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Multifunctional building skin for ultra-low energy construction of residential properties and inside refurbishments of terraced houses

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An integral concept for industrialized manufacturing of residential properties is developed over the past years. The primary principle of the system is the building skin; here structure and a high level of insulation are merged into an ultra lightweight wall without thermal bridges. This composition is pointed to enable industrial manufacturing. The holistic concept is based on the SmartBuilding (Slimbouwen®) principles. An important aspect of SmartBuilding is a strict separation of services and structure to facilitate a simple process in construction (to save time and to improve quality) and flexibility to facilitate future changes.

The integral, modular and lightweight features of this system make the walls very appropriate for industrial building of new dwellings. Yet the same principle is also well applicable for inside refurbishments of badly insulated houses (pre-war terraced houses) by replacing the inner cavity wall of masonry by this integrated structure and insulation. In particular the ultra lightweight feature in combination with the high load-bearing capacity makes this method so well practicable. Yet, the main advantage of indoor upgrading is that this does not affects the streetscape of appreciated neighbourhoods as outdoor upgrading often ends up in drastic urban renewal, as well as retains the social coherence of a neighbourhood.

This paper describes the main features of the new wall system and indicates possibilities for inside refurbishments of badly insulated terraced houses.

Keywords: renewal, SmartBuilding, integral building, industrialization
1. Introduction

In the Netherlands there are approximately 1,323,000 terraced houses built in the period 1945-1974, this is about 19% of the total housing units in the Netherlands (BZK, 2013). Figure 1 shows a typical residential area with terraced houses. These houses are often built in large series and were constructed to rapidly solve the housing shortage after World War II. Today, these houses no longer meet the demands and wishes of the occupiers in technical respect due to lacking insulation, bad acoustical performances, draughty connections of windows and walls, et cetera. Until 1974 building industry did not pay attention to energy saving. But also expectations regarding comfort did grow fast since these houses were built. About 30% of the terraced houses are owner-occupiers, 70% is rented, mainly from large housing corporations (BZK, 2013). Private property of terraced houses is extremely difficult to upgrade to a high insulation level, since this affects the appearance of a part of a block. Upgrading should be organised by a whole block, yet not everybody has the abilities to participate and what’s more, different owners have different needs, so it is hard to agree with all owners of a block. Large-scale renovation of corporate-owned houses is also complex, since people have (to be forced) to move to temporary housing, which has a large effect on the cohesion of a neighbourhood.

![Figure 1. Typical view of a residential area with terraced houses in the Netherlands](image)

1.1 Characteristic of terraced houses built in 1945-1974

Most of the terraced houses built from 1945-1974 have a masonry structure, while some are constructed by concrete walls with a façade made of brickwork (sometimes with large timber window elements). In both cases there is only a very small cavity in between the outer and the inner wall of some 20-30 mm (mainly meant for ventilation of penetrated rain through the outer wall). So there is little space to apply insulation material in the cavity. Adding an insulation layer of about 100-150 mm on the inside is difficult, since the interior of these houses is already quite small for today’s demands. And lacking a proper insulation layer leads up to high living expenses, since these houses consume a lot of energy. It is expected that living expenses of these urban neighbourhoods will be governed in several years by the energy bill instead of monthly rent. This will have huge impact on the affordability, and thereby problems caused by unoccupied houses. This implicates also a large risk for housing corporations.
Figure 2. Distribution of houses by date of construction in the Netherlands (BZK, 2013). 26% of the total (of 7.27 million houses) are built in the period 1945-1970.

1.2 Strategies to upgrade

The average numbers of demolitions of houses in the Netherlands varies from 10.122 to 19.057 over the last 7 years, with the average 13.932 (BZK, 2013). With this number one can calculate that it takes about 100 years to rebuild this category of housing stock. So demolition won’t solve the problem, even not when a drastic change in demolition and rebuilding is realised. Other, additional, actions are highly required.

Figure 3. Large-scale renovation has a large impact on the environment but also on the cohesion of a neighbourhood

In contrary to the technical state of these houses it is found that residents of terraced houses are in general very satisfied with the own living environment (WoOn, 2012). This research shows that they appreciate the amenities in the neighbourhood such as shopping facilities, playing opportunities for children, public transport, schools, green areas, et cetera (WoOn, 2012). Also the local infrastructure is often in a good condition and still meets modern needs. Drastic upgrading, renovations or replacements with new construction has a large impact of these neighbourhoods regarding the social coherence and should be strongly discouraged from sustainability viewpoint.
2. Lightweight building method to enable inside renovation.

Over more than a decade a lightweight system is developed that was inspired by a simple structural principle shown in Magaseat (Figure 5), a stool designed by Jeremiah Tesolin, (Tesolin, 2005). The structure of this seat consists of magazines folded and combined in a special way to create a small stool. The designer used this as “a comment on how there’s hidden strength and beauty in everyday things” (Tesolin, 2005).

