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## Designing a smart factory for mass retrofit of houses

To cite this article: K Lange and U-B Kraemer 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **323** 012155

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# Designing a smart factory for mass retrofit of houses

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**Abstract.** The North Sea Region (NSR) contains 22 million houses built in 1950-1985 that cause 79 Mton CO<sub>2</sub> emissions annually. Current deep retrofit home renovations are carried out on a limited-scale production and only in small projects. This results in the problem that nowadays renovation costs are way too high and the pace of renovation is far too low. Large scale renovations of existing homes towards energy-neutral are currently not addressed in the North Sea Region. Still, the retrofit of houses in the North Sea Region is essential to reach the European energy and climate objectives. However, the building sector in Europe is not creating the necessary production facilities. The target of the just started INTERREG project INDU-ZERO is to develop a blueprint for a production facility that can produce wide suitable renovation packages at a high volume and low cost.

## 1. Introduction

The North Sea Region (NSR) contains of a wide range of outdated housing (one-family houses and apartment buildings with poor insulation and high energy demands) built between 1950 and 1985, that do not meet the present-day and future energy and living standards. These households in each country in the NSR all have a structural demand for heat (heating and hot water) and electricity. In order to meet EU environmental objectives, the NSR countries all need to focus on renovation, resulting in energy-neutral houses in order to reduce CO<sub>2</sub> emissions. At the moment, mostly manual production facilities exist that can offer renovation solutions (often based on timber frame construction) for a maximum of 500 homes per year. As a result, the costs of renovations are high and the quality varies too much. Due to the high costs only a small number of homes per year are deep-renovated at the moment. Large scale renovations of existing homes towards energy-neutral are currently not addressed in the NSR region.

In the EU-funded Interreg project INDU-ZERO (Industrialisation of house renovations towards energy-neutral) the aim is to develop a blueprint for a production facility, based on Smart Industry and Circular Economy, that can produce wide suitable renovation packages at a high volume (15.000 units/year) at low cost (50% of current price). The consortium of the just started project consists of industry, government and knowledge institutes of six countries in the North Sea Region. This transnational collaboration is needed to combine all necessary knowledge and experience and to guarantee adoption of the project results.

The structure of this paper is as follows: In chapter number 2 the European background of the outdated housing situation and the consequences are described. In the third chapter a review of existing research projects which target the sustainability in the building sector is given. In chapter 4 the INDU-ZERO approach is described. In the fifth chapter the first results of the first deliverables are



described, followed by the sixth chapter where the next steps will be specified. The last chapter contains a short conclusion.

## **2. Background in the North Sea region**

Renovating the current houses in NSR is a serious challenge for meeting EU objectives. On the one hand, the potential of houses to be renovated is high. On the other hand, the market failure in the building industry hinders a faster renovation pace.

### *2.1. Potential of houses to be renovated*

There are a total of 22 million houses and apartments in the North Sea Region (calculated on the basis of TABULA Building Typologies) [1] that should be renovated to become energy-neutral within the scope of this project. The number of outdated houses of the NSR partners within this project scope per country are: Belgium 500.000, The Netherlands 4.3 Million, Germany 4,8 Million, UK 9,6 Million, Norway 810.000 and Sweden 1,2 Million. The current CO<sub>2</sub> emission of an outdated house is about 3,6 tonnes per year per house. To meet the EU 2030 objectives, almost 2 million houses per year would have to be renovated in the period 2018-2030 in the NSR. With the current state of technology, a small number of renovation packages per factory can be produced and a very limited number of such factories exist. The capacity of the current factories is to a large extent used for new buildings. For the NSR, an insignificant number of renovation packages can be produced at the moment. The NSR therefore seriously lacks production capacity.

