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Industrial network design by improving construction logistics

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Implementing an industrial network in the construction industry can be achieved by changing construction management activities directly on the construction site within the design and operation phase. Construction logistics plays a crucial role here, in particular on the downstream side where waste has to be efficiently collected, separated, sorted and, finally, transported from site to different waste management options. The objective of this paper is to introduce an approach for efficient construction logistics that can ensure successful implementation of an industrial network in the construction industry from the point of view of on-site materials management within the logistics of disposal. Two construction projects in Germany were investigated and it was found that the total number of material streams separated directly on site in each project could be increased from 1 to 7 and from 1 to 19 different fractions. The study also revealed that the reuse and recycling rate could be increased to over 75% in both projects and the total costs of construction logistics could also be reduced. It was thus possible to increase material resource efficiency on the downstream side for both construction projects – by 43% in project I and by 68% in project II.

1. Introduction

The bulk of material resources used in the modern European economy end up as materials that accumulate in the economy. The rest, however, are converted into emissions or waste (EEA, 2012). Although Europe has become more efficient in managing material resources over the past years, there is still a need to improve resource efficiency as a major step towards a 'recycling society' (EEA, 2012). However, an efficient economy can only be achieved with a considerable change in consumption, especially in production patterns (EEA, 2012), moving away from a 'throw-away' society towards a society that thinks in 'closed material loops'. The construction industry plays a crucial role here, as construction and demolition waste (CDW) represent a large part of total waste generation in Europe (Figure 1) and have a high potential for reuse and recycling (Brodersen *et al.*, 2002).

Improving resource efficiency in the construction industry by focusing on construction management on site and in its regional activities could be implemented by designing and implementing an industrial network around a construction site. In general, such a network is regarded as an organisational setting at a regional level where the main principles of industrial ecology find application (Mirata and Pearce, 2006). The network could offer a potential, for instance, for

- environmental benefits linked to reductions in resource use, pollutant emissions and waste handling needs
- economic benefits from reduction of the costs of resource inputs and/or waste management and from generation of additional income due to higher value of by-products and waste for recovery
- business benefits due to improved relationships with external parties or development of a green image
- social benefits by generating cleaner, safer, natural working environments (Mirata and Pearce, 2006).

Although this potential is desirable for contributing to a growth in efficiency, the number of functional, comprehensive

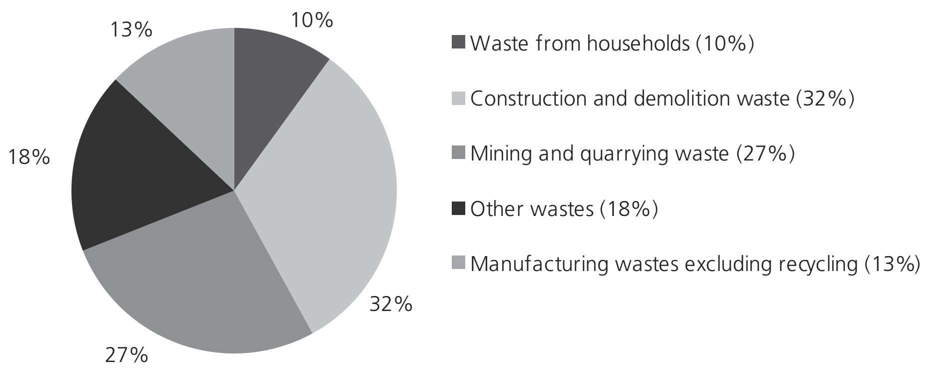

Figure 1. Total waste generation in the EU, EFTA (Norway, Switzerland, Iceland and Liechtenstein), Turkey and Croatia in 2008 (EEA, 2010)

examples of industrial networks in the construction industry is low. This is mostly attributed to the fact that the industry is considered to be diversified and fragmented, where construction parties pay most attention to conforming to their own contractual requirements (Cheng *et al.*, 2001) rather than getting involved in additional inter-branch tasks. In consequence, processes within the design phase, but especially within the operating phase, typically run inefficiently and prevent the implementation of an industrial network. This applies to the processes of construction logistics in general, but in particular to the logistics of disposal dealing with waste management on site. Indeed, construction sites are characterised by a high rate of mixed CDW, which leads to higher disposal rates or – in the best case – energy recovery from combustible waste, thus preventing the reuse and recycling of material directly from the site. Indeed, in Germany, the industrial waste ordinance GewAbfV (BBD, 2003) merely requires producers and owners of CDW to separate, store and separately collect only four waste fractions – glass, plastics, mixed metals, and mixtures of concrete, bricks and tiles. The regulation also allows that these fractions can be collected comingled as long as they are supplied to a pre-treatment facility that ensures the clean sorting of these fractions. It is thus legally allowable to collect on-site mixed CDW (without any hazard waste fractions) when ensuring separation of these four fractions at a sorting plant.

In order to secure smooth on-site waste management and enable the establishment of an industrial network around a site, alternative approaches concerning construction logistics could be applied. This especially concerns waste management on site within the logistics of disposal. An adequate and optimal construction logistics plan can be key to an effective and efficient implementation of material and waste flows on site during construction (Hasenclever *et al.*, 2011; Tischer *et al.*, 2013a).

