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MORE-CONNECT: New developments in prefabricated multifunctional building envelope elements and installation platforms for NZE renovation

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Abstract

Objective of the H2020 project 'MORE-CONNECT' is to develop and to demonstrate technologies and components for prefabricated modular renovation elements in five geo-clusters in Europe (The Netherlands, Denmark, Estonia/Latvia, Czech Republic, Portugal). MORE-CONNECT is based on three main innovations: product, process and market innovation. Product innovation includes prefabricated innovative, modular composed building envelope elements, including the integration of multifunctional components for climate control, energy saving, building physics and aesthetics, with advanced plug & play connections (mechanical, hydraulic, air, electric, prefab airtight joints) for ultrafast installing, limiting the total renovation time of 5 to 2 days. Process innovation includes a fully automated productions process, starting with digital imaging using advanced geomatics, on-line configuration of the renovation concepts by end-users and a fully automated BIM controlled production process. This process offers the possibility to produce 'series of one' in a mass production process. Market innovation includes the offering of a one-shop-stop concept to the end-user, i.e. the end-user deals with only one responsible party organizing the design, production, installing, financing, performance contracting and after care. A performance guarantee is offered for individual energy use and the quality of the indoor environment. Web based tools will link building characteristics, building energy potential and end-users demands.

Keywords: deep renovation, prefab modluar multifunctional elements

1. Introduction

The social and environmental urgency of large-scale integrated retrofitting of the European building stock is widely acknowledged and supported by Member states. However, the European building sector has not been able yet to devise a structural, large-scale retrofitting process and systematic approach. One possible solution to overcome accelerate deep renovation of the European building stock is to change the traditional renovation process, as a time and cost consuming tailor-made process on site, to a process with an extreme high grade of prefabrication. The application of prefabricated multifunctional renovation elements have the potential to reduce costs, reduce the renovation time and disturbance for occupants and, at the same time, enhance quality and performances, both in terms of energy efficiency, building physics as indoor climate.

The potential of these prefabricated deep renovation solutions have already been investigated within IEA EBC Annex 50 Prefabricated Systems for Low Energy Renovation of Residential Buildings (2006 -2011) [1]. Also the European Commission acknowledges the necessity of prefabrication of modules for building renovation. In 2014, in the Horizon 2020 Program a specific call was launched on this issue in Energy Efficiency (EE1: Manufacturing of prefabricated modules for renovation of building). The specific scope of this call was the investigation of innovative mass manufacturing processes to lower pre-fabrication costs and ease building integration processes, where also the aesthetics of existing buildings should be taken into account. This requires the development of new controlled processes and cost-effective automated/robotized tools. These innovations are combined with integrated processes and the use of advanced computer based tools like Building Information Modelling which will facilitate the industrialization of the whole construction process and integrate the value chain over the life cycle of the project. Moreover, the criteria and methods for evaluation of the benefits should be transparent and simple. In this call three projects were selected, MORE-CONNECT (www.more-connect.eu), BERTIM (Building Energy Renovation through Timber Prefabricated Modules http://www.bertim.eu/) and IMPRESS (New Easy to Install and manufacture Prefabricated Modules supported by a BIM based Integrated Design Process http://www.project-impress.eu/) of which MORE-CONNECT was the first one which has been contracted. The challenge of MORE-CONNECT is to make this major step forwards in deep renovation by the application of prefabricated modular building elements by a combination of product innovation, process innovation and innovative market approach, in a process of cost and quality optimization.

More-connect has four main objectives:

1. The development of cost optimal deep renovation solutions towards nZEB concepts with the possibility of extra customized features. The concepts will have a certain balance between demand reduction and renewable production, looking for the most optimal mix within the range of term ‘nearly’ in NZE including cost-efficiency and embodied energy.