### *2.2. Market failure in the building sector*

Unfortunately the EU energy and climate objectives in the NSR cannot be significantly influenced by the building sector at the moment. Currently, the INDU-ZERO partners experience that the building sector has looked only locally and regionally at one project at a time. This is why the production of renovation packages for renovating houses towards energy-neutral is still small-scale. Each house or apartment is served by means of tailor-made offers and most of the work is carried out manually. Due to the local approach, the costs for renovating houses to energy-neutral range between € 80.000 and €120.000 per house/apartment. In addition, the quality of the work varies due to the manual approach, so that no uniform performance guarantee can be given. No standardized renovation solutions are available for the EU market on a large scale. As a result, the cost for individual or low scale renovations into energy-neutral housing is too high to persuade house owners. Main reasons for the market failure of the building industry are:

1. Workload in the industry is high at the moment;
2. Suppliers experience these types of developments as a threat for their existing business;
3. In the current supply chain the producers and providers of (end) products are mostly Small Medium Enterprises;
4. The industry invested in traditional structures;
5. Lack of an upscaled Original Equipment Manufacturer (OEM) position that is found in other market segments;
6. The industry by itself will not initiate the proposed breakthrough in this project and has no incentive for innovation.

In order to meet the long term EU climate and energy objectives, the NSR outdated housing stock needs to be renovated into energy-neutral. These renovations must be solutions which will be suitable for the next 30 years, in order to meet future climate and energy objectives.

## **3. Research Review**

Other research projects in the field of energy efficient building exist. They focus on different aspects than the INDU-ZERO project.

*Build with CaRe:* The aim of the Interreg-funded Build with CaRe project was to mainstream energy efficient building design by raising awareness and increasing knowledge of the potential of energy savings. In collaboration with the building sector, a transnational strategy for increasing energy efficiency in buildings was developed. Within the project, an education and information programme was carried out to change behaviour in the complete building chain. This aided the setting up of a transnational knowledge and information network.

*Transition Zero:* Transition Zero is an EU Horizon 2020-funded project, carried out by Energiesprong, to establish the right market conditions for the wide-scale introduction of net zero energy homes across Europe. The aim is to kick-start net-zero energy refurbishment markets in the UK and France, using the social housing sector as a catalyst. This should be achieved by introducing performance-based solution requirements on integrated refurbishment packages and by establishing long-term, warranted energy performance contracts. Therefore, the regulatory and financing conditions for net-zero energy refurbishments have to be improved.

*More Connect:* The social and environmental urgency of large-scale integrated retrofitting of the European building stock is widely acknowledged and supported by Member states. However, as the European building sector is fragmented, it has not been able yet to devise a structural, large-scale retrofitting process and systematic approach. The aim of the EU Horizon 2020-funded project is to overcome these barriers by applying prefabricated multifunctional renovation elements which have the potential to reduce costs, renovation time and disturbances for occupants. At the same time, quality and performances (both in terms of energy efficiency as indoor climate) should be enhanced.

*Faster and Better to Zero on the Meter (SBNoM):* As the technical feasibility of zero on Meter (NoM) has been proven, the objective of this project is to accelerate and improve the industrialization of such renovations. This should be achieved through a chain approach in which supply and demand are linked. This involves the industrialization of NoM, standardization and the offering of recognizable 'packages' for these renovations. The costs should be reduced by industrialization and smarter installations or material use.

The INDU-ZERO approach is based on the findings of the above mentioned projects and knowledge. Automation and the development of a factory was not part of the former projects.

#### **4. The INDU-ZERO approach**

The overall project objective is the innovative up scaling and industrialisation of renovation solutions towards energy-neutral for NSR homes built in the 1950's to 1985's (which are in general of poor quality with respect to energy consumption, indoor climate and comfort), to lower costs, improve quality and increase the implementation of the renovations in the current housing supply in NSR.

Therefore, two main targets have to be achieved:

1. A smart factory blueprint which in itself is replicable in many countries will be developed. A production facility for thousands of renovation packages should not only be suitable for one type of house or one type of country, but consider the requirements of different countries. Otherwise, it would require different developments and factory designs, which would address a limited amount of houses, and therefore reduce the chance of realising mass scale renovation. Thus, this approach requires many countries to be involved to develop a factory design that is flexible and replicable throughout many NSR countries.
2. The developed elements of the renovation packages will be tested and produced for showcasing. The newly developed renovation packages will be produced and mounted as showcases in different NSR countries. However, the production will still be done in a conventional manufacturing process. The construction of the smart factory itself is not part of the project.