There is, however, little or no reported research into understanding and measuring the effects of construction logistics with respect to the application of an industrial network around a site. This particularly applies to the logistics of disposal. The paper aims to contribute to fill this gap, focusing on the analysis of on-site materials management within the logistics of disposal. The motivation of this research is to introduce an approach for efficient construction logistics to ensure the successful implementation of an industrial network in the construction industry, and two construction projects in Germany were investigated for this purpose.

The paper is organised as follows. First, a comprehensive overview of construction logistics, industrial network design, the case study methodology and eco-efficiency is presented. Then, the two construction projects in Germany are introduced, along with the concept of an efficient construction logistics model implemented at both sites. The results concerning the industrial network and resource efficiency investigated in the two projects are presented. The paper concludes with a summary and description of practical relevance and potential applications of the results.

2. Methodology

2.1 Construction logistics

In terms of industry-specific characteristics of logistics (Ebel, 2012; Krauß, 2005), construction logistics deals with the planning, operation and control of materials, personnel and information flows within a construction project (Schach and Schubert, 2009). The three areas of logistics of delivery, site logistics and logistics of disposal control the procurement and transportation of materials to and on site, the provision of materials, and the recovery and disposal of residual materials on site and from site (Boenert and Blömeke, 2003).

The planning and coordination of construction logistics is a difficult challenge, as companies are usually interested in their own supply chains on site (Voigtmann and Bargstädt, 2010). Traditionally, construction logistics tasks are performed by several different persons in different construction companies working on site, of whom only a few are occupied in the construction process itself. Thus, insufficiently planned and non-coordinated logistics processes are the consequence, and the reason for a high amount of non-productive actions and consequently disturbed work flow on site (Voigtmann and Bargstädt, 2010).

The efficient management of construction materials and waste planning tasks requires an integrated approach towards various logistical functions (Jang *et al.*, 2003). Fundamental construction operations of facilities, inventory control and communication planning need to be closely coordinated (Jang *et al.*, 2003). An efficient construction logistics approach for large-scale construction projects in Germany is introduced in Section 3.3 of this paper.

2.2 Industrial network

According to Williams and Curran (2010), there is no common definition of an industrial network, but Mirata and Pearce (2006) define an industrial network as an organisational setting at a regional level where the main principles of industrial ecology find applications. Some good practical examples of industrial networks, which often developed organically and with myriad objectives, are the municipality of Kalundborg in Denmark, the Kwinana industrial area in Western Australia and Fujisawa eco-industrial park in Japan (Williams and Curran, 2010). One of the main reasons for the establishment and success of such networks was that companies at a regional level could exchange their by-products.

Indeed, waste stemming from one production process cannot usually be reused or recycled in the same process, only within another process (Schwarzer and Steininger, 1997). If there is no suitable reutilisation process for the waste-producing enterprise, a network has to be firstly created by implementing integrated inter-company technologies and then expanded to include other companies (Schwarzer and Steininger, 1997). The prerequisite is that the participating companies provide a sufficient base for operation (i.e. all the individual partners ‘match’) (Schwarzer and Steininger, 1997). This means that, in particular terms of quality and quantity, the waste of one partner needs to be usable as a raw material for the other (Schwarzer and Steininger, 1997). Figure 2 presents the idea of establishing an industrial network in accordance with Williams and Curran (2010).

2.3 Case study methodology

In this work, a case study methodology was used as the main research method. This methodology is excellent for theory building, for describing ‘best practices’ in detail and for providing a greater understanding of the data gathered (Ellram, 1996; Kim

