Recycling prefabricated concrete components – a contribution to sustainable construction

C. Asam
Institute for Preservation and Modernisation of Buildings at the Technical University of Berlin

ABSTRACT: This contribution describes the latest development in the area of recycling of building parts from disassembled concrete prefabricated parts from GDR housing construction. The use of this method of recycling in construction is limited to structural engineering. According to knowledge gained during recent years, current activities including advantages and disadvantages of this construction method are shown. Moreover, the economical and ecological aspects are discussed and the future developmental potential of construction with recycled building parts is introduced.

1 INTRODUCTION

Already since 1998 there have been activities at the Institute involved in reusing demolished prefabricated components from buildings of large apartment settlements. In those days, still rather surreptitiously, one could already see that a not inconsiderable excess of residential buildings would have to be "taken from the market" in the new German provinces during the coming years in order to support the value of real estate and to work against the neglect of large areas of eastern Germany.

Since the focus of the problem of vacant buildings was often to be found in the newly built large apartment complexes during the GDR period, one was usually confronted with industrial prefabricated construction.

The building quality of this construction method was already known in 1998. After the change of political system, extensive reports on the building condition analysis and on renovation and modernisation costs from various sides were ordered. The IEMB occupied itself for the first time in 1993 with a 10-storey panelised structure intended for demolition and investigated the building-part quality there before the demolition [Hillemeier et al. 1994]. A reuse was not planned, despite the generally good building substance. The simultaneous investigations carried out concerning roof construction and renovation in concrete prefabricated buildings of the GDR apartment construction series resulted in the recognition that the prefabricated roofs could be dismounted without difficulty. The building quality was still so high after the dismounting that a reuse was possible [Spaethe et al. 1993].

Starting in 1994, the reuse of building parts from GDR demolished buildings was scientifically investigated for the first time [Mettke 1995]. Rubbish avoidance and protection of resources were in the foreground. The positive environmental aspect of reuse of building parts was clearly emphasised as the result of the studies.

Only starting in 1998 did the recycling investigations lead to first pilot studies on practical projects [Vogdt et al. 1998]. All the pilot studies attempted to accept the original building part geometry and to complete it with new materials in case of discrepancies.

The state support beginning in 2000 for the removal of derelict living spaces gave the recycling projects a large number of usable concrete prefabricated parts. The first pilot houses could be realised in 2001 with these. In the projects, alongside the positive characteristics (in those days, the actual realisation of a building from recycled materials of approximately the same new building quality was a success even amongst professionals), negative aspects were also shown, however. For example, the insistence upon the original building-part pattern led to limitations in the foundation design. Retaining the original stairwells from multi-storey buildings led to a disproportion of connecting surfaces to usable surfaces in the case of small buildings [Asam et al. 2005a]. Recycled walls were at times completed by new building materials in order to attain a variety of facades. These were usually completed in masonry construction. The combination of prefabricated parts and traditional building methods generally led to delays in the construction operation, then leading in turn to increased expenditures. The insight gained from these practical projects – all of them, including smaller apartment buildings – was clear. Although hardly a project could boast great economical successes, the persons involved were of one mind – that it is technically feasible. The efficiency depends to a great extent upon the surrounding circumstances.

2 INSIGHTS GAINED FROM CURRENT WORKS

Starting in 2003, another attempt was made to optimise the recycling building method with concrete prefabricated components. The works were concentrated on the area of recycling in housing construction and in structural engineering in a broader sense as well [Asam et al. 2005b]. The following decisive investigation points of emphasis were recognised:

1. The number of suitable donor buildings.
2. The quality of the recycled components.
3. The scope for architectonic design when building with recycled components.
4. The construction and developmental possibilities when building with recycled components.
5. The logistical optimisation when building with recycled components.
6. The economical significance of the method of building with recycled components for the building trade.
7. The ecological advantages of recycling compared to new construction.

The results of the research projects can be summarised as follows:

2.1 *The number of suitable donor buildings*

The number of suitable donor buildings is sufficient during the period 2000 to 2010 through the reconstruction measures in eastern Germany. Approx. 310.000 apartments built with prefabricated parts are to be demolished. Those Demolitions are still taking place, but not nearly so frequently.

