State of the Art of Demolition and Reuse and Recycling of Construction Materials

Anna Kühlen,
Institute for Industrial Production (IIP), Karlsruhe Institute of Technology (KIT)
(email: anna.kuehlen@kit.edu)
Rebekka Volk,
Institute for Industrial Production (IIP), Karlsruhe Institute of Technology (KIT)
(email: rebekka.volk@kit.edu)
Frank Schultmann,
Institute for Industrial Production (IIP), Karlsruhe Institute of Technology (KIT)
(email: frank.schultmann@kit.edu)

Abstract

Nowadays, due to globally increasing building densities in cities, demolition works are an inherent part of construction. And they are focal activities related to life-cycle-oriented management of construction materials, which aims at drastically reduce the deployment and consumption of primary non-renewable construction materials. To give an overview on related worldwide existing activities, the state of the art of demolition and of reuse and recycling of construction materials is summarized in a report of selected countries based on reports of these countries. Within this report, first typical structures of the demolition and recycling industry in different countries, typical phases of demolition and recycling processes and involved stakeholders with their characteristic competencies are described. Secondly, leading companies, associations and research institutions in selected countries are outlined. Leading processes are identified by distinguishing between design processes for deconstruction, deconstruction processes on-site and innovative on-site and off-site recycling processes. Thirdly, challenges related to demolition and reuse and recycling of construction materials are identified and analysed in terms of technical, economic, ecologic, organizational and educational and political/legal challenges. Finally, single, country specific, already existing approaches to meet these challenges are identified.

Keywords: State of the art, deconstruction, life-cycle-oriented management, construction materials, reuse and recycling

1. Introduction

Nowadays, due to globally increasing building densities in cities, demolition works are an inherent part of construction. Furthermore, demolition works are focal activities related to life-cycle-oriented management of construction materials, which aims at drastically reduce the deployment and consumption of primary non-renewable construction materials. To give an overview on related worldwide existing activities, the state of the art of demolition and of reuse and recycling of construction materials is summarized in the following report. For this overview, the state of the art in selected countries is analysed based on reports of these countries, firstly by describing typical structures, processes and stakeholders of the demolition and recycling industry. Secondly, by outlining leading companies, associations and research institutions as well as leading processes. Thirdly, by identifying and examining technical, economic, ecologic, organizational and educational and political/legal challenges. Finally, by identifying single, country specific and already existing approaches to meet these challenges.

1.1 Description of the demolition sector

The demolition sector[1] is by no means homogenous and currently displays a wide diversity of sophistication levels, varying within and between regions and countries. Diverse stakeholders, such as clients, planning engineers, emission and contamination experts, decontamination companies, demolition companies, authorities and neighbours, are involved in and/or effected by the demolition process. These stakeholders have different interests and influences on the demolition project. Related to building types, surrounding conditions and sometimes hazardous substances of the building usage phase, the fields of activities are diverse and therefore, a variety of different usually small- and medium-sized enterprises dominate the demolition sector. The demolition sector is assigned to code F43.1 (demolition and site preparation) within the industry branch classification scheme NACE (EC - NACE (2010)). In 2012 nearly 170.000 enterprises of this sector represent 5% of all construction activities in the EU. 95% of these enterprises employ less than 10 persons and only 3.5% have more than 50 employees (EC – Eurostat (2015)).

1.2 Processes of construction materials management

The demolition process of buildings and infrastructures is at least as complex and sophisticated as the construction process. Figure 1 (own representation based on DA (2015)) shows the classical process steps, starting with building auditing to plan preliminary decontamination and site clearance followed by demolition, crushing, sorting, reprocessing and recycling processes. Furthermore, involved stakeholders are assigned to each project stage.

[1] In parts of the world, where resource recovery is the standard, the term "demolition" is used synonymously with the terms deconstruction, dismantling and disassembly. But for most of the world, demolition with no thought to materials recovery is the standard and deconstruction is the best practice exception related to the careful disassembly/dismantling of buildings to recover materials for reuse. Hence, in the following, the term demolition is used in general terms.

