Developing an airy timber frame wall

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Abstract
An integral building concept is developed based on industrial produced, lightweight, load-bearing wall panels. The leading idea is to apply I-shaped studs combining structural solidity, thermal comfort, integrated piping and simple lightweight assembly. The I-shaped stud mainly consists of two fir laths 30x46 mm^2 at intervals of 400 mm. Combined with hardboard and insulation makes a solid wall with impressive buckling loads (full-scale laboratory tests found an average axial load of 176 kN/m' at buckling length 2.8 meter although the total dead weight is just 0.45 kN ~ 7.1 kg/m^2). The composite load-bearing wall consists of approximately 3-5% solid substance and 95-97% stationary air and yet it seems to be suitable for a 3-story dwelling even when applying massive concrete floors.
Since the composition of the wall panel is based on using durable materials and allows for full industrially manufacturing the integral building concept is meant to be preparatory for future house building.

Keywords
integral building concept, load-bearing walls, industrial building, light-weight house-building method

1. Introduction

This paper provides an overall view of research carried out to develop a lightweight building method. This method of house building is based on full industrially produced, load bearing wall panels. All described tests form a part of an extensive research programme including amongst others practical, acoustical, thermal, structural and economical considerations. Several students of various departments of the Faculty Architecture, Building and Planning of Eindhoven University of Technology have carried out studies and experiments in recent years. Acquired knowledge by the student-work will furthermore develop this house building method.

1.1 Background

Initial research started in 1995 as PhD-study about developing an integral building concept, based on full industrially produced lightweight wall panels. Full industrially production implies that a manufacturer can mass-produce components of a building *without* knowing specific circumstances and shapes of final use. Full industrially production will likely give a huge boost to building in improving quality and costs. But only if possibilities to vary housing remain unchanged since free architecture is one of the most important typifications of building. To retain good architecture in housing a boundary condition is adapted that is to facilitate nearly all current layouts and appearances of housing by this new industrial building method.
Furthermore the study will integrate contemporary technical subjects and possibilities like logistics, care of environmental consciousness, new transport and hoist possibilities, increasing demands of quality, decreasing number of skilled labourers, inevitability to improve working condition on site, improvements in communication and exchange of electronic documents, computer aided design and manufacturing, etc.
In the first year of the study a suitable wall panel was tested (in laboratory), feasible details were developed (for openings, supports, finishing, stability, etc) and practical applicability was checked (in pilot projects shown in figure 3). But then these practical projects changed the entire PhD-study. Not because pilots failed, but because practice clearly revealed that one cannot utilize advantages of accurate large-scale building parts if the foundation does not provide equal accuracy. Since this accuracy cannot be put into practice by known foundation methods, the focus of the PhD-study was completely turned to developing an accurate foundation method (described in a separate paper). The study regarding accurate foundation was finished in 2001 [Moonen, 2001]. Nevertheless developing the house-building method is continued all the time in ongoing educational projects, with research carried out by successive graduate students of different departments of the Faculty of Architecture, Building and Planning. The complex system is nowadays subdivided in different parts primary based on educational challenging. This makes developing the building system a fascinating ongoing movement, however with rather small progress.

2. Minimal wastage

The aim is to develop industrial parts for house building. Since INDUSTRIAL implies mass-production, *available from stock*, unknown of specific project-requires (whereas PREFABRICATION implies specific production elsewhere, *made to order*) some waste seems to be unavoidable when making a pre-defined plan. Figure 1 shows three schemes for assembling façades out of standard panels with regard to left over material. The sketch on the left refers to timber frame building with prefabricated elements of floor height (platform construction). This method is advantageous when prefabricated, but projected on panels of standard width there can be up to 30% waste direct after production. Dark areas in the sketch (in corners and for openings) indicate wastage when this façade is cut out of base elements. An industrial building system that goes by this sketch is called SIP's (Structural Insulated Panels). This system uses industrially produced elements made of two large OSB sheets with rigid insulation glued in between. A high percentage of residues when using SIP's confirms that this scheme is not consistent with the basic principle in our research regarding care of environmental consciousness. Another reason to minimize residues is that produced quantity is only partly utilised, making this scheme relatively expensive.

Figure 1: Feasible set-ups for full industrially produced walls. Set-up right is adopted in this study.