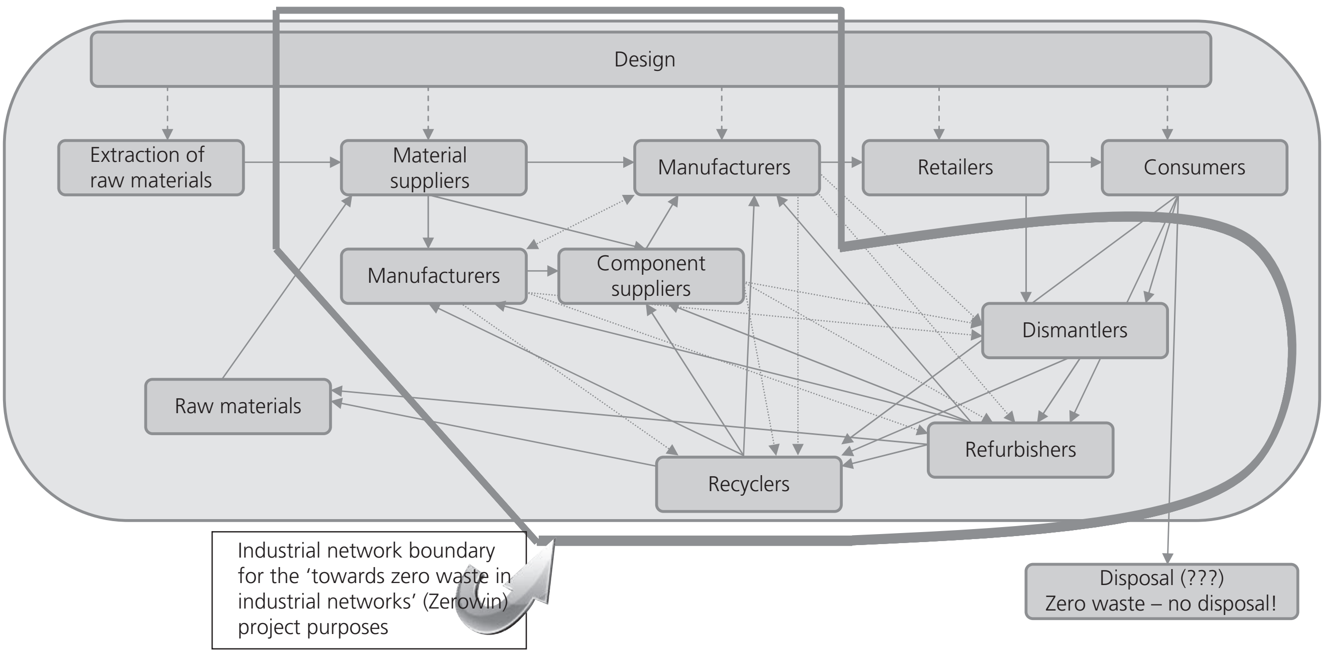

Figure 2. Proposal for the scope and boundary of an industrial network (Williams and Curran, 2010)

and Min, 2012). Case study research enables a researcher to answer 'how' and 'why' type questions (Baxter and Jack, 2008). The methodology should be carefully planned in advance and should support systematic gathering of the data required to address the research questions of interest (Ellram, 1996). A thorough literature review is beyond the scope of this paper, thus readers are referred to academic research on case study methodology (e.g. Eisenhardt, 1989; Meredith, 1998; Yin, 2008).

This work used explorative qualitative and quantitative multi-case research. The aim was to identify how an industrial network could be implemented around a site for two construction projects in Germany and if such a network is linked with an increase in material resource efficiency.

2.4 Eco-efficiency

The results of the progress achieved at the construction sites studied was evaluated and assessed by Obersteiner *et al.* (2013). Moreover, for these particular cases, the eco-efficiency method was applied. In general, a wide variety of terminology referring to eco-efficiency has developed in recent years, differing in its application, the background of the researchers or even in views on how to treat negative signs (Huppes and Ishikawa, 2005). As a result, the term eco-efficiency has been used in different ways and other terms used that overlapped with these meanings (e.g. environmental cost effectiveness and environmental productivity) (Huppes and Ishikawa, 2005).

The main aim from the point of view of construction logistics is to realise both cost-efficient and environmentally friendly material flows by integrating the logistics of delivery and the logistics of disposal. In particular, as the objective of this work was to analyse materials management on site within the logistics of disposal, the methodology described by Tischer *et al.* (2013b) was used to measure the eco-efficiency of waste management

$$1. \quad \mathrm{EE}_{\mathrm{CLD}i} = \frac{\mathrm{RR}}{100\%} \times \frac{1}{C_{\mathrm{CLD}i}/m_{\mathrm{wt}}}$$

in which $\mathrm{EE}_{\mathrm{CLD}i}$ is the eco-efficiency of construction logistics of disposal (in t/€), RR is the reuse and recycling rate (in % by weight) achieved in a construction project, $C_{\mathrm{CLD}i}$ is the absolute cost of construction logistics of disposal (in €) and m_{wt} is the total amount of waste produced on site in a construction project. The term $C_{\mathrm{CLD}i}/m_{\mathrm{wt}}$ can be defined as the relative cost of the logistics of disposal.

3. Case studies

3.1 Project I: Refurbishment project

The first project under investigation was a refurbishment project located in the Rhine-Main metropolitan region in Germany. As the greatest refurbishment of a building undertaken in Europe, the site area covered 13 000 m^2 with a building gross floor space of 122 000 m^2. The building site consisted of three base levels, divided into three sections with a total height of approximately 21 m, as well as two high-rise towers. The total height of the towers amounted to around 155 m. Both towers had three basement stories and were founded on a single floor slab with a depth of approximately 13 m below ground level.

The quantitative research was based on a complete set of data for the whole construction period (December 2007–February 2011). It was thus possible to observe how an industrial network could be implemented around the site and what benefits it would bring. It was also possible to investigate both the economics and efficiency of the implemented logistics concept on site.

3.2 Project II: New construction project

The second project investigated was a new construction project in Munich. One of the largest new construction projects in Germany, the site area is 35 400 m^2 with a building gross floor area of about 90 000 m^2 and floor space of about 65 000 m^2. Planned with an existing structure in mind, a new building complex with apartments, offices, shops, cultural and leisure facilities was proposed. Munich City Council decided to proceed with the project in July 2010 and preliminary construction commenced in 2011/12. All the units are expected to be ready for occupancy in 2015.

The quantitative research for this project was based on an accurately estimated set of data that was prepared within the design phase of the project from 2011 onwards. It was thus possible to observe how an industrial network could be implemented within the design phase of a new construction project. As in project I, it was also possible to investigate both economic issues and the efficiency of the implemented concept on site.

3.3 Implemented concept of efficient construction logistics

For the two construction projects, the concept of efficient construction logistics was implemented on site for both the logistics of delivery and the logistics of disposal. The concept was introduced, in general, in previous works (Goetz and Höchsmann, 2010; Tischer and Gartmann, 2010; Tischer *et al.*, 2013a, 2013b). The main characteristics are as follows.