2.1.1 *Obstacles*

Only a small number of demolitions are carried out in which the building substance is protected. Usually, only workers' protection and environmental protection are taken into consideration. This procedure is above all due to the fact that the marketing of the building is not applied as a source of building parts. The building becomes – legally, as well – rubbish, due to the building owner's desire to remove it. The demolition company must then guarantee a correct, prescribed treatment of rubbish according to German law of life cycle management. In this, the purity of material utilisation and/or deposit is in the foreground. An entire industry has become specialised in this area, which, for example, keeps crusher facilities available for concrete in order to make recycled crushed stone. This is why the potential suppliers of recycled building parts are not motivated to do this. Since the demolition work are for the most part financed with state means – given regardless of recycling technology – the demolition clients are not motivated to do this, either.

2.1.2 *Improvements*

The introduction of a bonus system for state-supported demolition measures which also consider environmentally relevant aspects could provide the necessary motivation. Similar to the way in which influence is taken on the operation phase of buildings, in which energy-efficient measures are especially supported when constructing new buildings and renovating them, building methods which save energy and protect recourses could be especially supported.

Moreover, a legally clearer demarcation between building product and rubbish should be discussed. The first step in this direction could be undertaken by the building owner, in which he understands his building (no longer being rented out) to be of a substantial value, and allows himself to become involved in the marketing of building parts as a "removal concept." Whether the desire can be transformed into marketing depends in general on the economical advantage.

This can most easily be communicated through a separated bidding procedure of the demolition measures according to building material and building-part recycling.

2.2 *The quality of the recycling components*

The quality was communicated in numerous investigations and can be reliably estimated for the constituent buildings [6]. The recycling quality of the building parts only depends on the reinforced concrete substance in exceptional cases, and especially on the demolition quality and usability of the individual building part in the new network.

2.2.1 *Obstacles*

Since the demolition buildings are generally 20 to 30 years old, one must only reckon with serious damage to the preliminary building substance on areas exposed to the weather. The focal points are especially the balconies and the weathered surfaces of the outer walls. Damages to the substance have been repeatedly found here. A problem not yet solved in demolition, nor in reusing, is that of three-layered outer walls with core insulation. In conventional demolition with ensuing building material recycling, the insulation must be removed before the concrete is shredded. This is very costly. Moreover, it cannot be determined which insulating material has been used without a damaging test. If the widely-used mineral wool has been used, protective measures towards workers and environment must be adhered to during the separation, since the wool is classified as being carcinogenic. The mineral wool problem also applies to reuse, so that outer wall components can only be designated as capable of recycling under certain conditions.

Other components are only suitable in individual cases for recycling due to their geometry. Examples of these are stairwells, lift and rubbish shafts, roof components and bath cubicles. Other building parts are difficult to dismount without damage, such as too-thin separating walls only 5 cm thick.

Storey slabs and interior walls have proven highly capable of recycling. These building parts comprise 42% of the building substance. This amount of recycled materials, theoretically available, is further decimated by damages during dismounting, transport, cleaning and off-cuts during processing. In the end, about 38% good, reusable preliminary building substance remains from a GDR-type apartment building.

2.2.2 *Improvements*

The increase in building-part quality after the dismounting therefore has the highest priority. A reliable method of minimising damages during handling of the recycled building parts is the estimation of the parts. As soon as money enters the picture, the quality increases. Moreover, the qualification of the demolition companies is to be planned. The measures must be integrated into a generally acknowledged quality system in which the certification of the components is also contained. Since at present the investigations are carried out at the level of pilot projects, one must reckon with further optimisation potentials in an overall introduction of the recycling building method. Construction capable of dismounting and recycling must be used more in new constructions as well, in order to increase the reuse quota.

2.3 *The architectonic scope for design when building with recycled components*

Since the basic consideration for the reuse of recycled components was the reapplication in resident construction, it had to be tested how the large wall and slab panels could be used in new contemporary architecture. Design seminars were carried out with architecture students and an architecture bureau in which up to three-storey buildings were to be constructed out of a limited number of components. It was striking with all the participants that a great curiosity for combining with the available building blocks was awakened. As with LEGO building blocks, a completely individual architecture resulted in each design despite the limited number of different building parts.

2.3.1 *Obstacles*

Due to the retention of the original structural module, compromises often had to be made in the function of the apartment floor plans.