The sketch in the middle reduces waste direct after production by using smaller panels. Yet in return problems of connecting and of stability are replied. This scheme is highly applicable for solid panels (as known for sand-lime elements) but is hardly suitable for lightweight wall with segmented structural parts. The sketch on the right in figure 1 is based on using vertical panels showing a façade out of panels with different widths. Further study show very little wastage if required panels are cut out of a continuous industrially produced strip since the part that is left over after cutting can be likely used in the opposite façade. Proportions of assembled components to make a façade are not influence by floors. This decision is made because disadvantages of making rather difficult connections of floor and wall are considered less momentous than advantages of fast construction on site. The overall idea is to have extended standard strips available from stock in different widths (400-800-1200-2000 mm). Also a small massive panel is available that can be cut in longitudinal as well as transverse direction to any size. These specific filling elements can be positioned in between panels enabling any required dimension to follow a predefined plan. The width of a filling element is always smaller than 400 mm (because after that an element of standard width is applied). If project requirements are received all panels will be cut to length, assembled to tailor-made components including windows et cetera, transported to site and simple put together. Transport possibilities mainly determine proportions of components that together form a façade.

2. Structural concept

The structural concept is based on studs supported by thin sheets. The photo on the left in figure 2 shows the initial horizontal cross-section of a lightweight wall with studs mainly loaded by axial compression. In both compositions of figure 2 all studs are forced to buckle in the strongest direction (lateral torsional buckling out-of-plane of the wall) since four thin sheets of 3 mm hardboard obstruct buckling in the weakest direction (in-plane of the wall). Thin hardboard can easily raise the required resistance when glued to rigid insulation (here expanded polystyrene) so folding of hardboard is obstructed. In the photo on the left in figure 2 hardboard sheets are connected to studs by means of longitudinal saw-cuts. Full-scale laboratory tests [Moonen, 2002] prove validity of this concept regarding buckling. With a deadweight of an element of just 7.1 kg/m^2, and a considerable buckling length of 2.8 meter, the average failure load under axial compression is 486.7 kN. This load can be compared for reference to the dead weight of a concrete block of 2.7 x 2.7 x 2.7 m^3 supported by 5 small fir laths of 2.8 meter.

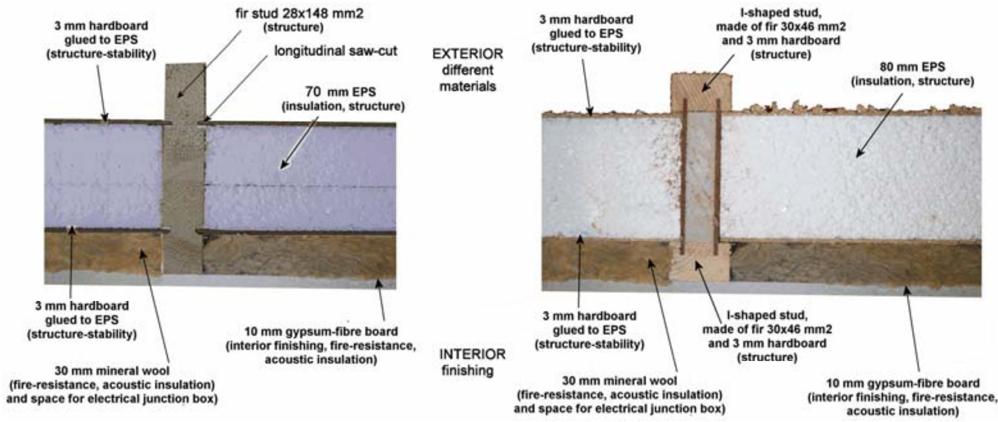

Figure 2: Left: initial cross-section, right: improved cross-section of lightweight panel.

But laboratory tests also revealed that buckling depends on accuracy of production. If a distance between two horizontal saw-cuts on one site of a stud is too narrow insulation is squeeze together. This may reduce buckling support because a sheet can come loose from insulation in the middle of two studs. The same can appear if two saw-cuts are too wide ripping hardboard apart from insulation nearby a stud. Therefore an improved cross-section is developed, shown right in figure 2. The structural principle is unchanged since the I-shaped stud is again forced to buckle in the strongest direction. And in addition the composition has a more constant thermal resistance and also increases the percentage of immobile air.

The improved cross-section is also structurally tested in laboratory [Moonen, 2004] in a full-scale wall with buckling length 2.8 meter. The average failure load is 176 kN/m'. These laboratory results give good prospects when compared to a required load of 60–80 kN/m' in a three storey house with concrete floors. The next structural test to be carried out will be shear test (regarding stability).

3. Details in "airy" wall panels by practical experience

Developing airy panels makes no sense if panels at the end cannot be used in real details. Therefore two trial-projects are realised in an early stage. Various details are tested by practical experience for instance in a workplace (4 photos left in figure 3) with partly a flat roof and also a pitched roof. A laboratory building (2 photos right in figure 3) is mainly set up to study construction with large panels.