2. The development of prefabricated multifunctional modular renovation elements in series of one concepts, in a mass production process. This concerns both multifunctional renovation elements for the total building

envelope and installation/building services. These elements can be combined, selected and configured by the end-user, based on his specific needs. The configuration can be made on the basis of a pre-selection of elements, based on the specific properties and measures of his home inventoried by advanced geomatics with various aesthetic and architectonic appearances. As input into advanced Building Information Modelling systems it can control and steer the further production process of these elements. In this way unique series of one can be made in a mass production process for the same reduced price of mass production.

3. The development and demonstration of new fully automated production lines for the fabrication of multifunctional modular renovation elements. These production lines that are effective on series-of-one as well as large series and seamlessly combine into mass customization principles. This is done by machine instructions from automated computerized numeric control instruction generation based on Building Information Modelling BIM and in-situ measurements. Plant management is organized in software solutions that support line-balancing as well as JIT (just in time) and flow. Line design supports scalability in product complexity, support of more than one product-market combination and output.

4. The offering of a one-stop-shop to the end-user to renovate their homes. One of the main problems for a European-wide market uptake of deep renovation is the lack of interest and understanding for the end-users. This problem is tackled by offering a so called one-stop-shop concept for the end-user. In this proposition the end-user will deal with only one party, responsible for the total renovation, starting from an inventory of the existing situation, inventory of specific end-user demands, translation into modular renovation kits, mounting and installing, financing and aftercare. The high level of prefabrication and the use of smart connectors (mechanical, hydraulic, air, thermal, electrical, ICT) will limit the actual renovation time on site to a maximum of 5 days with a goal for an average of two days, including the complete or partial removal of the existing facades and roofs or other elements. During the renovation the occupants can normally stay in their homes and have a minimum disturbance. The end-users will get a guaranteed energy cost proposition for their renovated homes, based on their individual household profiles. This guarantee is possible by the high level of quality control during the production process and the monitoring of performances of the most essential parameters related to energy use and remote diagnostics of the most important installations and building services.

2. Process innovation

Process innovation is the most important pillar for MORE-CONNECT. The multifunctional elements will be produced and offered as tailor-made solutions for individual as well as for housing companies, in a mass production process with the possibility of ‘n is 1 series’. This needs a process innovation. This process innovation is achieved by three steps:

1. The use of advanced geomatics to make inventories and gauging of buildings and buildings stock.
2. Web-based and/or digital decision tools will link building characteristics, building (energy) potentials, end-users demands to program requirements, technical solutions, component combinations in concepts, production automation.
3. This will be processed in BIM systems for the steering of industrial processes and for enhanced quality assurance.

Prefab concepts are already available, but mostly until now only developed for specific large scale projects. These are often fixed concepts, offered by the supply side of the market and project based. This often leads to a mismatch with the end-user needs as there is no individual configuration possible of industrial produced concepts. One of the innovation to be made is that the functionalities of industrial produced renovation concepts and aesthetics can be configured, within certain limits, by the end-user. This should give an opportunity that is comparable if a customer buys a new car or kitchen: the consumer can make an own configuration on the internet, within a certain platform, based on his own house. Therefore tools will be developed to inventory the requirements of the end-user and to translate these requirements into a program for seceding and producing the concept. Advanced Geomatics and/or digital databases of building stock, are used to inventory and measure the existing situation and possibilities. An overview of geomatics techniques is available now [2] that can be used for building reconstruction and to show advantages of their integration into different project phases. Including exact specifications of project requirements for surveyors and for cost optimization of the geomatics work (surveying, processing of data and information transfer into desired software in appropriate format). Photogrammetric and laser scanning methods have been compared, used and tested for the building documentation. Testing shows that both methods are convenient. Use of a particular method is based on project specifications and requirements as well as on ordering party preferences. Use of Ground control points (GCP) is recommended for higher accuracy demands (<5mm) and when larger objects (residential houses) are of interest. Geodetic total station provides fine and quick GCP measurements.

