Deconstruction, recycling and reuse of lightweight metal constructions

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ABSTRACT: Demolition techniques and the management of construction and demolition waste of buildings are key issues in the development of sustainable construction. Therefore, it is necessary to define the different terms clearly and to differentiate them from each other. This paper gives an overview of various terms and definitions from the field of deconstruction. Furthermore, existing demolition methods are shown and an outlook on the use of robots on the construction site in the future is given. Finally, today's limitations in recycling combined materials are shown and new solutions regarding the reuse of metal building envelopes are discussed.

1 INTRODUCTION

Demolition techniques and the management of construction and demolition waste of buildings are key issues in the development of sustainable construction. Therefore, it is necessary to define the different terms clearly and to differentiate them from each other. This paper gives an overview of various terms and definitions from the field of deconstruction. Furthermore, existing demolition methods are shown and an outlook on the use of robots on the construction site in the future is given. Finally, the planned works within the project PROGRESS regarding the reuse of metal building envelopes are described.

2 TERMS AND DEFINITIONS

2.1 *End-of-Life scenarios of buildings*

Any building has a limited lifetime. At the end of life, there exist typically three possibilities, the most appropriate option depending on costs, environmental conditions and other local issues such as preservation orders (Dorsthorst & Kowalczyk, 2002):

1. **Deconstruction**: A clearance could extend the lifetime and could be an alternative to demolition. During a building clearance, any non-load bearing parts of the building will be deconstructed. The rebuild process starts with the old skeleton.
2. **Reuse of Structure**: Deconstruction and reuse of the structure itself could be an alternative for some structures, especially those made of steel. This method helps to generate a second life for the load bearing structure e.g. for bridges or halls at another place.
3. **Demolition**: Complete demolition is the typical end-of-life scenario. To avoid waste and landfilling, reuse and recycling of materials should be taken into account.

The lowest impact on natural resources is achieved by reuse of whole structures or even a whole building. If a whole building can be deconstructed and rebuilt elsewhere, no waste is produced at all. If this possibility is considered prior to build, this is called “design for deconstruction” (Hechler et al., 2011). If whole structural elements cannot be reused, recycling of materials is the best choice with still little waste.

2.2 *Material recycling and product reuse*

The task of recycling is to keep assets in the economic cycle as long as possible in order to conserve natural resources and to avoid or reduce waste, thus conserving landfill space. At the same time, by choosing the appropriate recycling process, the associated ecological costs and burdens must be minimized. Figure 1 shows different types of recycling. A distinction is made between whether a product is supplied to the same or a different application case and whether it is product reuse or material recycling.

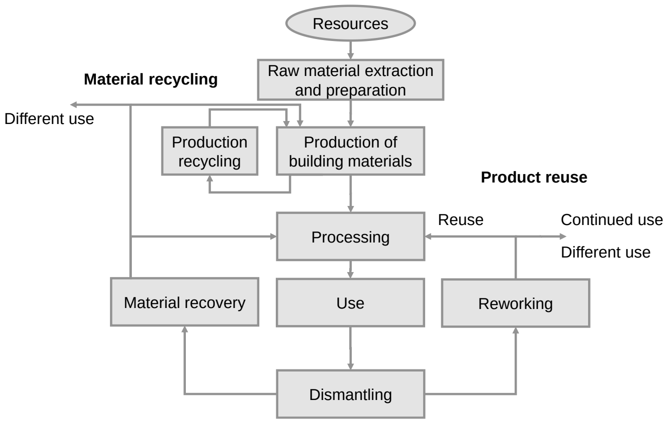

Figure 1. Types of recycling according to (Netzwerk Lebenszyklusdaten., 2007)

Both options (material recycling and product reuse) require that the product has already undergone a usage phase. If a production residue is returned to the processing or manufacturing process, it is called production recycling.

2.3 *Recycling stages*

Reusing and recycling is divided into three stages (BIS, 2011), which are:

1st order recycling is possible with all kinds of metals and glass. Steel is the world's most recycled material. After melting the sorted materials, a new product of the same quality can be made.

2nd order recycling can be done with all not-polluted mineral materials such as concrete, brickstone and general masonry. Recycling of concrete is the process of producing gravel which can be used instead of natural gravel (Figure 2 and Figure 3). Concrete however, unlike a 1st order material, while made from cement cannot be recycled into more cement.

Figure 2. Typical demolition waste

Figure 3. Gravel of concrete after recycling the waste on-site.

Nevertheless, processing waste concrete to produce recycled concrete aggregate (RCA) or recycled crushed concrete (RCC) has the potential to greatly reduce the quantity sent to landfill each year, and complements the government's sustainable development and waste minimization policies (Kirby & Gaimster, 2008).