In the auditing and planning stage, the client, planning engineers and depending on the type of structure also authorities formulate the tender specifications. The decontamination and demolition companies audit the structure themselves and bid for the project. During auditing and planning, national guidelines are applied depending on the gross volume and characteristics of the building/infrastructure to be deconstructed.

In the preparation and demolition stages, the accepted company plans the previous steps. Depending on the type of structure and available space onsite, different demolition, crushing and sorting techniques are applied to disassemble building elements and break the material into transportable or reusable pieces. During preparation and demolition, legal regulations regarding occupational health and safety, including impact limits, protection measures, etc. have to be applied. Furthermore, national guidelines are applied regarding best practices in demolition, namely deconstruction, processing and sorting such as in the German standard DIN 18007:2000-05. Especially, the prevalent type of construction, the prevalent materials, space availability, available (state-of-the-art) resources and entrepreneurial calculus determine the choice of technologies and applied resources in deconstruction, crashing, sorting and recycling processes. Within this context, waste fraction types and recycling paths/quotas of deconstruction materials are usually not predefined. Hence, the definition is left to the demolition companies, which face the challenge to constantly produce recycling material of good quality under changing and often not influenceable conditions.

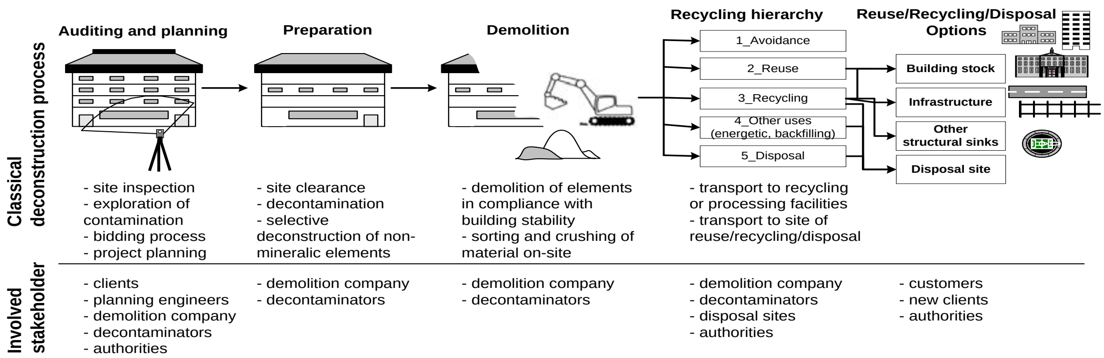

Figure 1: Classical demolition and reuse/recycling process (own representation based on DA (2015))

In the reuse, recycling and disposal stages, materials are reprocessed, crushed, sorted, etc. to gain recycling materials of defined quality (e.g. defined in the German standard DIN 4226-100 for recycled aggregates) or to be classified into waste fractions of different qualities and prices. During reuse/recycling a plethora of legal, often regionally differing regulations have to be applied. These regulations address material quality and waste classifications, contamination limits regarding soil and health protection, allowed reuse/recycling options as well as transportation allowances. Major potential customers of recycling materials are authorities (for instance, regarding road works) and individual consumers with resource-saving attitudes.

1.3 Level of professional competency and business processes

Depending on the diversity of involved stakeholders, education in the demolition sector encompasses very different professions and degrees. Table 1 (own representation based on DA

(2015)) gives an overview of the most common professional educations related to the type of stakeholders involved in the demolition process.

Table 1: Overview on educational degrees in the demolition and recycling industry (own representation based on DA (2015))

Stakeholder	***Profession/degree***
Planning engineer	*Architect, civil engineer*
Demolition site manager	*Civil engineer*
Health and safety coordinator	*Architect, civil engineer*
Foreman	*Master craftsmen*
Equipment operator	*Operator*
Skilled worker	*General training related to construction work (brick layer, concrete worker) and special training related to demolition work*
(Unskilled) worker	-