From this inventory based on geomatics, a visualization of the existing situation can be made, as well as a number of varieties of elements in architectural and aesthetic possibilities, suitable for application on the existing frames. The end-user can compose his own new facade within a certain aesthetical and technical allowable range. To determine the range, the bandwidth of solutions will be determined by supporting research for a standardized solution for the load bearing structure of the element, in combination with components integration and optimization from materials point of view: composition, materials choices and embodied energy and an optimization of insulation level thickness in combination with renewable energy production devices. By separating functionality from aesthetics in the development/design process (separate phases) consumers can be shown that their needs are affordable and reachable in the combination of function and design.

3. Requirements for building envelopes for NZE renovation

The EPBD [3] defines nearly zero energy building as a building that has a very high energy performance and requires the calculation of primary energy indicator. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby. If the system boundary for energy performance of buildings is defined as (primary) energy use of whole building's (heating, cooling, ventilation, DHW, lighting, HVAC auxiliary, appliances) with the inclusion of on-site renewable energy production, there are no specific requirements on heat loss in building regulations. Kuusk [4,5], Arumägi [6], and Alev [7] et al. have shown that additional thermal insulation of building envelope have important role in improving of energy performance of existing building stock in Northern Europa. Nemry et al. [8] modelled building stock for the EU-25 and reported that heat losses due to building ventilation, through roofs and external walls are important for a majority of dwellings and most cases bear a significant potential for economically efficient environmental improvements, especially for additional roof and façade insulation. Sousa et al [9] showed that in Portugal the average thermal transmittance for any part of building are extremely high and, even in the most recent period, in some cases the actual legislation is not fulfilled.

For construction companies and producers of modular renovation panels it in necessary to know specific properties of building envelope:

- thermal transmittance (U, W/(m^2·K)) of exterior wall, roof, floor, windows, doors, etc;
- linear thermal transmittance (Ψ, W/(m·K)) of connections, details and thermal bridges;
- air leakages (q_{50}, m^3/(h·m^2)) of building envelope.

Indoor climate and energy simulations were made based on national energy simulation methodologies in six countries to determine what kind of requirements nZEB and deep renovation sets for building envelope. The selection and development started with an inventory of the initial performance criteria and requirements in five geo-clusters in Europe:

- Northern (represented by Denmark),
- Continental Northern East (represented by Estonia and Latvia);
- Continental Centre (represented by Czech Republic);
- Mediterranean focuses (represented by Portugal);
- Western Central (represented by the Netherlands).

Indoor climate before renovation represented indoor climate category (ICC) III (an acceptable, moderate level of expectation) and after renovation ICC II (normal level of expectation). The indoor climate and energy simulations were made to six reference buildings, correspondingly on national energy simulation methodologies and requirements. All input data used in energy calculations represent the typical case of that country. Due to the diversity of the European buildings sector and climate, each state have to define national nZEB approaches reflecting national, regional or local conditions. In most of the countries the energy performance of buildings is defined as (primary) energy use of whole buildings. In Denmark the nZEB is referred to BR2020 which calls for a total primary energy use of 20 kWh/m²/year (primary energy factor for district heating=0.6 and for electricity=1.8). Portuguese regulations define that the nZEB solution corresponds to the cost-optimal renovation solution of the envelope. Differences in climate and nZEB regulations cause also different requirements for heat loss of modular prefabricated insulation panels in different countries. In the northernmost country, Estonia, the strictest requirements exists on thermal transmittance of building envelope. Even adjoining state countries Estonia and Latvia have almost similar climates, differences in energy regulations cause stricter requirements on thermal transmittance of building envelope in Estonia. Similarly, stricter requirements on energy performance of buildings in Denmark [10] causes stricter requirements on thermal transmittance of building envelope than in Czech Republic. In Portugal, requirements on thermal transmittance of building envelope are the lowest for nZEB.

Minimizing heat loss of building envelope is not enough for nZEB in Estonia and Latvia. On site heat and electricity production is need in both countries: ~7% of solar collectors for DHW per heated area and in Estonia additionally ~5% of solar panels per heated area for producing electricity. As in Portugal the use of district heating is not popular, the heat pump (COP=4.1) was used there as renewable energy source.