The potential of RCC/RCA differs according to the local market. If natural gravel is cheap, the demand for recycled concrete is low. If no natural resources exist (e.g. the Netherlands) the potential is high and the possibilities for recycling are high as well (Blengini, 2009).

3rd order recycling concerns thermal use. Wooden materials and plastics are possible sources of energy for power plants. If no thermal use is possible (eg. due to pollution or contamination) landfilling is the only possibility.

3 DEMOLITION TECHNIQUES

3.1 *State-of-the-art*

Today's demolition process relies on one of eight basic methods: pulling, impact, percussion, abrasion, heating (or freezing), expanding, exploding or bending. Most of all deconstruction work is done by excavators. Wrecking balls are effective against masonry but are less easily controlled and often less efficient than other methods. Newer methods may use rotational hydraulic shears and silenced rockbreakers attached to excavators to cut or break through wood, steel, and concrete.

The use of shears is especially common, because controlling the deconstruction process is important to avoid unstable states or unwanted demolition of neighboring houses. Two different kinds of sheers are used depending on the main material: Scrap metal shears are able to cut steel or wood highly controlled and cracking shears to crack concrete. The needed oil pressure varies up to 320bar. If cracking shears cannot be used – which is possible especially for parts of the foundation, hydraulic hammers are used.

The two disadvantages are the sound level and the implicit vibrations. General waste is separated with sorting grapples. However innovative techniques like expansion/bursting, either static (buster with wedges or chemical expansion agent) or dynamic (explosion, high pressure water/gas and CARDOX), or abrasive methods (hammer drills and diamond boring machines) are available. They are designed to reduce noise, dust and increase the safety of the demolition site.

The size of an excavator used for deconstruction depends mainly on the height of the building. If the height over ground is more than 15m, high-reach or longfront excavators are used. With those types of machines, buildings up to 50m can be deconstructed by heavy machine use.

3.2 *Possibilities of robot application on the construction site*

Beyond digital prefabrication, there are various efforts to bring robotics to the demolition construction site. Advances in quadrocoptor and machine vision technology have fuelled the use of these systems in stocktaking and inspection, but also in construction progress analysis. With these approaches, there are still far-reaching questions regarding the level of detail and sensible interfaces for rectifying deficiencies.

Manually controlled construction machines slowly follow their distant relatives from agriculture and receive assistance systems. The move to an autonomous construction machine will probably be the first step in construction site logistics for civil engineering, where it will be possible to take a role model for the already autonomous transport operations in the mining industry.

In the field of steel construction, semi-automated systems for welding were developed at an early stage or sheet metal forming systems were brought from prefabrication to the construction site. However, such robots are not suitable for use beyond prototype development due to their low handling compared to their own weight. For similar reasons, different directions of development are emerging for lightweight steel and metal construction. While the focus of robotic applications in steel construction will probably remain in the factory, development options for assembly and disassembly will open up for lightweight metal construction due to the low dead weights.

Due to the large dimensions of a building, modular components will continue to be in the foreground. Up to now, quite complex plant technology has been used, which represents closed systems in terms of both hardware and software. The possible flexibility of the robot is limited here. As a universal tool carrier, it should be able to carry out various work steps, e. g. cutting or screwing.

The demand for more flexible machine and software platforms will increase in the near future. The desire for individualized construction and increasing demands in terms of recyclability and reusability necessitate a rethinking of the concept of integral and differential construction.

The main challenge for the work on the construction site is to support people in their work with machines. In addition to occupational safety, health protection and a shortage of skilled workers caused by various factors, the closing of the digital leak in the construction process is the driving force for innovation in this area. Since the construction site is currently dominated by machines without intelligence, there is great potential for improvement. However, this is also associated with high technical challenges.

Changing environmental influences and constant structural changes in the working area of the machines do not occur in the industrial factory environment. In addition, restrictions with regard to floor loads and passageways as well as the immense installation space distinguish the construction site from the industrial hall. In addition, suitable safety technology and understandable interfaces to man-machine communication will be needed in order to make building robotics a reality. For this reason, RWTH Aachen University is developing novel interfaces such as haptic programming and approaches to crane-based robotics. (Brell-Cokcan et al., 2017)

4 REUSE OF LIGHTWEIGHT METAL CONSTRUCTIONS

4.1 *Today's limitations in recycling combined materials*

If a building is being planned today, a lot of energy is done in reducing the needed heat-energy and to optimize the building process. The goal is to lower the producing costs and thus to use preproduced parts such as claddings. When it comes to the end-of-lifetime all cladded parts are difficult to put in to recycling, because different materials were used, which are difficult to separate decades later.

Figure 4 shows as a typical example the separation from a three-material roof, which was build from corrugated iron, Styrofoam and cardboard.