2.3.2 *Improvements*

A clear improvement in the floor plans was attained through the geometrical adjustment of some components. Especially the processing of the walls made up for the problem of inflexible door and window openings among the recycled components. One strived to keep the working expenditures at a minimum as well. Additionally integrated new building parts such as stairs brought further qualities into the design. The foreign application of components (e.g. a slab as a wall, pertinent due to a higher clearance height or interior components in areas exposed to the weather, property demarcation walls and garages) also provided good solutions. The application was limited, however, by technological limitations and building-part quality.

2.4 *Construction and processing possibilities when building with recycled components*

It was established in the architectonic design scenarios that a change of the original structural module/grid and, with it, the original components, is a prerequisite for good and functional architecture. There were sufficient processing possibilities in the slabs and interior walls. It was advantageous that the slabs were made of prestressed concrete with immediate bond without end-anchored reinforcement. Through this, the slabs could be cut off without any loss of tensioning force. It was similar with the interior walls. These were exclusively provided with transport and ring-anchor reinforcement. When cutting, one had to take care that they could still be transported. The processing (trimming with the help of concrete saws) should be kept to a minimum. The possible processing costs are given by economic factors. The unchanged application of the component is seen as an optimal application.

Since the original welding joints would often fall off during the processing, a new system was consistently used during the connecting technique. The new joints were completely made of a screwable heavy-lift dowel system to ensure better dismounting in the future. This joint technique is comparable to that of a wooden house.

2.4.1 *Obstacles*

Since the available components are not building parts originally intended for dismounting and/or recycling, all the recycling activities (pilot houses) are subject to compromise.

2.4.2 *Improvements*

Recyclable building components should be planned for the future. The followings pointers are helpful for this.

Component documents of the building and the components are to be on hand until the final removal. A demolition free of destruction or with limited destruction must be planned. One should aim towards a homogeneous combination of building parts. Multi-layered building parts which are difficult to separate should be avoided.

Since preliminary material constructions have a utilisation period of several decades, it is not possible to plan a second application during the production period. The possibility of processing (e.g. saws with concrete) should be taken into account. The reinforcement is to be chosen in the building components so that the component can be freely cut for the most part.

2.5 *The logistical optimal solution when building with recycled components*

The basic necessary condition for building with recycled components is the presence of a sufficient number of building parts. Previous experience has clearly shown that, despite surface demolition measures of prefabricated buildings in the eastern German provinces, the building material "panels" was not available in sufficient quantities since the great majority of the buildings were torn down.

2.5.1 *Obstacles*

Only about 4% were demolished in a way that protected the substance. The cheaper demolition was always chosen when no conditions of environment protection or workers' protection were required in the demolition. The alternative variant of demolition plus marketing of the dismounted building parts is not taken into consideration, although accompanying dismounting projects have shown that some building parts (usually slab components) can always be directly marketed through the demolition company. This is only possible to a limited extent, however, since the running construction operation must not be disturbed. Already in this situation one can run into delivery troubles in the application of our pilot projects, although the ratio of donor building to pilot projects was approx. 200:1 to 300:1.

A further obstacle is the lack of professional processing possibilities of the components. The "just-in-time" production of the recycled building parts initially used for our pilot project can only be recommended for small projects and when dismounted building parts are already available.

2.5.2 *Improvements*

The preferred variant is that of an intermediary site in which the dismounted building parts are stored, processed and examined without rush or hurry. In this connection, the necessary quality assurance could be regulated with the certification of the components. Should a building commission arise, the available recycled components could be transported from the intermediary site to the construction site. The advantage to this compared with a new part is the lack of a production phase. A recycled building part can be delivered immediately after just a brief processing time.

2.6 *The economical significance of the method of building with recycled components for the building trade*

One can say, in general, that recycling is especially profitable with building parts that have extensive production procedures. This could be an expenditure of craftsmanship on the one hand, producing high wage-costs through its great amount of work involved (e.g. historical building parts such as stairs, doors, etc. which are already successfully marketed via historical building-part stock markets). On the other hand, building parts particularly intense in terms of energy, such as the concrete prefabricated parts described in this contribution, are particularly economical. Concrete is especially intense in terms of energy due to its high proportion of cement which holds together the stone gradings. Approx. 80% of the primary energy expenditure for the production of concrete is in the cement. Approximately 50 to 55 litres of heating oil are needed for the production of 1 m³ of concrete. The reuse of concrete prefabricated parts requires, on the other hand, only 2.6 litres per m³ of "panelling." Converted to the realised pilot houses, this means that 4500 l to 6000 l of the equivalent of heating oil per house are saved through the use of concrete recycled components. This is one of the reasons why reuse in the area of building-part production is already today 50% cheaper than a comparable new concrete building part. This advantage will become even greater with continued energy price increases.

