading effects. The edge frame of the external cladding is also the panel’s frame therefore it has to meet several requirements, such as upper drainage and drip caps. The external cladding and frame have to be assembled in the last stage once anchoring is done.

3.3 OPTIMIZED DESIGN. Adapting to real cases, climatically tuned up envelope

The last step in the adaptive wall façade design is its integration in real buildings with different characteristics and climates. Invariant features that are intrinsic and define ADAPTIWALL and common to all these scenarios are: external cladding, insulation, buffer + THEX, insulation, internal cladding; the switchable insulation material and devices; the THEX dimensions; the buffer thickness; and the anchorage between components.

The variant features depending first on the building and then on the climate are defined. The features depending on the building characteristics are: the overall panel length and width to fit within the floors offset and external surface dimensions; the external and internal cladding material, to comply with national regulations and users acceptance and needs; the anchorage system and perimeter sealing to the existing structure; and the ratio between the opaque area and the window surface to respect the situation before retrofitting. The features depending on the climate conditions and thermal performance regulations are: the thickness of both switchable insulation layers and glazing to comply with the thermal resistance requirements; the melting point temperature of the buffer’s PCM depending on the annual temperatures to be balanced; and lastly the adaptive system configuration through the year. Based on the methodology developed in the first designing stage - theoretical design- all these component features are defined.

Once the architectural design adaptation is developed for the three local retrofitting cases its energy performance is assessed. Dynamic simulations of the full scale buildings models are made to adjust the control strategy and evaluate the impact of the façade on the building’s energy performance and indoor comfort. The results are used to obtain the optimized design of ADAPTIWALL.

4 Conclusions

The ADAPTIWALL panel development faced a complex integrative process of innovative components. The methodology phases are defined by the upscaling process while the integrative process can be described as addition steps and interaction solving considering aspects from structural engineering, architecture, building physics, material science, Life Cycle Analysis (LCA) to Life Cycle Costing (LCC).

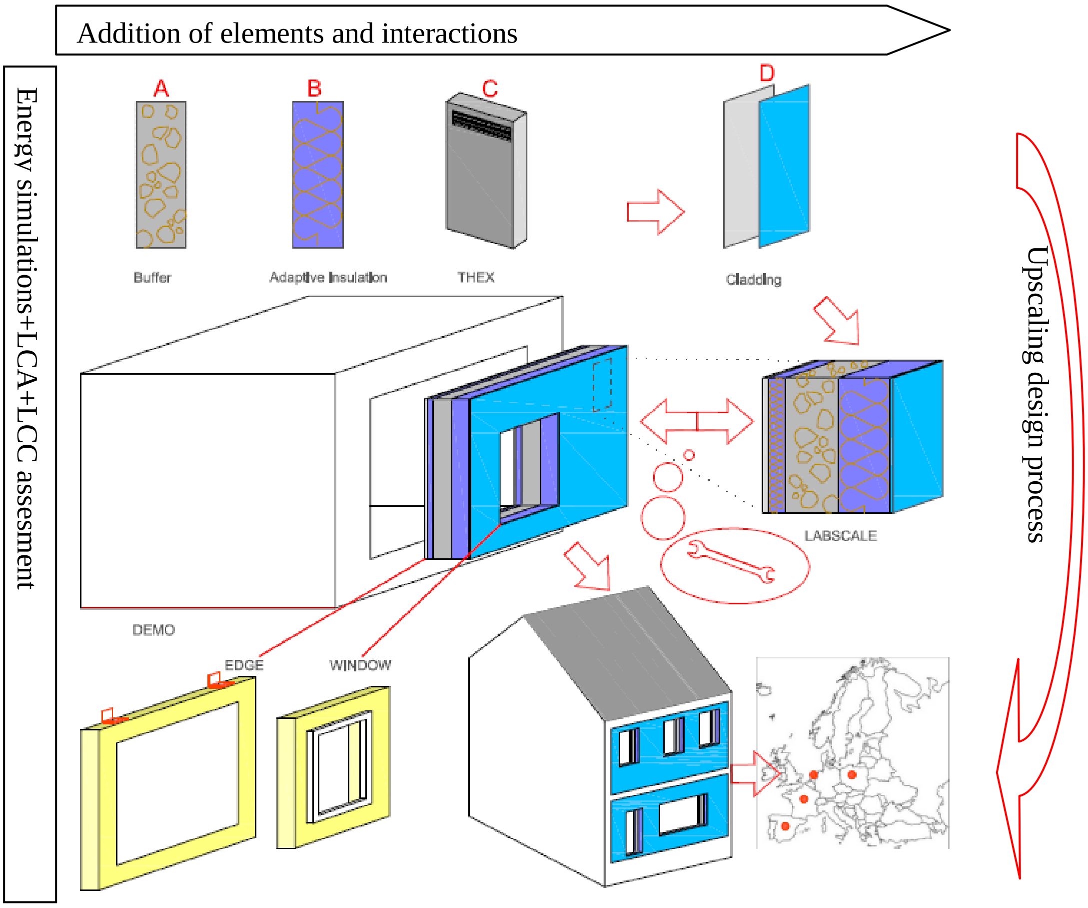

Figure 5 : Design stages and process to integrate the ADAPTIWALL components

Acknowledgments

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