Figure 5. inspiration for a lightweight structure: Paper that is floppy in a separate magazine becomes very rigid when combined in a proper way (Tesolin, 2005)

A derived composition of this principle is used for a load bearing wall where l-shaped studs are supported by thin sheets (made of 3 mm hardboard) that become very rigid when these thin sheets are forced to stay in plane by rigid insulation (EPS, expanded polystyrene, is used) as can be seen in figure 6. Based on this simple principle a method for house building is developed, with a special focus on full industrial production.
Figure 6. Principle of lightweight wall: I-shaped studs, supported by thin sheets, forced to stay in plane by rigid insulation. The double I is meant to simplify connections.

In the last decade extensive research has been performed regarding this type of wall in particular on practical use, and on acoustical, thermal, structural and economical feasibilities. Also some demonstration projects have been realized. The prototypes, and the laboratory and numerical tests are performed by many students of various tracks of the Department of the Built Environment of Eindhoven University of Technology as part of their study. In the next paragraphs the main points regarding these experiments and findings are sketched out.

2.1 Tailored to industrial production

Full industrial production implies that walls can be mass-produced, at least in large-scale components, for buildings without knowing the specific circumstances and shapes of its final use during production. Figure 7 shows the principle, indicating a pre-defined plan that is build up by a small number of standard widths. In this figure there are only two special pieces required to produce a large wall with the exact pre-defined location of the windows. Since sizes and composition of all parts of this wall are standardized, this implies that mass-production is possible, with different widths available from stock, and already produced unknown of specific project-requires.

This principle is further developed with this specific boundary condition to facilitate nearly all current layouts and appearances of housing by this new industrial building method: enabling to design a house without restrictions of a building method.

Figure 7. Industrial principle. Basic elements are symmetrical, to use leftover parts.
2.2 Structural concept

The structural concept is based on studs supported by thin sheets, shown in Figure 6. Full-scale laboratory tests [Tan, 2002; Moonen, 2004 and Seijkens, 2008] prove validity of this concept regarding buckling. With a deadweight of a structural wall element of just 17 kg/m² the average failure load was a spectacular 705,1 kN (~320 kN/m², with sample standard deviation of 7,4%). Also unpublished laboratory research on the shear resistance of the lightweight walls in 2012 showed an adequate stability performance.

2.3 Wall panels without vapour barrier

A study regarding the internal and external moisture exposure of the lightweight wall showed that the structure doesn’t depend on vapour barriers in avoiding internal condensation. In fact, a vapour barrier is not wanted because it can be harmful in a summer-situation when air-conditioners create a cold indoor climate. Computer simulations have lead to a suitable set-up with several layers of different kind of insulation materials to enable the leaving out of a vapour barrier (Schellens, 2004).

2.4 Acoustical performance

Figure 6 shows different graphs of the lightweight wall with and without plaster boarding and/or mineral wool compared to the required value of a partition wall in between two dwellings. This graph shows that one partition wall with mineral wool and 20 mm plaster board almost meets the required values. So some additional development and laboratory research is required, but one may conclude that it will be possible to meet these high requirements by some minor changes/additions to the current composition.

Figure 8. Laboratory results regarding acoustical performances of different kind of finishing applied to the lightweight wall

2.5 SmartBuilding principle

The lightweight wall is developed based on Slimbouwen® (SmartBuilding) principles (Lichtenberg, 2005). An important aspect of SmartBuilding is a strict separation of services and structure to facilitate a simple process in construction. In traditional building processes construction and services are mingled which leads to inefficient procedures. The SmartBuilding principle aims to construct the shell of a building independent of services. Next services are applied as separate activity. After that, finishing is applied. Since activities of different subcontractors no longer interact with work of others, time can be saved, and
what is more: quality may be improved. However the most important reason for a clear separation of structure and services is that this may result in flexibility to facilitate future changes.

Figure 9. The composition of the lightweight wall enables services to be applied after the walls are mounted on site, independent from other construction work.

3. Inside upgrading of terraced houses enabling a “one by one” approach

Upgrading insulation from the inside out, keeps the appearance of a detached block unchanged, so a decision to upgrade can be made on individual choices. Also all activities are performed at the inside, so there is no need to gear this to a timeline to upgrade adjacent houses.

Figure 10. Principle of inside upgrading of insulation, leaving the appearance intact.

3.1 Using lightweight walls as structural inner wall with integrated insulation

The lightweight wall, described in the previous chapter, is strong and rigid enough to take over the load-bearing function of an inner wall in a masonry structure. According to earlier design calculations the required load in a three storey house with concrete floors is some 60–80 kN/m² (Moonen, 2005), so with the average load of 320 kN/m² as found in the laboratory test (Seijkens, 2008), there is enough capacity to take over the bearing function of the inner wall.

Since the insulation is integrated in the structural wall, the lightweight wall needs no more area to improve the thermal insulation. Especially since detached houses are already quite small, this is an important feature.