3.3.1 Planning phase – designing construction logistics

Starting within the planning phase of a project, the design of a construction logistics plan at an early stage was implemented as follows. First, all potentials and restrictions for the site regarding logistical aspects were identified. Then, in consultation with the building owner, the architects, the main contractor and local authorities, the framework conditions to put a logistics system in place were determined, these being tailored to the particular needs of each actor. Finally, a handbook was created where all logistics aspects for the construction phase of the specific project were written down. This handbook was then used as a signed guideline for all the main contractors and subcontractors to fulfil their work in consideration of these logistical processes (Tischer and Gartmann, 2010).

3.3.2 Operating phase – logistics of delivery

The strategic process-oriented coordination of logistics was based on the optimisation and regulation of all transports to and on site. This was implemented as follows (Figure 3). Each executing company and contractor had to register, either manually or via online registration, its material delivery to site. Through a software-based interface, the companies selected the date, time and handling place on site for each delivery. When the material was delivered, the logistics service company ensured just-in-time handling and transportation of the material to the place of integration (Tischer *et al.*, 2013b).

3.3.3 Operating phase – logistics of disposal

The logistics plan concerning disposal was implemented as follows (Figure 4). Right from the beginning of each project, the logistics service provider provided each executing company with moveable containers. The companies were thus able to collect their waste, separated into predefined categories. The logistics service provider was responsible for the transportation of different wastes to the collecting station on site, as well as the transport of the separated material fractions to refurbishing or recycling companies and manufacturers (Tischer *et al.*, 2013a, 2013b).

4. Results and discussion

4.1 Industrial network

Table 1 shows the material changes that could be realised in total across both projects, based on an analysis of the resource exchange and material flows from construction site to different industries and project partners.

A total quantity of 37 480 t of CDW was produced on site across both projects. Due to on-site separation and recovery activities, 997 t (2·7%) of that amount could be reused as material for other construction sites, 27 854 t (74·3%) could be recycled, 1163 t (3·1%) supplied to energy recovery and 7356 t (19·6%) collected for backfilling recovery (Figure 5). However, during the demolition and gutting phase in project I, 111 t (0·3%) of insulation materials containing asbestos had to be separated and delivered to landfill. In total, 10 036 t (26·8%) of waste could be diverted from landfill, 2685 t (7·2%) from incineration and 4093 t (10·9%) from sorting plants (Figure 6).

Although the concept of efficient construction logistics was implemented in the same way for both projects through the logistics service provider together with the owner and the main contractors on each site, the network and its effectiveness (measured by the total number of material streams separated directly on site) differed between projects (Figure 7). In project I, 19 material fractions were separated and directly sorted on site for reuse and material recycling. Compared to the baseline scenario of just one material stream for recycling, it was possible to supply all these materials to different recyclers, manufacturers and refurbishers. In project II, it was estimated that seven material streams could be directly separated on site

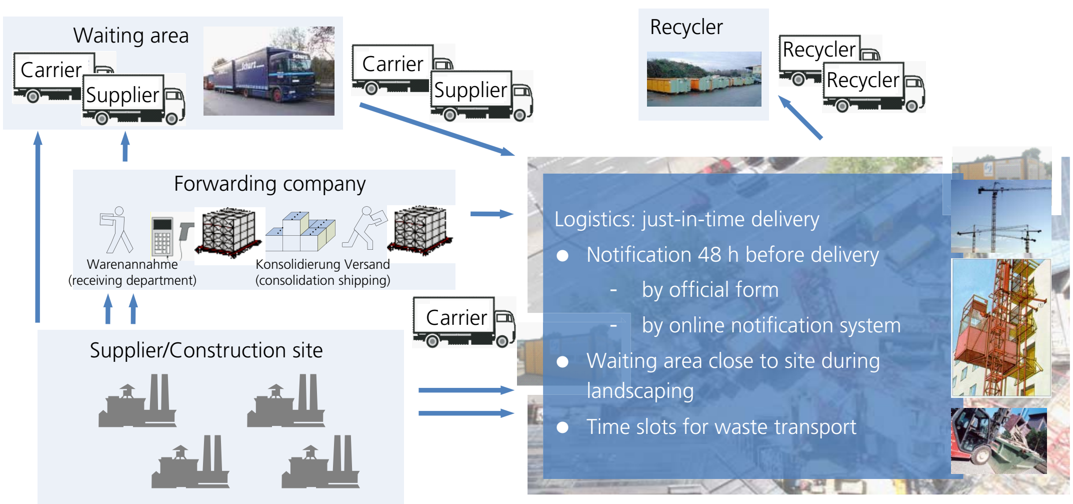

Figure 3. Procedure of logistics of delivery (Tischer *et al.*, 2013b)