Figure 3: Practical projects to study details of walls with just 5% of vast material in real practice.

4. Wall panels without vapour barrier

Students of the department of building physics have studied internal and external moisture exposure to develop a wall that doesn't depend on vapour barriers in avoiding internal condensation. 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 are used to gear composition and materials to one another until a suitable set-up without vapour barrier is found (left in figure 2, section in between two studs). Simulating sections over rectangular studs showed that condensation does not occur if 50 mm additional insulation is added at the inner side of the outer cavity [Moonen, 2004]. In future the improved cross-section will be considered.

5. Supports for heavy loading

Another student's research is to test heavy loaded connections (figure 4). The idea is to have vertical load applied on an extended steel strip (photo in the middle). The strip is welded to an U-shaped part of a steel member that embraces a wooden stud. Because of this lateral support the wooden stud cannot split at early load. Yet compression of wood particles underneath bolds determines ultimate loading. Even with little solid material in the I-shaped stud (left in figure 4) an ultimate force of 30 kN is reached. The graph shows plastic behaviour that forced us to stop the test. There is still a lot of additional research required to make this support into a practical bearing, but these preliminary results show great promise.

6. Acoustical performances

Another preliminary test regards acoustics. A panel of 1.23x1.48 m^2 that consisted of three I-shaped studs (figure 2) with interior finishing (gypsum fibreboard) and mineral wool in between fir laths is tested in a standard set-up in our acoustical laboratory. The acoustical insulation measured [Moonen, 2004] corresponds to insulation of a double glazed windowpane of fair quality. Acoustical specialists have suggested improvements so it is expected that the composition of the wall (figure 2) will once more alter.

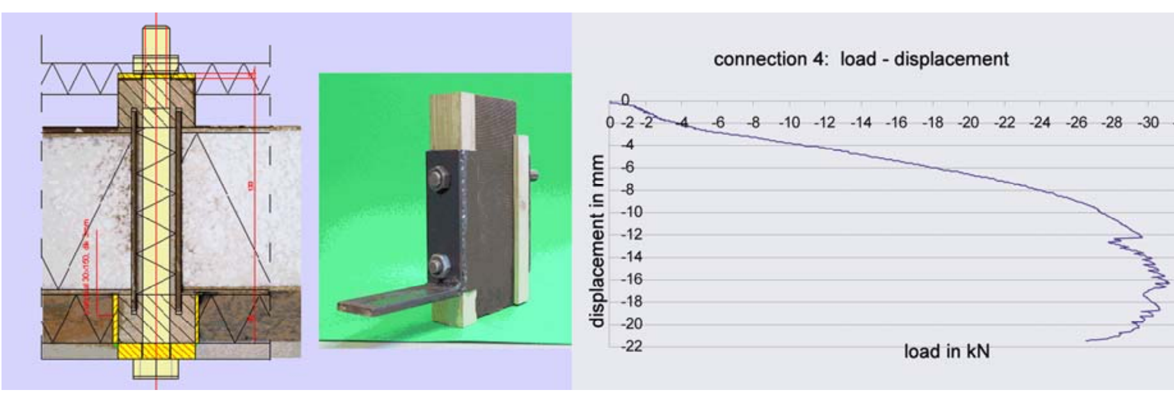

Figure 4: Concept of connection to transfer heavy loads in the small studs of the wall panel.

7. Discussion and preliminary conclusions

Basics of a lightweight building method for housing are developed as ongoing research issues. The base component of the building method is a load-bearing wall with an overall contribution of solid material 3-5% leaving approximately 95-97% of the volume for immobile air and yet is able to resist heavy loading. This wall is for the most part composed out of fully industrial produced panels that are cut to length and assembled in ready-to-mount elements including windows, doors, et cetera. Small adaptable filling elements are developed that can be assimilated into these ready-to-mount elements. Two pilot projects and several revisions of existing housing plans confirm that this composition is appropriate for realising almost any pre-defined plan.

This paper shows that advanced insight by research often leads to modifications in composition and cross-section. At present the cross-section of the wall is reconsidered with a focus on outstanding acoustic performances. The impact is not known at this stage, but a renewed cross-section will probably strongly affects previous tests regarding structure, building physics or construction. Yet it is likely that this change puts most previous tests out of use so we will have to repeat most described tests in due time.

This paper summarises results so far. In our firm belief we are on the way to develop a practical building concept preparatory for future house building. And if not, the integral approach has already led up to many educational challenges for graduate students of various departments of the Faculty Architecture, Building and Planning of Eindhoven University of Technology.

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