Rapidly building with lightweight modules and a dry assembled foundation: used in a mock-up for home units made out of reclaimed materials

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Abstract

The current practice of house building is wasteful, not efficient and badly in need of a reset. Society is ready for a change towards eco-homes; yet industry stays traditional. A transition to a durable, industrial and flexible approach is required. To accomplish such, a system is developed combining industrial manufacturing as well as reusing waste materials from demolition. To demonstrate the potential of the building method, a mock-up for a hikers’ cabin is developed by students of Eindhoven University of Technology. The cabin is an accommodation for short-stay holidays, commissioned by SNK (organization of natural campsites). Cabins are constructed by two fully assembled modules with a lightweight structure based on inner doors (reclaimed from demolition), timbered (inside and outside also reclaimed materials from demolition) and with insulation obtained from reclaimed inlay elements of modular ceilings. Also many other materials (such as plumbing, wash-hand basins, toilet bowls, light switches, etc.) are reclaimed from buildings due for demolition. The result is two fully assembled modules that are extreme lightweight and stable. On site, modules are joined on a foundation which is assembled of dry elements (reclaimed from demolition). All activities on site (making a foundation, placing modules and connecting a cabin to all services) are thus tailored for a one-day-construction.

Keywords: reuse of demolition waste, industrialized building, sustainable design, lightweight system, integral design, multidisciplinary, demonstration project.
1 Introduction

Today’s traditional way of building new houses is in many means wasting, inefficient and complicated as Lichtenberg [1, 2] points with several indicators:
• 25% of all transport of goods is building related;
• building industry is responsible for 35% of the total waste production;
• 30% of building related waste comes from new buildings (packaging, surplus);
• efficiency of on-site labour is less than 40% (some research findings consider this even less than 20% [3]);
• making building materials accounts for 8–10% of the total energy consumption;
• 40% of all energy use (CO2-emission) can be influenced by building methods;
• traditional building requires 1000–1500 kg to realize 1 m² net floor surface;
• fail costs determine up to 10% of construction costs, with profits around 1-2%;
• building structure, hollow cores, voids, etc make up 25% of a building volume.

Even though the indicators are researched with data collected in the Netherlands, they might as well serve as eye-openers for many Western European countries.

1.1 The challenge

Conventions in the building sector make it hard to implement actions to address the indicators above. Yet, a change is necessary if we are to meet EU aims to cut CO2 emissions by 20% by 2020 [4]. To reduce emissions to 80–90% by 2050, it is even more essential to re-evaluate the way we build today [5, 6]. However, to jolt a sector awake that is established over centuries is not an easy thing to do.

Evidently, the next step is to re-view building and to re-consider approaches and re-create new. To realize this, new concepts have to be developed, and to be proven thoroughly by demonstrating full scale solutions to a large audience. To tackle most of the indicators mentioned, a new prosperous solution shall comply with at least three core values:
• industrialized building: off-site production requires innovative materials and arrangements preferably based on lightweight and rigidity. Using pre-produced parts makes building on-site, in the main, a simple and fast assembly activity. With industrialisation to a high degree overall transportation, waste, and costs are reduced while quality and efficiency are improved;
• flexibility/lifespan enduring concepts: lessons from the past show that requirements of buildings change over years, mainly owing the desire to increase the level of comfort. And what’s more the lifespan of a structure (50 years and more) and of services with wires and piping (10–20 years) differ a lot. A successful solution that is more resilient to future needs regarding changeability necessitates to have a strict separation of services from structure;
• reduction of environmental impact: to be achieved by reducing materials, volume, weights, energy, emissions, waste, transport, etc. Building systems have a huge effect on the environmental impact (considering preparation,
construction, and usage over years, as well as finally dismantlement). Also
energy consumption and CO₂-emission depends on the required transport, and
on construction and demolition waste.

1.2 An auspicious track

Almost two decades of research at Eindhoven University of Technology [7–9]
has led to a building method that is indeed able to comply with the core values
explained above. The components of this method are shown in Figure 1. Here,
some researched and proven technologies are combined to create a promising
panel that is strong yet lightweight. The composition is inspired by aircraft
structures, where elements are composed of very thin material. On the analogy of
this, a panel is developed with a thin skin to make it extremely lightweight as
well as rigid and robust. For comparison, the structural wall shown in Figure 1
makes an excellent insulation since it consists of approximately 3% solid
substance and 97% stationary air. This, combined with a weight of just 14 kg/m²,
plus the panel’s coherence, and the open area in between wooden laths (where
afterwards services can be located), makes this composition ideal for
prefabrication. This lightweight panel is adapted for stabilization as well as
structural load bearing. Various laboratory tests [9–16] found an average load
bearing capacity of 176 kN/m¹ (being the equivalent of a concrete block of
1 x 1 x 7 m³ on top of this slim wall [16]). This structural capability makes these
panels fit for buildings up to 3 stories high. The panels also enable a damp-open
structure as research shows that this composition does not need a vapour barrier
[17]. And research regarding acoustic performances shows that the panels are
able to provide ample sound proofing [18].