To design the blueprint for a Smart factory suitable for manufacturing renovation packages for renovation towards energy-neutral, the following steps have been identified:

- A selection of a maximum of three renovation packages has to be identified. These three renovation packages have to be suitable for all partner countries.
- Based on the chosen packages the concept process of automating the manufacture of the renovation packages for façade and roof components has to be developed. Therefore, suitable automation tools, e.g. robots, conveyor belts, drilling tools etc. have to be designed and/or selected. The automated production process of the renovation packages has to include factory lay-out, logistics, production data management, installation, building information management and simulations.
- Based on the designed processes, a Virtual Reality model (VR model) will be developed. This quiet new method of virtualization is chosen to present the projects' results not only to the scientific audience but also to a wider range of target group like potential house owners or investors.
- The developed renovation packages will be produced as prototypes for testing. After testing, the renovation packages will be produced for showcasing. In selected partner countries, a real retrofit of an existing house will be implemented.

## 5. First results

For developing wall and roof elements, the structure of the elements and the materials to be used has to be determined. Four types of composing elements were considered as a starting point: Timber frame structure (TF), metal frame structure (MF), structured sandwich panel (SSP) and structural insulation panel system (SIPS). After a short description of the potential structure of the roof and wall elements, the evaluation and decision process of the choice of structure is depicted.

### 5.1. Overview on structures of wall and roof elements

The four structures to be compared base on different construction methods and materials.

- Timber frame structure (TF): Wood framing, in construction, is the fitting together of pieces of wood and sheets to give a structure support and shape. Modern light-frame timber structures gain strength from rigid panels (plywood and other plywood-like composites such as oriented strand board (OSB) used for parts of wall sections). In between the gaps joists insulation like glass- or mineral wool is placed. To meet stringent insulation demands, like for example in the Nordic countries, an additional insulation layer made from expanded polystyrene foam (EPS) can be placed on one side of the element. On this, the outer cladding is applied. A ventilation gap is needed to keep the timber and insulation dry. [2]
- The metal frame structure (MF): The main structural components of light metal or steel framing are made of galvanised cold formed steel sections. These can be prefabricated into panels or modules. In between these metal frame sections insulation like glass- or mineral wool is placed. On an additional insulation layer on the outer side, the outer cladding can be applied. Depending on the insulation that is used, a ventilation gap could be needed. [3]
- The structured sandwich panel (SSP): SSP, like structural insulation panel systems (SIPS), are used in the construction industry. [4] The SSP is a sandwich structured composite which consists of an EPS insulation and an OSB sheeting positioned between two layers of fibreglass. The OSB serves as a mechanical attachment layer to provide fastening opportunities. These layers form a light but very strong panel. Like in the other panels, an outside cladding is possible.
- The structural insulation panel system (SIPS): SIPS, like SSP, is a sandwich structured composite. It usually consists of an insulation layer of rigid core glued between two OSB