When building with recycled building parts, the cost advantage sinks by 26% compared with the usual massive construction method. These were the experiences gained with the pilot houses. The cost advantage especially shrinks because the recycled building parts were not planned for reuse. New construction measures were required for this that had not been tried on the market often led to compromises. Moreover, the usual new-building tolerance of new prefabricated parts of +/- 5 mm could not be attained. In the pilot projects, one must work with tolerances of the location construction of +/- 20 mm, which resulted in somewhat higher costs.

2.7 *The ecological advantages of recycling compared to new construction*

Alongside the economical advantages, especially influenced by energy and raw material prices, the ecological aspects especially speak out in favour of the use of building parts.

The recycling of building components in the building trade is especially significant in terms of saving raw material resources and energy when dealing with building materials with a long life and high degree of energy expenditure. Figure 1 makes clear the significance of the building carcass with regard to material and energy currents. E.g. 85% of the material mass is concentrated there. Figure 2 shows an ecological-balance comparison of a reused concrete prefabricated part with different recycled concrete, new concrete and masonry. The comparison with recycled concrete is particularly interesting. A clear advantage is recognisable in the primary raw material consumption, especially in mixture 3 in the approx. 50% recycled stone gradings. The energy values, on the other hand, show no improvement over the new concrete.

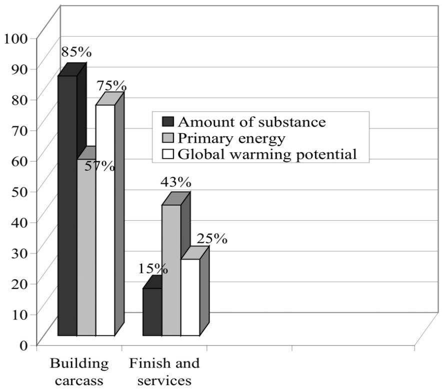

Figure 1. Comparison of carcass and finishing of a typical row-house in massive construction (sand-lime masonry, concrete slabs, ETIC) according to the German regulation for energy saving in buildings, simple design. The amount of substance, primary energy and the global warming potential in relation to the gross storey area are compared. The data are based upon our own calculations with the software LEGEP.

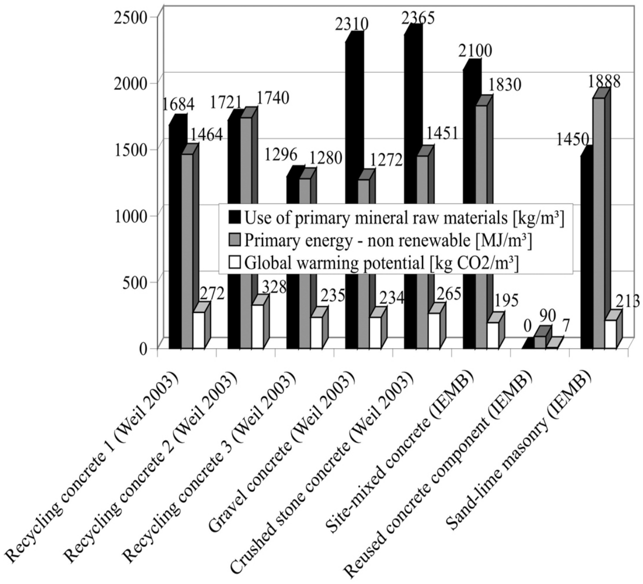

Figure 2. Ecological-balance comparison of the production (up to the factory gate) of a cubic metre of building material of new materials, recycled and reused materials.

This is above all due to the cement content of the mixtures, which tend to be somewhat higher in recycled concrete than in new concrete. The cementing material holding the stone gradings together primarily determines the ecological consequences. Since this binding remains when it is reused, the ecological balance for the building-part recycling is all the more advantageous the more energy-intensive the adhesive is.