![Figure 1: Test piece of prior research with a thin skin, I-shaped studs supported
by ridged insulation.](image)

1.3 The lightweight panel composition evolved

A new project – a request for a sustainable hikers’ cabin – provided a challenge
to develop this technology into an environmentally friendly use within a
cradle-to-cradle production [19]. The initially construction of the cabin was
designed as a traditional timber frame, but by no means could this meet the
budget goal (as set in the feasibility study). The innovative breakthrough came
when the lightweight panel of Figure 1 was transformed into a solution made from waste materials reclaimed from demolition (Figure 2). Next a full-scale product (mock-up) was created in close cooperation with industry to express the possibilities of reusing materials and to clear the way for commercial production of hikers’ cabins.

Figure 2: Panel made of reclaimed materials.

Figure 3 show the mock-up of the hikers’ cabin at different places. All wood in the photo (for façade, floor and roof) and also what cannot be seen (for structure) originates from demolition and is in fact already been used some 40–100 years before in previous buildings. The timber is reclaimed from old beams and planks and processed by sawing to become as new. In addition we also incorporate inner doors from demolition into our structure because there is almost no second use for old inner doors. Furthermore, reclaimed wood is used in making furniture, kitchen, etc. The reclaimed wood from demolition is processed in such a sustainable way that the reclaimed wood is FSC-certified [20].

Besides wood, the bathroom interior, sink, toilet, light switches, sockets, etc. are reclaimed as well from demolished buildings. This project demonstrates that it is possible to reuse about 94 vol.-% of materials used earlier in buildings to create a building that everybody interprets as a brand-new building. And by making this mock-up we also could justify that it is possible to reduce costs by using merely materials from demolition (compared to a timber frame construction).
The hikers’ cabin

Making a hikers’ cabin started with an intensive students’ project, initiated by the Dutch association for hikers’ cabins (STN) and the Dutch coordinating organization of natural campsites (SNK) who contacted Eindhoven University of Technology (TU/e) [19]. Hikers’ cabins are meant for people travelling from cabin to cabin on foot or by bike. SNK wanted to have a more modern appearance of their outmoded log cabin as well as a pronounced expression of durability. Therefore SNK asked for a design with a strong recognizable shape, a pronounced durable appearance and of course at little expenses. For this program the students’ design team chose to create a pointy tent-like shape that everyone knows from campsites, with full off-site manufacturing and maximum use of reclaimed materials from demolition.

The design team was eager to develop a hikers’ cabin as an outstanding example of sustainable building. Selecting and using proper materials in a correct way has always been the focus of the team’s design, and this became even more important when the possibilities of reusing materials from demolitions were discovered. Especially when they choose to make old damaged inner doors (made of cardboard with a honeycomb structure in between) as the core of the building system. Interior doors from demolition have hardly no reusable value, because doors are almost always (slightly) damaged during demolition or transport. There is hardly any market for reuse of inner doors with a honeycomb core because recovering is laborious and new doors are cheap. Yet dumping is relatively expensive because of the large volume of the doors. A good utilization for reclaimed inner doors is found in supporting studs (or beams) inside a wall, roof and floor element. In this inner part of the structure also damaged doors can be reused. Figure 4 shows that using doors in this composition combines insulation, high load-bearing capacities and lightweight (approximately 36–43 kg/m²) [22].
Figure 2 (and Figure 4) shows a reclaimed inner door that is connected to studs on both sides (of I-shaped parts made of small reclaimed timber and hardboard). A side issue of this composition are the cavities at the inside as well as at the outside. A cavity can be useful, for instance to conceal pipes and services (for water supply, heating, electricity, etc.) at the inside of a floor, wall or roof. The part of the I-shaped stud can also be used as a batten to attach inside finishing (here we timbered this with scrap wood, sawn into planks).

Insulation is reclaimed from ceiling parts that are collected in large quantities in the demolition of offices. A ceiling part is often made of mineral wool and thus ideal as insulation material inside the elements.