To decrease the energy consumption for space heating and cooling, ventilation, and domestic hot water by at least 80 % compared to the original consumption depends strongly on energy performance of the building before renovation. Depending on country's climate, regulations and energy use of building before renovations, 80 % of energy reduction may cause stricter or weaker requirements on energy performance than national nZEB requirement.

The production of heat and electricity on site is unavoidable in all countries except Denmark. In Estonia the share of renewable energy is the largest, because energy performance value includes also energy used for appliances and lighting that cannot decrease by modular insulation panels. Almost the total area of the roof is covered with solar collectors and PV panels in Estonia to degrease the primary energy for space heating and cooling, ventilation, and domestic hot water 80 %.

To eliminate different requirements on energy performance in different countries the last simulations were made for ZEB (Zero Energy Building = the use of primary energy on annual basis = 0 kWh/(m^{2}a) for space heating and cooling, ventilation, and DHW), Similarly to previous cases, it was possible to reach the goal by minimizing the energy use and maximizing the energy production on site form renewable sources.
Similarly to previous cases, each country found the optimal solution themselves.In table 1 an overview is given for the requirements for U values to come to several levels of renovation.

Table 1. Evaluation of necessary U-value for each geo-cluster

		Heat transmittance values,W/(m^2·K)					
		Portugal	Czech Republic	Netherlands	Denmark	Estonia	Latvia
Before renov.	U_{wall}	0,92	0,8	1,90	0,50	1,10	1,10
	U_{roof}	0,94	1	2,80	0,40	1,00	1,25
	U_{floor}	0,78	1,28	2,00	0,50	0,60	0,49
	U_{window}	3,10	1,12	2,80	3,10	1,60	2,56
	U_{door}	3,10	3,46	2,50	3,10	1,60	2,56
National nZEB	U_{wall}	0,47	0,21	no definition	0,14	0,11	0,19
	U_{roof}	0,32	0,15		0,11	0,08	0,16
	U_{floor}	0,86	0,27		0,34	0,22	0,19
	U_{window}	2,40	1,00		0,70	0,80	1,20
	U_{door}	2,40	1,00		0,70	1,00	1,20
80% reduction	U_{wall}	0,47	0,21	0,18	0,14	0,08	0,19
	U_{roof}	0,32	0,15	0,15	0,11	0,06	0,16
	U_{floor}	0,86	0,27	0,29	0,34	0,15	0,19
	U_{window}	2,40	1,00	1,60	0,70	0,60	1,38
	U_{door}	2,40	1,00	2,00	0,70	0,80	1,30
After renov. (ZEB)	U_{wall}	0,47	0,21	0,18	0,14	0,08	0,08
	U_{roof}	0,32	0,15	0,15	0,11	0,06	0,08
	U_{floor}	0,86	0,27	0,29	0,34	0,15	0,11
	U_{window}	2,40	1,00	1,60	0,70	0,60	0,81
	U_{door}	2,40	1,00	2,00	0,70	0,80	0,81

4. Assessment tool for energy, embodied energy and costs

In MORE-CONNECT a simplified but effective approach has been made to make a pre selection of prefab panel configurations, in relation to building performance standards. In the first model it is assumed to be a zero energy situation, related to future renewable energy supply systems. It is optimized to perform the ‘best’, not related to primary energy (as the connections to grids are net calculated, i.e., energy in = out). Four levels of optimization criteria have been taken into account:

1 Environmental (operational energy, materials-embodied energy): 'ERL', energy reference level

2 Socio-cultural; i.e. comfort and health: 'SRL', Social reference level

3 Technical; for instance the max available roof surface, energy equipment concepts: 'TRL', technical reference level

4 Economical; investment or loan budgets: 'CRL', Cost ref level

The basic approach is given in Fig. 1.1, different combinations of measures that all lead to 0-energy (the X = Y axis), and further evaluated from an Embodied Energy perspective for the different prefab-element configurations, as well as for a cost perspective.