Figure 4. Hybrid element consisting of steel, foam and cardboard. All materials are glued together. With help of excavator-work, the steel can quite well be separated from the foam / cardboard. To remove the foam from cardboard, man-power is needed. Such difficult separation processes tend to increase demolition costs.

Hybrid materials tend to increase the expenditure of separation and thus for the whole dismantling.

If just the deconstruction is focused on, non-glued constructions are preferred as there consists a lag of technique applicable on-site. Figure 5 shows the separation by excavator of an insulated wall, which was build out of two covering sheets with insulation as filling.

Figure 5. Removing of steel and capsuled insulation by excavator work.

The excavator just opens the cladding. The insulation falls down separately. The whole cladding can be removed without any impacts to the building itself (Figure 6).

Figure 6. View of the hall with removed facade.

As a result, the needs for lifetime and of the end-of-lifetime are important both. Today, the lifetime is focused on only. There is no effort put in the separation of hybrid materials yet. Techniques applicable on-site need to be invented in the near future to avoid the amount of waste generated by the dismantling of modern buildings and to increase the recycling or reuse of combined materials with steel.

4.2 *New solutions for the reuse of metal building envelopes*

For many buildings, it is the failure or deterioration of the envelope that precipitates its premature demolition. This can be aesthetic deterioration, changing architectural design or, as is often the case, the need to update the envelope to modern standards of thermal performance. Therefore, the deconstruction and management of construction and demolition waste of the existing building envelopes is a key issue in the development of sustainable construction. Metal building envelopes are used primarily in industrial and commercial buildings. Two common forms of construction are: double-skin designs and sandwich constructions. On the interior side, double-skin designs consist of cassette profiles in which the thermal insulation (mineral wool) is placed. From the outside, trapezoidal profiles are fixed with screws to the flange of these cassette profiles. Sandwich constructions consist of two thin metal covering layers and are available with linear, trapezoidal or wave-shaped profiles that are joined in a shear-resistant manner via core insulation (mineral wool or polyurethane).

One part of the PROGRESS project is the consideration of the in-situ reuse (see Figure 7) and aims at the design, production and testing of pilot hybrid solutions for refurbishment of existing building envelopes while reusing the structural components and improving the structural and building physical performance of the building. Different concepts for innovative hybrid solutions for the building envelope have been elaborated and will be investigated within the course of the project.

	Relocated reuse		**In-situ reuse**	
	Same layout	**Different layout**		**Same layout**
Primary structure	(A) Deconstruction and re-assembly on a new site	(B) Several (or all) frames are integrated into the new building layout		(G) Deconstruction and re-assembly on the same site
		(C) Reuse of individual components on different site(s)	(D) Reuse of components in the new building on the same site(s)	
Secondary structure and Envelope		(E) Reuse of individual components on different site(s)	(F) Reuse of components in different configuration	

Figure 7. Basic use cases in the scope of PROGRESS project.

4.2.1 *Hybrid construction of reused liner tray profiles and sandwich panels*

Existing buildings show a different energetic quality depending on type of construction and age. For façade constructions in lightweight metal construction made of steel liner tray profiles, heat transfer coefficients have been determined. Depending on the variant and insulation thickness, heat transfer coefficients of between 0.18 and 0.84 W/(m²·K) are obtained. It can be seen that the conventional cassette wall construction with separation strip cannot meet the current minimum requirements according to DIN 4108-2 irrespective of the insulation material thickness, which in this case corresponds to the respective height of the liner tray profile. In the case of an additional insulation layer, proof of the minimum requirements can always be provided, but the different specifications according to EnEV can only be complied with from certain insulation material thicknesses.

In order to be able to energetically renovate existing facades, which were designed as cassette walls, without impairing the interior of the building, it is generally necessary to dismantle the building element which forms the outer part of the building. While in this way a possibly occurring rear ventilation - i.e. thermal ineffectiveness - of the renovation component can be avoided, this leads to a temporary and possibly permanent alteration of the load-bearing behaviour and requires a separate structural analysis. Depending on the evenness and quality of the installation base, an additional intermediate layer - e.g. 20 to 40 mm thick mineral wool insulation boards - may be required as an intermediate layer.

Figure 8 shows an example of a "hybrid element" consisting of a liner tray construction and a sandwich panel.