After placing the insulation in the outside cavity the elements can be covered by hardboard sheets to make a smooth surface to apply a waterproof layer. The waterproof layer is one of the few materials where new material is used to guarantee water tightness. A wooden finishing of timber covers the waterproof layer for aesthetic reasons. For this, also reclaimed timber is used, however these planks are thermal modified to prolong the lifespan of these planks. And of course the outer finishing is made in such a way to optimize ventilation to lengthen the lifetime of timber.

2.1 Mock-up as a start

The mock-up that was build and exposed attracted many expressions of sympathy. Already its design was awarded with the Dutch Wood Challenge Awards 2011 [23]. The mock-up was also invited as a special item at the Dutch Design Week 2012 in Eindhoven [24] and was featured in a promotion film [25]. At the Dutch Design Week 3,500 visitors came to see the mock-up along with the exhibition about the process of development. Many visitors signed up to be kept informed about possibilities for a short stay in a hikers’ cabin.

In addition, RECRON the Dutch association of entrepreneurs in the Recreation market has embraced the concept for its thematic arrangements to offer special experiences. The “personal story” regarding the unique building
method merely made of demolition waste is a unique selling point according to RECRON. To emphasize this, every Trek-in house goes with an official certificate explaining where which part of the house is recycled from. This certificate makes each house unique, especially when the building materials originate from buildings that stood in the same region as it is being placed or if materials come from well-known buildings. A certificate provides information about the previous life of materials, the FSC-certificate, and other sustainable measures taken to make the public aware of feasible features of sustainability in everyday surroundings.

2.2 Creating a network of hikers’ cabins

The mock-up was well received with many visitors expressing interest for a short-stay. This gave rise to set up a manufacturing line resulting in already 8 cabins by somewhat more than one year. All cabins are in commercial use on different camping sites scattered over the Netherlands [26] as shown in Figure 5.

![Figure 5: Sites of commercial available hikers’ cabins, (reference date February 2014, source www.trekkershutten.nl/trekkershutten/terreinzoeker).](image)

2.3 Industrialized production

Making lightweight lodgings fits to industrial production, because details as well as lay-out and sections are designed with a central position for production and transport. Restricted sizes of transport led to a system with two modules where at the end the load-bed of a trailer accounts for dimensioning of the two modules.

A further point of interest in design is to part subcontracted work in construction, according to Slimbouwen® principles [1, 2]. The idea is to have distinguished layers (or elements) for specialisations in construction. For
instance, all supplies for heating, ventilation and sanitation are grouped in the lay-out. This enables a plumber to elaborate a special box for equipment plus piping providing heating, ventilation, etc. The box is filled up in a plumber’s shop to such a level that all equipment functions and is tested. For each cabin, a plumber simply places an integrated box with limited additional piping in a module. Thus most of the work is shifted away from the place where modules are assembled. Activities that need to be done inside a module is organized such that this doesn’t interfere with work of others. The same counts for an electrician, who applies all pipes and wiring in one sequence in a phase where no other work takes place, while his work is simplified as he can use the cavities of wall, floor, and roof elements. Only after plumber and electrician have completed all work for services and wiring, the interior finishing is to be applied. This optimal unravelling of specialists and subcontractors, reduces costs, improves quality and shortens delivery time [2, 3].

Figure 6: Manufacturing, transporting and placing the ready-to use modules.

In this set-up the modules are fully ready-to-use when brought to a location. Since circumstances at a building site are hard to control and attuning labour is difficult [3] this set-up is designed to enable a one-day-construction on-site.

3 A dry assembled foundation

The small weight of modules (and a stable form to enable transportation) offers opportunities for a very simple foundation and a good chance to make this a detachable system to correspond to the same basics as those that govern the modules. Another precondition is a one-day-construction goal. So a casted concrete foundation was not preferred, as this requires several construction days and in addition time to cure. Instead a system is developed proceeding from precast concrete tiles (recovered from demolition) to support a bracket. It was found that eight brackets suffice for the two lightweight modules. Underneath the brackets there are concrete tiles to spread the load. However, uplifting of the modules due to wind load is more determining than soil resistance underneath tiles for this lightweight building. Uplifting is prevented by using a galvanized bar with screw thread cut at one end. This bar is dug into the subsoil in order to fix the bracket. As it can be seen in Figure 7, there are two rows of brackets, each supporting a galvanized steel beam (recovered from demolition). This steel beam is fixed to each bracket by means of the galvanized bars with screw thread, thus
after placing the two modules on top of the beams and after fixing the modules to these beams, the whole structure is able to resist wind forces. The brackets have a possibility to adjust height, so in case of initial settlements of the foundation it is easy to re-establish levelling, if needed. Another big advantage of this foundation is that it can be completely removed at the end of the life time or if a new arrangement of buildings is indicated without leaving a footprint.