In organizational terms, the demolition process (especially the deconstruction process) has project character, similarly to the "normal" construction process. A client, who is usually consulted by a planning engineer, calls for tenders and then accepts an offer of one demolition company. This company either performs the actual demolition process on site itself or acts as a main contractor and assigns single tasks to subcontractors and experts. Usually, for each demolition project new project teams are created. The engagement of subcontractors often follows long-term cooperation/alliances. In general, at least the removal of hazardous materials is done by a subcontractor. Following demolition on site, deconstruction material is landfilled or recycled, either by the demolition company itself or a special recycling company (DA (2015)).
Demolition works are one of the most dangerous jobs in the construction sector, due to confined space on site, parallel work, time pressure, hazardous materials, harmful impacts, such as noise and dust, as well as regularly unpredictable building statics and working conditions (Gabriel et al. (2010)). Hence, for instance in Germany a coordinator for safety and health matters has to be employed by the client by law, according to the construction site ordinance (BaustellV (2004)), when more than one contractor (including subcontractors) work on site. This coordinator consults the client, the planning engineer, the demolition company and subcontractors during planning and execution of the demolition process (§3, BaustellV (2004)).
Furthermore, often a waste concept has to be designed beforehand, where created debris /recycling material has to be quantified and their disposing has to be clarified. For instance, in Germany demolition companies can receive a quality label for deconstruction works by fulfilling defined and regularly controlled quality criteria, for example related to education and skills of employees and subcontractors as well as quality of equipment (RAL (2015)). In Germany, Denmark and Netherlands, paper-based documentation of buildings is dominating (Brewer and Mooney (2008)). Project progress and performance is almost daily reported to the project planner and controller via tablet or cell phone.

2. Leading Edge

2.1 Leading construction materials management industries

To identify leading companies in the demolition industry, it is suitable to look at major demolition tasks and respective leading companies performing these tasks. Tasks can be roughly divided into two main tasks levels: On the one hand, demolition is performed on different structure types, including complex bridges and viaducts, high-rise buildings, and industrial and chemical plants. On the other hand, demolition works are carried out in different sectors, such as the energy, petrochemical, infrastructure, education, industrial, residential and commercial sector. Related to demolition works in different sectors, there are some synergies with residential recycling, waste-to-energy and landfill gas-to-energy facilities. The tasks within these levels can overlap. As, the industry is scattered into small and medium sized enterprises, an overview of leading companies in the industry according to the outlined tasks is difficult. Nevertheless, Table 2 (own representation based on the scope of this report) shows a selection of leading companies and associations of different countries based on the scope of this report.

Table 2: Selection of leading demolition and material recycling companies and associations based on the scope of this report

Country of origin	***Company/institutions name***
Australia	*Instant Waste Management; Liberty Industrial (Deconstruction, Remediation & Civil); National Federation of Demolition Contractors*
Canada	*Milestone Project Management, Winnipeg; 3R Demolition*
Germany	*German Demolition Association (Deutscher Abbruchverband e.V., DA); RAL Community of Goods for Demolition Works (RAL Gütegemeinschaft Abbrucharbeiten); Gesamtverband Schadstoffsanierung e.V.*
Netherlands	*Nihot air recycling technology*
UK	*Absolute Demolition Ltd*
US and Canada	*National Demolition Association; Building Materials Reuse Association; Construction Materials Recycling Association*

2.2 Leading life-cycle-oriented management of construction processes

Common practices of deconstruction[2] of the demolition industry are (DA (2015), VDI/GVSS 6202 (2012)): Identification of hazardous materials, such asbestos; inventory listing of materials to determine, where each item will be sent; structural deconstruction starting from the roof down to the foundations and non-structural deconstruction, such as the removal of appliances, windows, doors and other finishing materials, which can be marketable components. Further practices are: cleaning and/or refinishing of materials after separation from the structure to increase the material value; secure and dry storage of dismantled building components; location of material salvage, encompassing non-profit reclamation yards and dismantling contractors and on-site or off-site recycling of materials that cannot be salvaged or taken to landfills. Additional

[2] The careful disassembly/dismantling of buildings to recover materials for reuse.

aspects, which are considered especially by leading stakeholders of the demolition industry, are: Bespoke risk assessments and method statements, compliance with standards (such as BS6187:2011) - safe systems of work, state-of-the-art, high-tech demolition specific equipment, experienced and trained personnel and best practice and innovation.