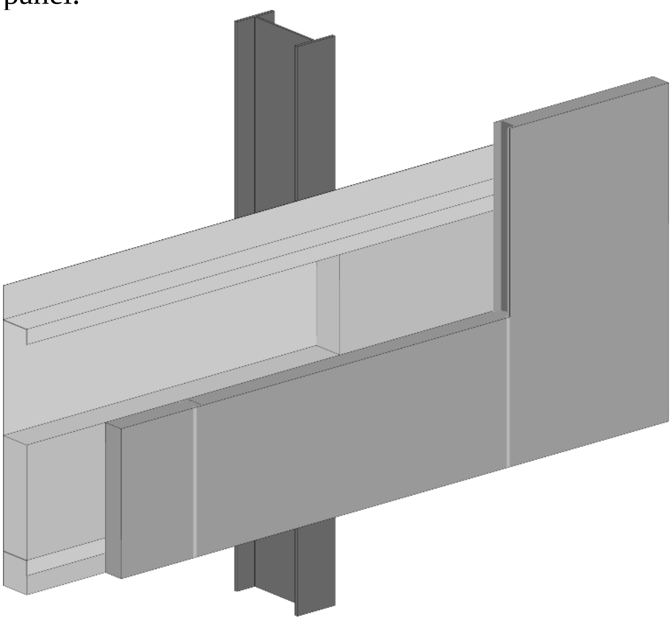

Figure 8. Hybrid element consisting of steel cassette and steel sandwich element. (Kuhnhenne et al., 2017)

The energy saving potential due to heat transmission, which is opened up by the renovation of these façades, as well as some of the resulting building-structural questions with regard to load-bearing behavior and loadings are discussed in (Kuhnhenne et al., 2017).

4.2.2 *Reinforcement and over-cladding of reused sandwich panels*

In order to create the possibility to reuse sandwich panels, one solution could be to reinforce them with steel profiles from the outside. In this way, current standards of thermal performance could be achieved by adding an additional insulation layer, the load bearing behaviour of the sandwich panels could be improved by the attached profiles and a new look for the façade could be created by over-cladding with any façade element.

Regarding the reinforcement with additional steel profiles, it is important to achieve the highest possible resistance to the occurring forces. In order to reduce the deflection, a high moment of inertia is recommended. When looking at the possible shapes of steel profiles, the hat section is ideal. Due to its two webs running vertically to the direction of force (in bending tests), it has a surface moment of inertia that is about twice as high as that of other profiles.

4.2.3 *Investigations within the PROGRESS project*

Within the framework of the project, prototypes of these innovative construction systems will be produced in order to test their structural and thermal behaviour. From the production procedures, first findings regarding feasibility and characteristics of the new constructions will be derived. Full scale prototype tests will be performed for each of the novel hybrid construction elements. In order to test the real performance of the new solutions regarding their ease of assembly and disassembly, the modular research building (CUBE-DemoHouse, Figure 9) of RWTH Aachen University will be used. The modular substructure in steel allows a flexible replacement of components and has the following dimensions:

- Width W x length L x height H:
  7.5 m x 7.5 m x 7 m
- Volume: 332 m³
- Number of storeys: 2

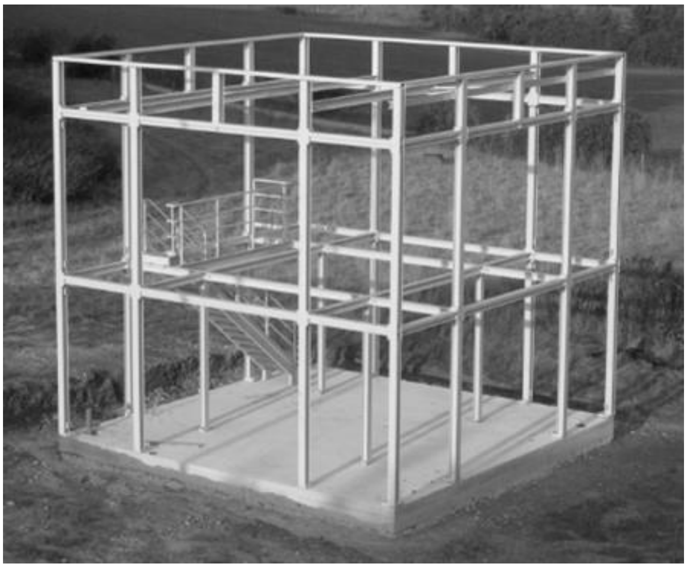

Figure 9. CUBE-DemoHouse of RWTH Aachen University.

5 CONCLUSION AND OUTLOOK

In this paper, different terms and definitions regarding deconstruction, recycling and reuse of lightweight metal constructions have been presented and differentiated from each other.

Existing demolition techniques and the possibilities of robot application on the construction site have been discussed.

Furthermore, today's limitations in recycling combined materials and new solutions for the reuse of metal building envelopes have been shown. Within the framework of the project, prototypes of these innovative construction systems will be produced in order to test their structural and thermal behaviour. The results of the project will be published after the end of the project duration.

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