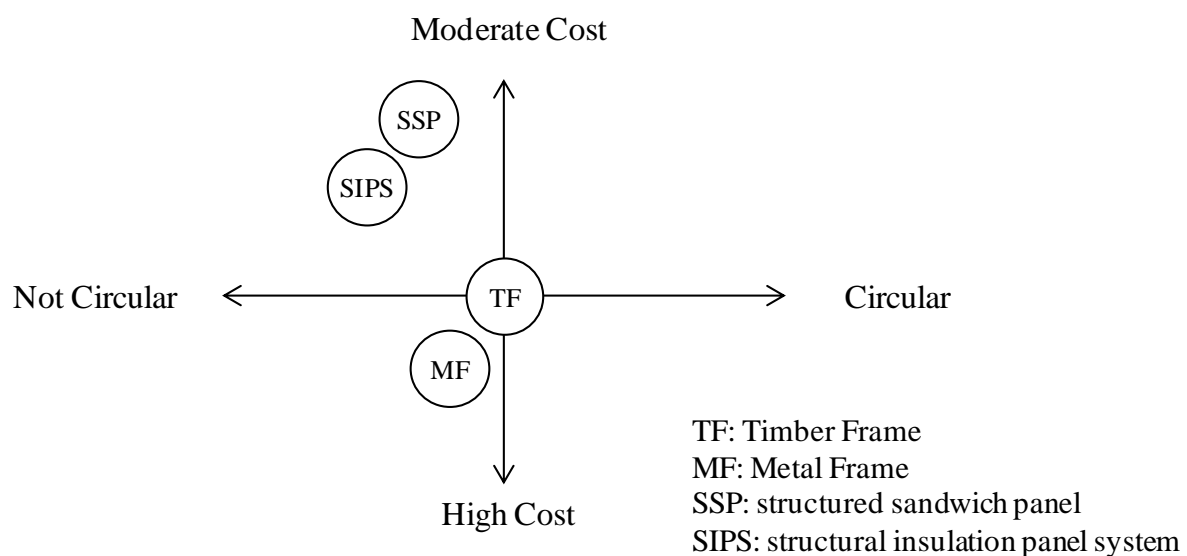
panels. The core insulation might be expanded polystyrene foam (EPS), extruded polystyrene foam (XPS) or polyurethane foam (PUR).

### 5.2. Assessment

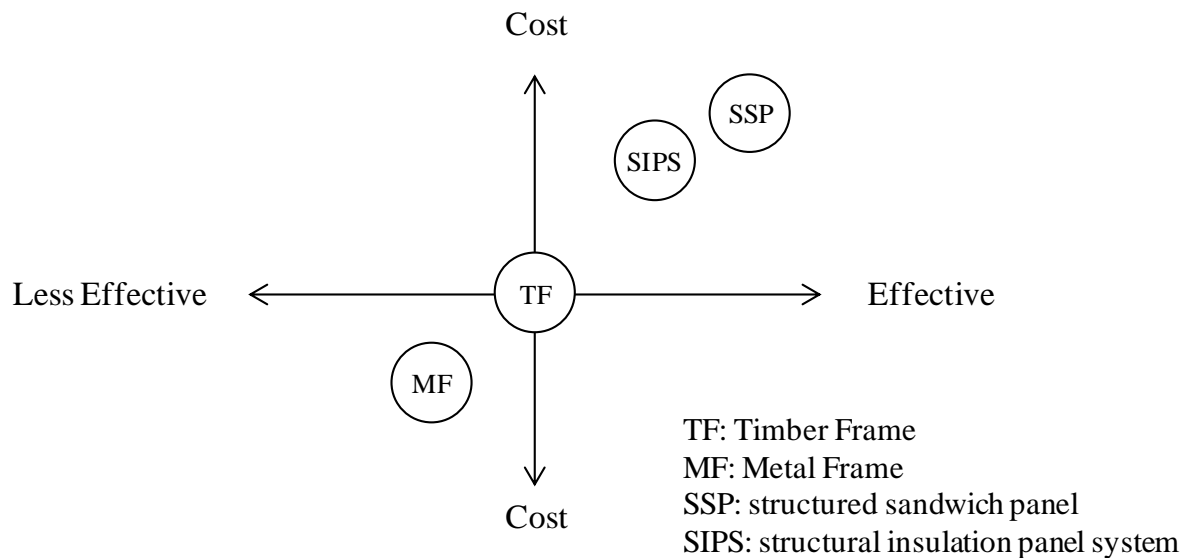
The methodology used to prioritize the kinds of structure of the wall and roof elements to be further developed in the project based on a semi-structured decision process in three expert groups. For the assessment of different structures and materials each group of experts had to assess the design of the structures timber frame (TF), metal frame (MF), structured sandwich panel (SSP) and structural insulation panel systems (SIPS) on the following predefined criteria:

- **Costs:** The concept of total cost of ownership (TCO) is used for the assessment of each technology. Total cost of ownership do not only consider the purchasing price of a product. Moreover, all direct and indirect costs involved in buying and using a product over its life time are counted in to help buyers and owners decide on different alternatives. [5]
- **Circularity:** The renovation packages to be developed in the project should be based on the principles of circular economy and optimized for low embodied energy. Circularity describes the sustainability of a product considering its whole live cycle. Circular building concepts and Cradle-to-Cradle frameworks imply radical changes for the construction sector and have to be considered. [6] [7]
- **Effectiveness:** Effectiveness describes the effort to make a good insulation panel with integrated technology like heating and ventilation. Characteristics like thermal insulation or thermal bridges, sensitivity to humidity, deformation or delamination have to be considered. The possibilities for upscaling automation the production process are also taken into account.