3 PILOT PROJECTS

Since the recycling construction method was conceived from the very outset as a practical alternative for small-part apartment construction, a prototype was built in the TUB test hall at the beginning of the pilot programme. The test building was made of interior walls and prestressed concrete slabs of the type WBS 70 and provided with a variety of construction details which were needed for the pilot projects to be realised subsequently. The adaptation of the component geometry through sawing procedures, component strengthening, processing of damages and connecting technique amongst the components are especially notable. Until the beginning of 2007, 9 small houses could be realised in the recycling construction method being introduced through private initiatives. Several buildings will now be shown as examples.

3.1 *Prototype at the TU Berlin*

Figure 3. Processing of the demounted components with a concrete saw.

Figure 4. Test building after completion in the test hall of the TU Berlin.

Figure 5. The test building after being moved.

The test programme comprised the construction of a flat roof from shortened and whole slabs, the realisation of a high-pitched roof out of diagonally sawed walls and shortened slabs. The walls were made of both whole and cut components. The connections were made with demountable heavy-lift dowels. The building was dismounted after the test phase. Since 2006 a Berlin architecture bureau has been using the prototype as an exhibition pavilion.

3.2 *Pilot house in Mehrow near Berlin (Architecture bureau CONCLUS)*

The first pilot project in Mehrow was occupied in 0ctober 2005 (200 m² living area).

The construction method of the prototype studied before was realised. The slab and wall components were supplied by a donor building 8 km away. Demounting, processing and remounting took place "just in time," within 12 days. The façade was covered with an external thermal insulation composite system (ETIC). Altogether, 118m³ of prefabricated concrete units were reused. This corresponds to an oil equivalent of 5900 litres.


Figure 6. Mounting of the building carcass.


Figure 7. Building carcass after completion.


Figure 8. Building after completion.

3.3 *Pilot house in Schildow near Berlin (Architecture bureau CONCLUS)*

The second pilot project in Schildow consists of a main and subsidiary house (280 m² living area). The transport distance was 33 km. The special feature of the building is the sattle roof, built entirely out of recycled concrete components. The facades were covered with an ETIC. Altogether, 245 m³ of prefabricated concrete units were reused. This corresponds to an oil equivalent of 12.250 litres.


Figure 9. Behind: Building carcass of the main house.
Front: Foundation of the subsidiary house.


Figure 10. Building carcass of main and subsidiary houses completed.


Figure 11. Animation of the finished building.

3.4 *Pilot house in Berlin-Karow (Architecture bureau CONCLUS)*

What is special about the pilot house (180 m² living area) is that recycling components were also used for the walls. Through this, higher spaces could be realised. The components had to be transported 23 km. Altogether, 91 m³ of prefabricated concrete units could be reused and 4600 litres of heating oil saved. This building was also provided with an ETIC. It was occupied in October 2006.

Figure 12. Building carcass.

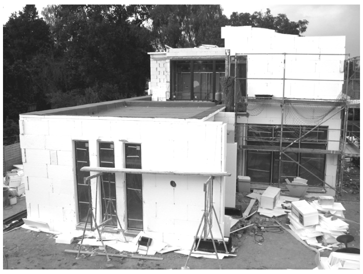

Figure 13. Installation of the ETIC.

Figure 14. Building after completion.

4 CONCLUSION

Recycling of building units is an alternative variant for a kind of construction which protects resources and saves energy. Especially long-living, durable, energy-intensive building materials, such as concrete, can be kept in the life-cycle longer through recycling. Prefabricated constructions are the prerequisites for constructions necessarily capable of being taken apart. As before, quality assurance and the marketing possibilities of building products are to be adapted to recycling systems. The economical components are responsible for the successful dissemination of the concept. The savings in costs of 26% in the case of optimal application in the building carcass area offers a lucrative complement to new building methods. This depends on several courses to be set, however. Alongside the logistics, back-building and remounting plans must be combined with each other; legal construction regulations and financial aspects must be improved. In this connection, the state is also asked to assume a leading role. Through the not inconsiderable support of back-building plans, for example, there is the possibility of providing motivation for the housing companies to occupy themselves with the possibility of a reuse of building units, through the differentiated support of demounting on the one hand and conventional demolition on the other hand. Construction methods capable of being demounted and reused should be developed and applied in the future.

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