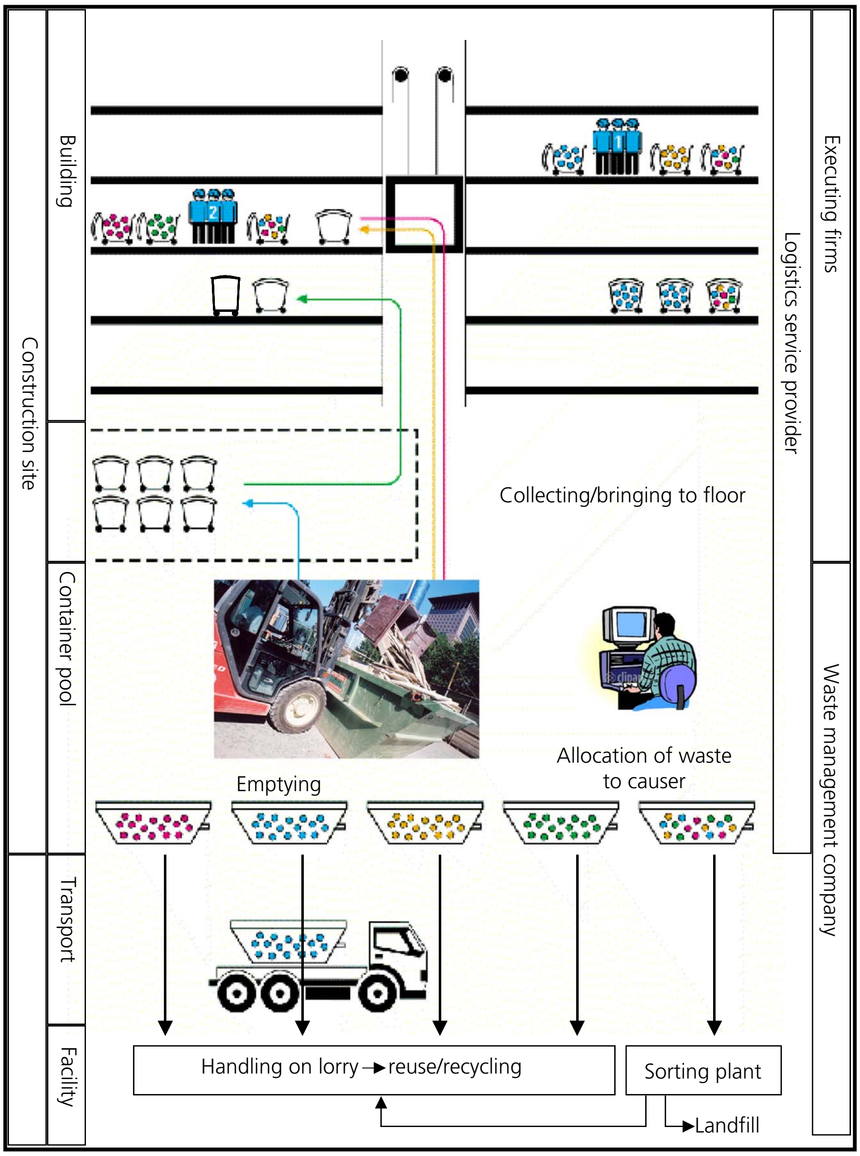

Figure 4. Procedure of logistics of disposal (Tischer *et al.*, 2013b with permission of bauserve GmbH)

for material recycling, again representing a significant increase on the baseline scenario of just one material stream for recycling.

However, the question is raised of why the number of material fractions sorted on site in project II was much lower than in project I. Project I was a refurbishment project and most of the waste materials were collected and separated on site during the demolition and gutting phase. During the construction phase, when new materials were being delivered to site, 'just' eight material fractions were sorted and collected. This number is consistent with the results found in project II, which was new construction.

Another important factor was that the building owner of project I aimed to certify the project according to international sustainability systems, which impose high standards for the reuse and recycling rate of CDW. Finding project partners such as recyclers and manufacturers around the construction site for the majority of generated waste streams and documentation of these results was thus necessary to enable certification of the project (Tischer *et al.*, 2013a, 2013b).

Material fraction	European waste catalogue (EWC) No.	Total waste in both projects: t	Product, industry use	Waste management option	Net benefits at source (compared with baseline) Diverted from …
Marble floor	—	178	Another construction site	Reuse	Landfill
False floor	—	699	Another construction site	Reuse	Landfill
Paper and cardboard packaging	150101	164	Secondary paper	Material recycling	Energy recovery
Plastic packaging	150102	77	Secondary plastic	Material recycling	Energy recovery
Mixture of concrete, bricks, etc.	170107	15 465	Road aggregate	Material recycling	Sorting plant
Wood	170201	2 096	Furniture, finishing	Material recycling	Energy recovery
Glass	170202	1 418	Secondary flat and bottle glass	Material recycling	Landfill
Plastic	170203	92	Secondary plastic	Material recycling	Energy recovery
Bituminous mixtures	170302	256	Road material	Material recycling	Energy recovery
Copper, bronze, brass	170401	42	Secondary copper	Material recycling	Sorting plant
Aluminium	170402	532	Secondary aluminium	Material recycling	Sorting plant
Iron and steel	170405	119	Secondary iron	Material recycling	Sorting plant
Mixed metals	170407	3 018	Secondary metal	Material recycling	Sorting plant
Cables	170411	52	Copper and plastics	Material recycling	Sorting plant
Insulation materials (asbestos)	170601	111	—	Landfill	—
Insulation materials (hazardous substances)	170603	845	Aggregate for bricks	Material recycling	Landfill
Gypsum-based construction materials	170802	6 896	Backfilling recovery	Recovery	Landfill
Mixed CDW	170904	4 072	Different sorted fractions	—	—
Mixed CDW	170904	1 018	Solid recovered fuel	—	—
Fluorescent tubes	200121	2	Secondary glass	Material recycling	Sorting plant
Inventory/bulky waste	200307	120	Another construction site	Reuse	Sorting plant
Other: blinds, motors	—	17	Secondary iron	Material recycling	Sorting plant
Other: EPDM (rubber) (facade)	—	47	Secondary EPDM	Material recycling	Sorting plant
Other: carpet, plastic floor, etc.	—	144	Secondary materials	Material recycling	Sorting plant