![Figure 7: One module put on the dry assembled foundation.](image)

3.1 Optimal venting

Apart from making a foundation that is fast to build, this special foundation also has an optimum venting underneath. Wood structures in particular require good venting to benefit service life. A wood structure with a standard concrete foundation might result in problems with decay especial at locations where wood touches concrete. Lodges often moulder nearby the foundation since it is not possible to ventilate at the point of contact in a proper way after wood gets wet. With the dry assembled foundation venting solves this issue.

3.2 One-day-construction on site

Since several hikers’ cabins are already constructed, we have found that making this type of foundation can be assembled in about 3 hours. The overall procedure is as follows: in the early morning the foundation is made, at the same time that two modules are loaded on a truck and are transported to the site. Around noon the modules arrive at the site, where a crane puts the modules on top of the steel beams of the foundation. The module with the services box is placed at its exact
location, the second module leaves a small gap in between the two modules. This is to enable a fast connected of pipes and services inside the module to the mains of the local grid. After connecting and testing, the second module is shifted towards the first module to become one building. Both modules are fixed to each other and a small strip of waterproofing is applied to cover the joint of the two modules and to make the building waterproof. In the afternoon the interior and outer finishing will be completed to hide the connection between the two modules. In this sequence a mounting team of two workers can finish all work on site within one day (and if needed, the first lodgers can already move into this cabin that very evening for a stay to enjoy a unique experience).

4 Advantages

Transferring manufacturing from on-site to a factory, including a large amount of reclaimed materials and by adopting Slimbouwen® principles [1, 2] leads to major benefits to be achieved, such as:

- less waste: relocating manufacturing to a factory improves waste management resulting in up to 75% reduction of waste at a building site [2];
- cost-efficient: the hikers’ cabin amounted to a reduction of 24,6% compared to traditional timber frame;
- improved labour conditions: conditions to work indoor have a controlled environment, tools are computerized and aids and devices can be optimized;
- less transportation: reduction arises due to bulk transport (materials to factory) instead of low-loaded movements (to building sites), plus workers travel less;
- reducing CO₂-emission: reusing wood from demolition preserves sequestered CO₂ for a further 30-50 years instead of to incinerate wood. Also less transport gives less CO₂-output;
- less ‘new’ raw materials needed: because of reusing materials and parts.

5 Conclusions

There are quite a few indicators to outline that the way we build houses today is wasteful, not very efficient, quite complicated and desperately in need of a reset. New systems have to be developed, based on industrialisation, by considering flexibility/lifespan enduring and aiming to settle up a strong reduction regarding environmental impact. Yet, industry is traditional, so to accomplish such a transition we need more than good research. An important aspect in this is to make people aware that alternative systems are applicable. In the context of a traditional building industry this implicates that many demonstration projects are required, since “seeing is believing” is essential to get a thing moving.

Therefore developing a system, that combines a lightweight structure that incorporates a large number of reclaimed materials from demolitions, that is completely manufactured off-site and that adopts Slimbouwen® principles for a proper unravelling of building specialisations needs more than scientific evidence, even though substantial benefits speak for themselves.
That’s why several demonstration projects are embraced (Figure 8) to run simultaneously with research that is meant to improve the system. A holiday accommodation is chosen as demonstration subject, since this fits well to attract a crowd. A holiday accommodation can serve as advertisement for the system to convince people, since one cabin accommodates up to 100–150 persons per year, who can experience the comfort and aesthetics themselves during an overnight stay. With by now 8 commercially hikers’ cabins available we introduce yearly about 1000 people to this recycling and construction method where guests experience at first hand the quality and possibilities it provides. Regarding the use of reclaimed materials, they discover for themselves that reclaimed materials do not have to appear as waste. On the contrary, the environmental awareness of people might cause them to consider it positive that the home has been built from reclaimed materials. A certificate elucidates the origin of materials and expresses that environmental awareness goes hand in hand with modern conveniences.

![Figure 8: Three different hikers’ cabins.](image)

A hikers’ cabin consists of lightweight parts composed out of reclaimed material to make ready-to-use modules which are transported to a site for assembly. All manufacturing and construction takes place off-site in a factory. Apart from subjective experiences of staying overnight in an aesthetic pleasing and comfortable hikers’ cabin (notwithstanding its’ 94 vol.-% of reclaimed materials) there are also a range of objective advantages, such as: less waste, less transportation, improved labour conditions, building efficiency, cost-efficiency, reducing CO₂-output and a lower impact on the direct environment.

References