An additional advantage is that the new inner wall is ultra lightweight. With only 17 kg/m² it will be easy to bring the new wall elements into the houses. And because of the double I-shaped stud, connecting two wall parts is quite easy to perform on site.
Although many research topics have yet to be performed, the prospects of developing an adequate method for upgrading detached houses, situated in a complex urban and social environment are quite promising. This also shows potential in regard of sustainable improvements to prevent demolition of valuable neighbourhoods. In the next paragraphs some additional advantages are described to make more use of the lightweight feature of the wall.

### 3.2 Possibilities to enlarge the usable area

Detached houses from the considered building period were built with a different family situation compared to today’s demands. In early days with large families there was a need for a large kitchen area, while today’s habitants request to have a larger living. Since the lightweight walls are also applicable for inner walls and since the dead load of the wall is very moderate, the layout of a traditional small dwelling can be approved at the same time while upgrading the technical performance of a house.
3.2 Adapting to an urban need to have more apartments for single occupation

Because of shifting family situations in the Netherlands the demand side from the housing market differs from the supply side. As an example, the demand for single occupied apartments increases while the demand for family houses decreases (BZK, 2013). So with the lightweight property of the wall in mind, one can consider completely other layouts to transform a family house into an apartment for other users.

![Figure 13. Complete other layouts are possible to gear traditional buildings to apartments for single occupation.](image)

3.3 Improving facilities in a neighbourhood, f.i. parking, playing ground etc.

Although many residents appreciate the neighbourhood where detached house are located, there are yet facilities that can be improved by the special features of this way of upgrading. One is for instance a lack of parking facilities that many districts face. In the period that these districts were designed, the number of cars was much lower than today. For new building sites the requirements for parking places are in the order of 0.6 - 1.3 parking places per family house in urban environments (Den Haag, 2011). In the enquiry regarding the satisfaction of the own living environment (WoOn, 2012), is found that a lack of parking places is one of the arguments that residents don’t like.

![Figure 14. Insufficient parking facilities in urban neighbourhoods](image)

Since 70% of the detached houses are rent from a housing corporation (BZK, 2013) and a housing corporation has a commercial interest in keeping a livable district, the corporations have opportunities to
create new plans and new urban arrangements. Figure 15 shows such an application where 4 houses in a detached block have a new lay-out, enabling the former back garden to be transformed in a public space. This public space may be used for extra parking lots, a new playing ground for children or a green area.

![Figure 15](image1.png)

Figure 15. Changing the layout of specific houses can create extra public spaces to be used for additional parking, playgrounds or green areas.

Building with lightweight systems also offers completely other possibilities, as shown in Figure 16, where a new plan is drawn for the head of a block. This is rather simple with a lightweight building system, since the existing footings can be used and the existing infra structure can stay intact. By designing new heads of blocks a neighbourhood can be upgraded to obtain a new appearance. Also extra functions such as accommodation to enable elderly care close to their familiar surroundings or a small care centre are possible to improve the livability of a neighbourhood.

![Figure 16](image2.png)

Figure 16. The looks of a detached block (same as figure 15) can be transformed by rebuilding specific houses. A lightweight system enables a drastically change of a layout that is still build upon the existing footing and uses the existing infra structure.

4. Conclusion

There are still many detached houses built in a period where there was hardly any interest in energy saving. These houses are difficult to upgrade because of the complex situation. Renovation of individual owned houses is complicated due to different needs and possibilities of adjacent owners. Also upgrading of corporation-owned houses is not simple at all, since residents are difficult to move to temporarily housing. And large scale demolition has a negative impact on the social coherence of a neighbourhood.

The situation is complex for Dutch housing corporations since they possess more than 750,000 of these moderately insulated terraced houses (built in 1945-1974). To prevent that monthly cost for energy exceeds the monthly rent, it is necessary to upgrade thermal performances. However, if the current speed of demolitions is unchanged, rebuilding takes up to 100 years to upgrade all of these houses.
So additional to demolition (more desirable: as alternative for demolition) a new method is researched to improve the insulation layer from the inside of a house. Here an additional layer is a hardly satisfactory solution because these houses are already small; reducing the inner area (with 100-150 mm of insulation per side) leave little use for the remaining rooms. To develop an adequate solution to upgrade from the inside (without reducing the inner usable area) needs extensive research. The main principle for inside upgrading will be based on ultra lightweight wall elements: this research will be built on earlier research performed in the last decade. This system was initially developed to make industrially produced houses, yet this seems also applicable for renovations. The main advantage is that insulation is integrated in the structure, so by replacing the inner wall a well insulated facade is obtained without loss of usable floor area. Upgrading from the inside out also enables a “one by one” approach, since it keeps the appearance of a detached block unchanged. The main advantage is that a decision to upgrade can be made on an individual choice for a specific house. All activities are performed at the inside, so there is no need to gear this to a timeline to upgrade adjacent houses.

Another advantage of inside renovation with ultra lightweight elements is that construction is simple because elements can to be carried in by hand (weight is just 17 kg/m$^2$). Further benefits are possibilities to improve a neighbourhood by changing the layout of houses, for instance by gearing the type of houses to new demands of residents or by creating extra parking facilities, new playgrounds or additional green areas.

5. References