Table 1. Material exchanges within an industrial network (recovery of materials for use in another process) and net benefits achieved

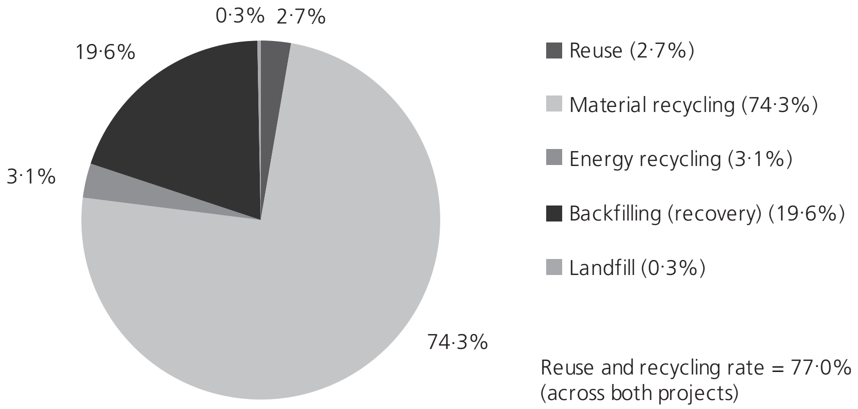

Figure 5. Percentages of waste according to disposal options for both projects

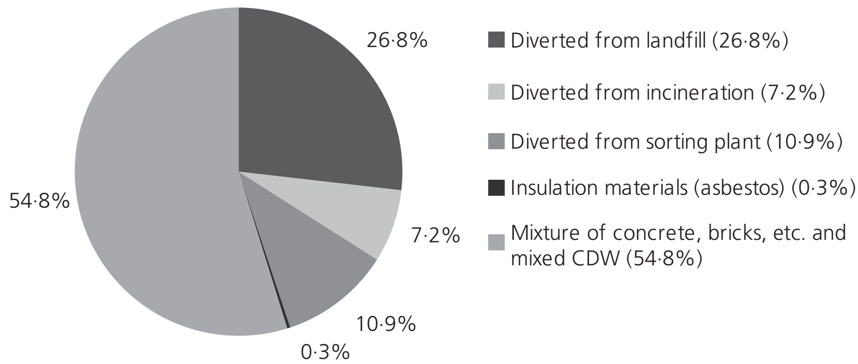

Figure 6. Percentages of waste diverted from landfill, incineration and sorting plants for both projects

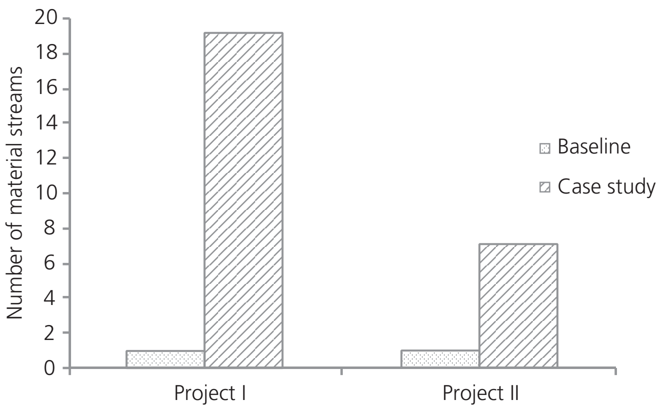

Figure 7. Absolute number of material streams separated directly on site

Waste fraction	EWC No.	Total: t	Reuse: t	Material recycling: t	Energy recovery: t	Backfilling (recovery): t	Landfill: t	Reuse and recycling rate: %
Paper and cardboard packaging	150101	70·4	—	70·4	—	—	—	100·0
Plastic packaging	150102	60·4	—	60·4	—	—	—	100·0
Mixture of concrete, bricks, tiles and ceramics	170107	13 934·4	177·9	13 756·5	—	—	—	100·0
Wood	170201	1 885·2	—	1 885·2	—	—	—	100·0
Glass	170202	1 417·8	—	1 333·9	—	83·9	—	94·1
Plastic	170203	91·6	—	91·6	—	—	—	100·0
Bituminous mixtures	170302	255·7	—	255·7	—	—	—	100·0
Copper, bronze, brass	170401	42·4	—	42·4	—	—	—	100·0
Aluminium	170402	532·0	—	532·0	—	—	—	100·0
Iron and steel	170405	119·3	—	119·3	—	—	—	100·0
Mixed metals	170407	2 965·6	—	2 965·6	—	—	—	100·0
Cables other than those mentioned in 170410	170411	51·8	—	51·8	—	—	—	100·0
Insulation materials containing asbestos	170601[a]	111·2	—	—	—	—	111·2	—
Insulation materials consisting of or containing dangerous substances	170603[a]	804·2	—	804·2	—	—	—	100·0
Gypsum-based construction materials	170802	6 976·6	698·7	—	—	6277·9	—	10·0
Mixed CDW	170904	3 827·0	—	2 328·3	765·4	733·3	—	60·8
Fluorescent tubes and other mercury-containing waste	200121	2·4	—	2·4	—	—	—	100·0
Inventory/bulky waste	200307	120·0	120·0	—	—	—	—	100·0
Other: blinds motor	—	17·2	—	17·2	—	—	—	100·0
Other: EPDM	—	47·1	—	47·1	—	—	—	100·0
Other: carpet, plastic floor coverings	—	144·4	—	—	144·4	—	—	—
Total		33 476·7	996·6	24 364·0[a]	909·8[a]	7095·1[a]	111·2	75·8[a]