In a first step, the characteristics of the four structures with regard to costs and circularity were discussed, taking the timber frame structure as the starting point. The results were fixed on a two-dimensional coordinate system (see figure 1). Next, the characteristics of the four structures with regard to costs and effectiveness were assessed. The results again were fixed on a two-dimensional coordinate system (see figure 2). In order to finalize the assessment, the results were discussed in the peer group to aggregate the findings in a joint figure.



**Figure 1.** Assessment of structures – Circularity and Costs



**Figure 2.** Assessment of structures – Effectiveness and Costs

The positioning of the four structures in the coordinate system was a long and controversial process. Different points of view had to be balanced. To give a short overview, main arguments for each structure are depicted in the next section.

### 5.3. Discussion of main criteria

All structures and their advantages and disadvantages had to be evaluated and compared. Therefore, not only the as-is-situation has to be considered. Also potential future developments had to be discussed.

#### Timber frame structure (TF):

*Circularity:* A timber frame wall consists of different materials each with its own circularity. Main materials of the wall elements are: Timber frame, glass- or mineral wool insulation, oriented strand board (OSB), expanded polystyrene foam (EPS) insulation, damp barrier foils and the cladding. In theory each component could be separated and recycled on its own. However, actual wood frame constructions are difficult to disassemble as there is contamination due to adding spray foam in corners, adding glue to between panels or (chemically) treating materials to make them resilient. Although timber frame has a potential for a good circularity this treatment has a big negative impact on the recyclability of the used materials. Timber has a low carbon footprint and is renewable. Softwood species are fast growing and some are grown widely across (northern) Europe. Untreated softwood can be downcycled in wood based products or as fuel.

*Effectiveness:* Wood has relatively good thermal insulation values compared to other building materials. As the frame is self supporting, the choice of insulation can be tailored to the environmental situation. Softwood when exposed to humidity can deform and create air gaps. Thus frame and insulation need to be kept dry and ventilated to prevent sagging. Looking at the production process it is important to note that timber frames can also be prefabricated into panels or modules.

*Cost:* Timber is relatively expensive per volume. However, softwood is cheaper than hardwood, even when it is FSC certified.

#### Metal frame structure (MF):

*Circularity:* A metal frame wall consists of several different materials with their own circularity. Main materials of the wall elements are: Steel frame, glass- or mineral wool insulation, chipboard (OSB),

EPS insulation, damp barrier foils and the cladding. Like wood frame constructions, these are difficult to disassemble due to the addition of spray foam or glue. Raw materials are non-renewable. The production of steel has a high carbon footprint. It requires a lot of energy and material and releases CO<sub>2</sub> during the process. Still, steel is quite easy to recycle. Steel frames even have a possibility to be re-used.

*Effectiveness:* Because of the ‘c shape’ of the metal frame, insulation is held in place very well and hardly any sagging occurs. As the frame is self supporting, the choice of insulation can be tailored to the environmental situation. However, there is a big risk of air gaps where the insulation does not fill up the frame correctly. Metal itself has very bad thermal insulation values. There is a very high chance for thermal bridges. Thus, an additional layer of insulation is needed to dampen this effect.

*Cost:* Metal frames themselves are quite expensive to produce.

Sandwich panels (SSP):

*Circularity:* As the structured sandwich panel (SSP) and the structural insulation panel system (SIPS) are sandwich composed panels, an end-of-life recycling and reuse is difficult. Although some components might be easy to reuse, most components are glued together. Thus, separating materials is difficult and labour intensive.