Diverse processes of deconstruction and recycling related to these practices and additional aspects and up-to-date leading deconstruction and recycling processes based on the scope of this report are outlined in Table 3 (own representation based on the scope of this report).

Table 3: Overview on life-cycle-oriented construction material management processes based on the scope of this report

Main process	***Description/content/application***
Integrated design & Design for deconstruction processes	- *Upstream approach considering deconstruction during their design process.* - *Combination of simple construction methods with high-grade, durable materials with visible separation layers and mechanical fasteners such as bolts.* - *Deconstruction, Separation and disassembly of components / building elements.* - *Standardized materials, inventory systems for reclaimed materials (via bar codes, RFID,GIS) and their consistent application throughout the project.* - *Avoidance of difficult construction methods and materials in deconstruction such as nails and adhesives.* - *Avoidance of hazardous materials altogether.* - *Avoidance of mixed material grades to improve material quality.* - *Saving/ Adaptation of existing structures to new needs.* - *Modular building elements, that can be reconfigured as desired.*
Deconstruction processes	- *3D Demolition Simulation software for Extreme Loading for Structures (ELS) (Roaf et. al (2004)): used to model the collapse of a building. ELS software is based on structural-analysis using the applied element method (AEM) for tracking of cracks, separation of elements, and collapse of structures under extreme loads. ELS provides demolition scenarios and predictions for structural defects resulting from seismic activity as well as visualisation of forecasted structural responses.* - *Smartwaste software tool developed by Building Research Establishment (BRE): assists in preparing and implementing Site Waste Management Plans and waste monitoring reporting. It includes a calculator for costs of embodied energy of waste and labor for waste disposal as well as an interactive map to find for instance waste management facilities, recycling sites, transfer stations and landfill sites as well as local reclaimed and recycled products and equipment for recycling and reprocessing.* - *ERO Concrete Recycling robot: conceptual robotic concrete demolition machine that also bags the crushed aggregate in the same process.*
Innovative on-site and off-site recycling processes	- *Full site assessment: identifying decommissioning requirements and other separate assets to maximizing material value and recovery. Maintaining the building stability during structural separation and alterations.* - *Soft Stripping: non-structural deconstruction of internal fixtures and fittings.* - *Single stream recycling plants (off-site): sort waste materials.* - *Diversion and Recycling Tracking (DART): online tool used to process waste materials from building construction and demolition sites.* - *Separate handling of building plastic and electronic waste.*
Separation processes	- *Vacuum systems for separating film plastics.* - *Magnets for recovering ferrous metal.* - *Optical-sorting technologies for separating wood and aluminium. For instance, cameras and laser technologies to identify and sort objects and materials.* - *Vibratory Screens for separating small stones and rocks, for reuse in construction.* - *Gypsum plasterboards and blocks "closed-loop" recycling: recycling process separates gypsum from paper and both materials return in their original products.* - *MRF (Material Recovery Facility): can recycle between 80 to 90 % of construction demolition waste in a single skip bin system. The facility extracts a variety of materials, including sand, wood, metals, brick, light materials and concrete by a rotating electro magnet, a flotation tank, a sand oscillation screen and a shredder.* - *Bulk Handling Systems (BHS): automated process for sorting significant percentages of the C&D material which is made up of small pieces. Eliminates inefficient hand sorting and keeps these materials out of the landfill.*

	- *Air Separation Technology (AST): accurately separates rock, wood and light material by using air pressure, wind shifters and drum separators.* - *Pneumatic vacuum systems for small rubble removal (intended for post disaster demolition process) and commercial machinery used currently only for loose stone such as roof ballast.* - *Brick mortar removing power tools that plane or grind off the mortar.* - *De-nailing guns for nail removal.*

3. Perceived Problems and Challenges and Potential Solution Approaches

Aim of deconstruction and recycling of construction materials and buildings is to drastically reduce the deployment and consumption of primary non-renewable construction materials. Actual barriers in this industry can be found in Nakajima and Russell (2014). Furthermore, challenges faced to design for deconstruction make it difficult for architects to incorporate material recovery procedures into the initial building design (Hobbs & Adams (2012)). In the following different challenges are further described and analysed.