[a]In Tischer *et al.* (2013a), the total amount of waste for material recycling, energy recovery, backfilling (recovery) was calculated slightly differently; the reuse and recycling rate was not 76% but 79%. This is due to the fact that the final calculations and assessment in June/July 2013 led to minor adjustments after submission of the publication of Tischer *et al.* (2013a) in December 2012

Table 2. Overview of total amount of wastes and respective recovery/disposal options of the different waste fractions in project I

4.2 Environmental assessment

Through the implemented concept, it was possible to decrease the environmental impacts of logistics processes compared with the baseline scenario in both projects. As shown in Table 2 for project I, a total quantity of 33 467 t of CDW was produced during the construction period (Tischer *et al.*, 2013a). Of this, 997 t (3·0%) could be reused as material for other sites and 24 364 t (72·8%) recycled. Furthermore, 910 t (2·7%) waste could be supplied to energy recovery schemes and 7095 t (21·2%) waste collected on site for backfilling (recovery). As noted earlier, during the demolition and gutting phase, 111 t (0·3%) of insulating material containing asbestos had to be separated and sent to landfill. In total, the reuse and recycling rate was 75·8% by weight.

For project II, 4003 t of CDW was estimated to be produced during construction (Table 3) and 3490 t (87·2%) of this was estimated to be recycled. Furthermore, 253 t (6·3%) waste would be supplied to energy recovery and 261 t (6·5%) waste would be collected on site for backfilling (recovery). In total, the reuse and recycling rate was estimated to be 87·2% by weight.

4.3 Economic assessment

Detailed data collection and analysis by screening secondary data and interviewing people responsible for materials and waste management in each project resulted in a complete picture of the total costs for implementing resource-efficient construction logistics. The main results were as follows (Figures 8 and 9). In total, the cost of construction logistics was €4 514 262 in project I. Compared with the baseline scenario of €5 194 899, this represents a decrease of 13·1%. A similar reduction was found for project II: a reduction of 10·6% from €2 349 462 calculated for the baseline scenario to €2 099 744 in the case study.

In order to assess the materials efficiency of the logistics of disposal on site for each of the projects as described in Section 2.4, the relative costs of the logistics of disposal were calculated as

- in project I, 132·6 €/t in the baseline scenario and 112·3 €/t in the case study
- in project II, 299·6 €/t in the baseline scenario and 237·2 €/t in the case study (Figure 10).

4.4 Eco-efficiency

In addition to the analysis of environmental impacts, based on the results of the economic assessment it could be shown that material resource efficiency (measured as eco-efficiency) increased on the downstream side for each project within the logistics of disposal: in project I by 43% from 0·0047 t/€ to 0·0067 t/€ and by 68% in project II from 0·0022 t/€ to 0·0037 t/€ (Figure 11).

5. Conclusion

The aim of the research described in this paper was to increase material resource efficiency on construction sites by improving the logistics of delivery and especially the logistics of disposal, thus enabling the implementation of an industrial network around two selected construction sites in Germany. The main results are as follows.

Waste fraction	EWC No.	Total: t	Reuse: t	Material recycling: t	Energy recovery: t	Backfilling (recovery): t	Landfill: t	Reuse and recycling rate: %
Paper and cardboard packaging	150101	93·6	—	93·6	—	—	—	100·0
Plastic packaging	150102	16·4	—	16·4	—	—	—	100·0
Mixture of concrete, bricks, tiles and ceramics	170107	1708·2	—	1708·2	—	—	—	100·0
Wood	170201	210·6	—	210·6	—	—	—	100·0
Mixed metals	170407	52·7	—	52·7	—	—	—	100·0
Insulation materials consisting of or containing dangerous substances	170603	41·0	—	41·0	—	—	—	100·0
Gypsum-based construction materials	170802	617·8	—	617·8	—	—	—	100·0
Mixed CDW	170904	1263·6	—	750·1	252·7	260·7	—	59·4
Total		4003·7	—	3490·2	252·7	260·7	—	87·2

Table 3. Overview of total amount of wastes and disposal options of the different fractions in project II