The virgin raw materials for the production of OSB have a low carbon footprint. FSB certified OSB is available. Raw materials can contain recycled woods like chipped construction wood. However, OSB needs high heat and pressure to be produced, just like plywood, particleboard and MDF. The reuse of OSB is difficult due to its relatively low durability. Recycling of OSB is difficult as well. OSB waste is usually incinerated and used for energy. Moreover there are limited possibilities for downcycling (e.g. downcycled boards).

*Effectiveness:* The main advantage of SSP modules compared to SIPS modules is the size and thus the handling possibilities. SSP walls and roofs usually consist of one or two large panels (up to 15m). This minimises the mounting effort and thus the construction time at the construction site. Moreover, this minimises joints which minimises air penetration. Because of the EPS foam which is an integral part of the wall (less gaps) the insulation core and raw insulation values are good. As SSP panels have very few internal structures, the insulation value is very homogenous and thermal bridges are eliminated. The production process can easily be automated due to the structure of the panels.

*Cost:* OSB, used in both sandwich structures, is less expensive than plywood and similar fibre/composite boards.

Structural Insulation Panel Systems (SIPS):

*Effectiveness:* SIPS walls and roofs usually consist of multiple smaller standard size panels. Linking these requires the mounting of timber beams in the wall which is an additional time consuming process at the construction site. Moreover, this diminishes the R value locally. One particular weakness of these SIPS panels is air penetration at joints or penetrations. Still, due to the hard foam insulation core, raw insulation values tend to be good.

*Cost:* OSB, used in both sandwich structures, is less expensive than plywood and similar fibre/composite boards. Looking at the insulation core of the SIPS module, costs for EPS are low. Other materials like extruded polystyrene foam (XPS) or polyisocyanurate foam (PIR) or polyurethane foam (PUR) are more expensive. The production process can be automated.

To conclude, the sandwich structures result to be more promising when developing a smart factory with the aim of reducing the cost of retrofitting houses on a large scale. The assessment of the effectiveness shows that the SSP modules even outmatch the SIPS modules. First, SSP is cheapest due to the use of EPS and OSB, both cheaper as other components in the SIPS module. Second, the SSP production process is less complex as less components and materials have to be handled. This results in a reduced construction time and costs. A further argument is the possible size of the SSP modules which can lead to a minimised mounting effort and thus a reduced construction time at the



construction site. However, the circularity of the sandwich panels is not assessed that good compared to the timber and metal frame structures. To reduce the effort of separating materials and thus to improve circularity, the connection between different layers and alternatives for the OSB and EPS will be investigated in the next steps. Future developments and solutions could be found in debondable or environmentally friendly glue or mechanical connections like click systems.

## 6. Future Outlook

The next decision will deal with the selection of the house types to be renovated. Depending on the house type, the renovation packages and the wall and roof elements as well as their production process in the smart factory have to be designed.

For each partner country (Netherlands, Belgium, Germany, the UK, Sweden and Norway) the housing stock regarding existing house types (e.g. detached house, demi detached house or terraced house) has to be analyzed. The challenge of this step lies in the differences in the types of residence in all the different countries. Moreover, different roof types for each type of residence have to be considered. In the end, three house types have to be identified which are of interest for all partner countries.

Following these basic decisions on module structure and type of residence and roof, the production processes for these modules have to be identified, analyzed and optimized for a smart mass production of modules for retrofitting houses in the North Sea Region.

## 7. Conclusion

The aim of this transnational approach is different to current regionally centered projects in the retrofitting sector of existing houses. The practical implication lies in the development of a blueprint for a smart factory which is able to produce house elements on a large scale. Up to now, high-volume solutions for renovations towards energy-neutral are still not available. In order to ensure the right choice of module structure this paper describes the research implication of the step of assessing different common types of walls and roofs. Based on this decision as well as the choice of the type of residence to be considered, the next steps of developing the smart factory will follow. Here, the automatization process, robotics and logistical aspects will be focused.

## Acknowledgments

This paper contains results from the INDU-ZERO project, which is co-funded by the European Commission in the Interreg North Sea Region Programme 2014-2020 under grant agreement no. No.: 38-2-10-18; Date: 15/01/2019.

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