Embodied energy (primary) is in the same graphical range as final demand operational energy and uses the same Y –axis. Embodied energy is not added to operational energy, since that is in the zero energy case free available renewables. This provides a curve showing the lowest impact from materials for any 0-energy concept, which is the overall energy optimum, see Fig 1.2. The energy demand calculation will deliver different energy demands for different insulation levels, accompanied by different amounts of PV panels to supply that demand. All combinations are 0 situations, and both together add up to Embodied energy performance. For easy comparison, only the prefab element is evaluated, where it is further assumed to have an in house heating and ventilation system. This is in fact the same for any panel-element configuration (for instance a heat pump or heat exchanger).

The axis for cost can be detailed in different ways: the example in Fig 1.3 is chosen as direct investment costs, which indirectly can be related to available budget, either from investment or from a maximized loan and interest budget over x years. It can be chosen locally, whether to relate to and calculate in monthly interest and rebate, or investment or else. This gives an environmental and economical range of optimizations. (ERL+CRL). Limits to E Cost can be detailed by the right Y axis currently gives just investment cost and provides a maximum shown by the added lines in Fig. There is a technical reference level TRL, here introduced as roof surface: this maximizes PV output, and all solutions should stay below that maximum, see Fig 1.5. These two lines in combination with the graph gives an area in which solutions are feasible, as shown in Fig 1.6.

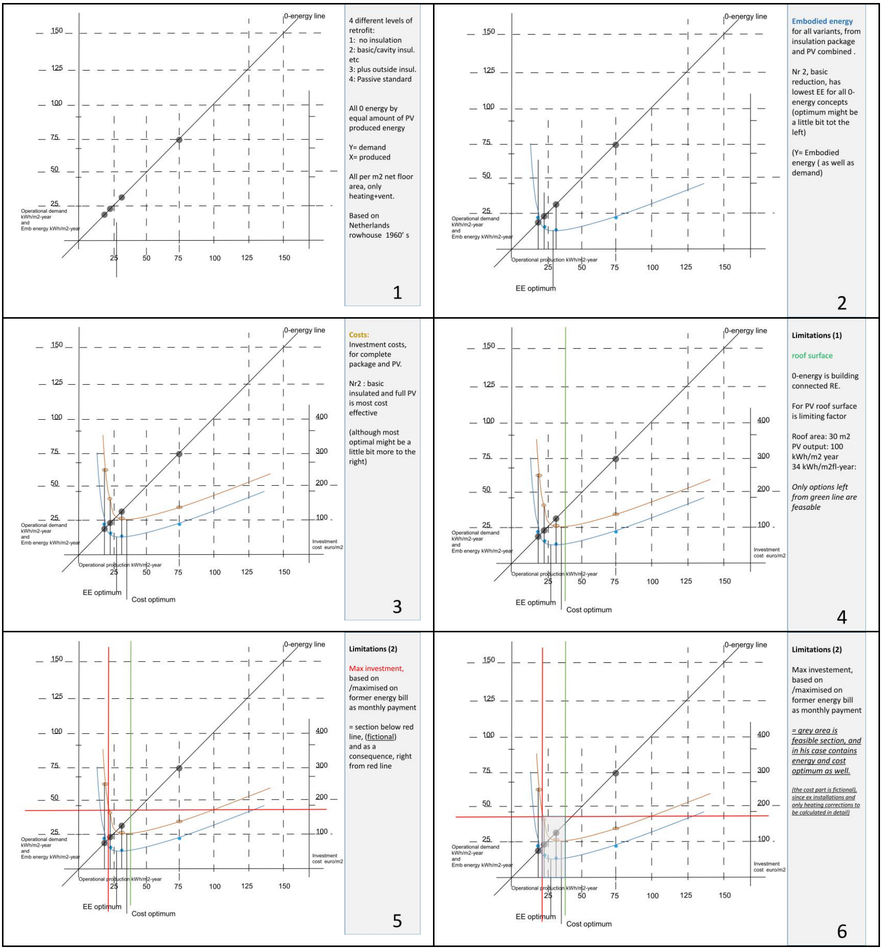

Fig. 1 Assesment methodology to come an optimization between energy, embodied energie and costs

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