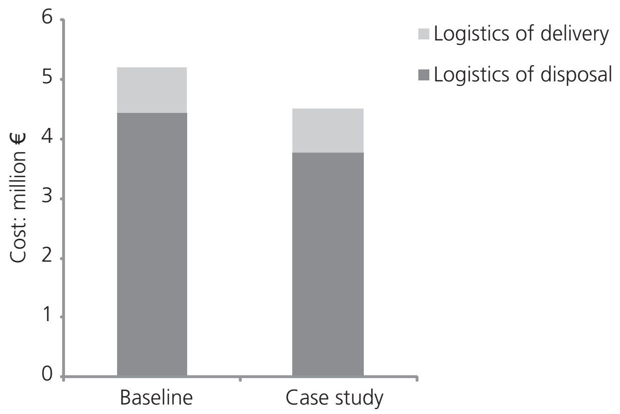

Figure 8. Cost of construction logistics for project I

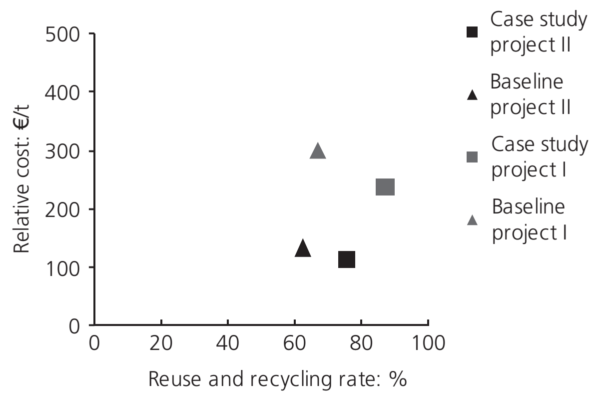

Figure 10. Relative cost of logistics of disposal compared with the reuse and recycling rate for both projects

(*a*) Working with the owner and the main contractors on each site, the concept of efficient construction logistics could be successfully implemented. The actions undertaken were

(*i*) selecting downstream companies to use residues from construction process as raw materials in their own production
(*ii*) separating residues already on site into different material fractions
(*iii*) optimising the transportation of materials to and from installation points on site
(*iv*) ensuring just-in-time delivery.

(*b*) The total number of material streams separated directly on site could be increased from 1 to 19 fractions in project I (refurbishment) and from 1 to 7 in project II (new construction).
(*c*) In total across both projects, 10 036 t materials could be diverted from landfill, 2685 t from energy recovery and 4093 t materials from sorting plants.
(*d*) The reuse and recycling rate could be increased from 62% to 76% in project I and from 67% to 87% in project II.
(*e*) By implementing the logistics approach, the calculated total logistics costs reduced in project I by 13% compared with the baseline. In project II, the total costs could be decreased by 11% compared with the baseline scenario.
(*f*) Material resource efficiency was calculated to increase on the downstream side by 43% for project I and 68% for project II.

The results obtained in this study highlight the benefits of efficient construction logistics and could be used to implement and support the idea of establishing an industrial network around any site. However, successful implementation of such a concept can only be achieved if the site project partners, the design team, all construction companies and especially the building owner, are equally determined to proceed in this way.

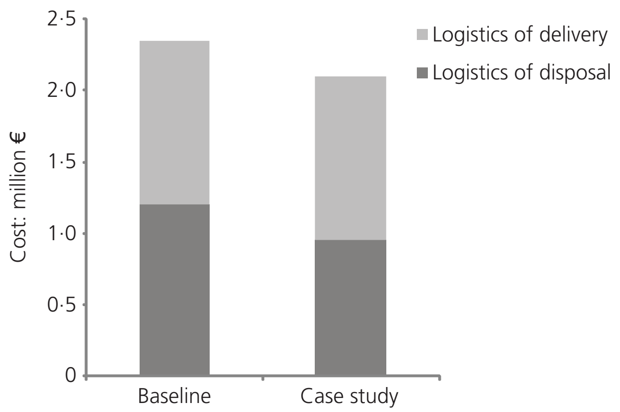

Figure 9. Cost of construction logistics for project II

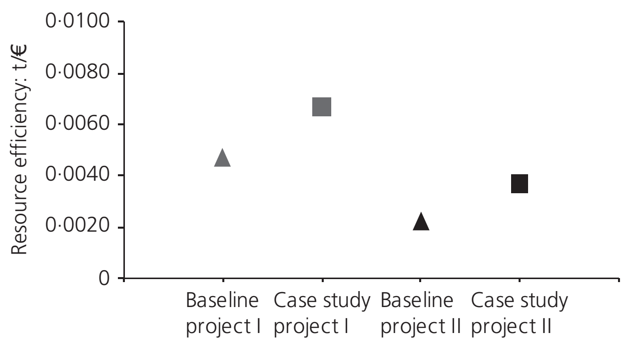

Figure 11. Resource efficiency of construction logistics of disposal for both projects

Compared with the construction industry status quo, the approach can lead to environmental and economic benefits on site and thus to an increase of productivity of logistic aspects on the downstream side.

A major limitation of the research was that only two construction projects were investigated. It remains for future research to verify if the results can be generalised. For this, further case studies of praxis examples are necessary. Additionally, it would be interesting to know whether, and if so how, the concept of efficient construction logistics would influence the successful implementation of an industrial network from the upstream point of view, measured with quantitative, certain data and information. A complete picture of the establishment of an industrial network around a construction site could thus be drawn and assessed.

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