3.1 Technical challenges

Technical challenges of the deconstruction and recycling industry are often caused by unknown material qualities in existing buildings that are deconstructed. Establishing the structural performance of reused components can be perceived to be difficult by engineers who will be hesitant to use salvaged structural components unless they have been tested in accordance with current standards. This hampers reuse and recycling options. Hence, relevant technical developments to enhance reuse, recycling and waste tracking are economical material sampling methods for decontaminations and material quality measurements and documentation. These would enable fast determination of material quality and subsequent options of recycling material usage based on regional material demands. Within this context, actual knowledge on regional demands is required to locally reuse materials, which leads to one issue of organizational challenges (see section 3.4).

Furthermore, the use of non-reversible joints can make the deconstruction of building components difficult or impossible and therefore state technical challenges of design for deconstruction. For instance, in North America wood frame dominates residential low-rise building, which are often difficult to dismantle due to a large number of fasteners (Falk and Guy (2007); Davis (2012)). Framing members such as stick framing or trusses for roofs can be dangerous to remove and may require special equipment or bracing during the deconstruction process. The use of mechanical and easier to loosen joints might reduce this technical challenge.

Also, innovative approaches for automated separation and decontamination of building elements e.g. via robots or self-controlling machines are required. They seem promising for instance, in the context of separation of outer walls thermal insulation composite systems, separation of layer composites as well as decontamination in contaminated sites and in decommissioning and deconstruction of nuclear power plants, such as the system MAFRO (Baulinks (2015)).

Furthermore, technical development of cost effective methods of raw materials sorting and of material processing plants are required to produce secondary raw-materials of constant quality. This also includes optimization of existing processing plants.

Further technical challenges exist in the automation of deconstruction processes, such as the acquisition of building information, processing of analogue and digital building information, operative project planning, emission management or site surveillance and control, e.g. via sensors. The application of digital building models and sensors onsite would enable planners and deconstruction companies to automatically plan, track and document project performance and related impacts on employee's health or the local environment, such as adjacent neighbours or buildings. However, the demolition industry seldom adapts digital building models and planning methods, yet. At the moment the digitalization is limited to digital building documentation via Word/Excel on tablets.

Moreover, good examples demonstrating effectiveness of design for deconstruction, of selective deconstruction, material recycling and reuse are required to overcome technical challenges.

3.2 Economic challenges

Major economic challenge is the lack of economic incentives to use recycling materials in new constructions in most countries. Reasons are comparably cheap raw materials and low costs of construction units, expensive material sampling methods, differing material qualities of recycling materials and temporal and spatial divergence of demand and supply.

In many countries the main structural building components are often not salvaged due to a perceived lack of demand. Only single, high value, quick sale items are usually collected by selective deconstruction and often sold to a heritage market. This problem is one of both, supply and demand. Retailers do not carry products that are not demanded and consumers do not buy products they do not know. This is closely related to the awareness of the value of reclaimed building components. Sampling of built-in materials or building elements and tests of reclaimed components for structural integrity are costly and impede material quality determination and material reuse/recycling options. Although there are some national and regional online marketplaces and platforms for recycling materials and used building elements (in Germany on national[3] and regional[4] level; in Austria[5]; Canada[6]; Netherlands[7]), the comparability and quality assurance of the offered materials/elements are not always given. Some clients even specify that they want all "new" materials. Here the liability of designers or recyclers can be a significant concern. "Without legislative action to create an artificial economic driver, the current market for deconstructed material is […] to remain economically feasible" (Nakajima and Russell (2013)). Widely spread recommendations among countries are to "encourage financial burdens on the landfill process through tipping fees or taxes" to force reuse/recycling or "provide financial incentives for efficient designs that facilitated end of life deconstruction" and recycling (Nakajima and Russell (2013)).

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[3] http://www.euwid-recycling.de/recyclingboerse.html, http://www.ihk-recyclingboerse.de/, http://www.bauteilnetz.de/bauteilnetz/website/stdws_adresse/bauteilboersen.html
[4] http://www.bauteilboerse-gronau.de/aktuelles.html, http://www.bauteilboerse-bremen.de/, http://www.ihr-umweltpartner.de/Gebrauchtboerse.html?kat=anzeige&ukat=step2&view_boerse_kat=14
[5] http://recycling.or.at/rbb/cake_rbb/
[6] http://www.owe.org/, http://www.greenguide.com/exchange/
[7] http://www.oogstkaart.nl/oogstkaart/

Furthermore, the demand is low, as reused building components are currently not available. More work is required by the design team to anticipate material requirements and identify potential sources. The question is, if there is enough of a single used component type to meet the demands of a new construction project. Then, design would need to be adaptable. Furthermore, production costs of recycled concrete aggregate vary depending on its use. Concrete components of existing buildings may need to be stored, moved and transported between sites and locations that might result in higher costs for new construction projects. Moreover, recycled aggregates might contain contaminant residuals, which reduce the compressive strength of the aggregate by up to 18% (Chini, et al (2001)). If the quality of recycled aggregate is lower than the virgin aggregate materials, the price should also be lower. However, the cleaning, processing, inspection, storage, and sale of recycled aggregate can result in higher costs than virgin aggregate. Other materials such as timber are extremely cheap to buy new and clean (e.g. in North America). Also, they are difficult to separate from other building components. Hence, there is very little economic perspective in recycling these materials.

In general, many industry professionals state that deconstruction result in higher overall costs for a project than traditional demolition and landfilling. Without a clear market and value for salvaged products little attention is paid to maintaining quality of demolition products. Moreover, according design for deconstruction additional time is often required for architects and engineers to include the added features to facilitate building deconstruction.

3.3 Ecologic challenges

Major ecologic challenges are that information on the life cycle of products as well as planning for end of service life are rarely considered and not yet mandatory at the building design stage (design for deconstruction). Values for use of reclaimed materials are mainly aesthetic and there are health concerns regarding the use of recycled material, which might contain hazardous substances. Environmental benefits are secondary.

Environmental product declarations (EPDs) (ISO (2006)) quantify ecologic information on the life cycle of products, based on Life Cycle Assessment (LCA) studies of independent institutions. EPDs represent a complete, robust and scientifically validated source of information of the environmental impacts of products along their life cycle. Even though they are not yet mandatory, EPDs are defined as a source of quantitative information on product life cycles in a standard way by the European Commission (EC, 2003). When available, EPDs can be used to assess the use of resources and the impact of construction works on the environment, according to the Construction Products Regulation (CPR) (EP (2011)). EPDs of construction products based on recent European standards (CEN (2011), (2013)), with the environmental assessment of construction waste flows, can be an important source of data for decision-making at the end-of-life of building materials and to ‘close the loop’ in their life cycle. Nevertheless, most EPDs are cradle to gate, including recycled content but no waste management processes or “recyclability” except in uses of steel and other metals, where recycling is more or less guaranteed. Hence, these gaps in reused/recycled materials for standards of life cycle stages, inventory data and allocation rules are major issues in the adoption of LCA.

Furthermore, if design for deconstruction would become a requirement or common practice, the likelihood of major portions of the building being salvaged can be greatly improved and the environmental impacts of that stage can decrease.

3.4 Organizational and educational challenges

A major organizational and educational challenge is a lack of knowledge by designers and builders on issues of component reuse. Designers are often not aware of supply sources and of actual materials. Although this issue has been highlighted by many green building rating programs, it is not highlighted in education programs, which tend to focus on waste reduction on site. The producer responsibility in the construction industry is not well established, and return of materials/components to their source only occurs if they have economic value. Many residential constructions are not big enough to fall under the regulations that do exist. Therefore, the client is not forced to provide a waste management plan and any demolition waste is most often sent to landfill, but may implement material reuse where gains can be created. Furthermore, this lack of awareness makes demolition crews more likely to work recklessly and simply remove components as quickly as possible. Deconstruction and reuse still tend to be a niche activity. Although there are various resources available including scattered retailers and deconstruction practitioners, the mainstream industry seems unaware of the possibilities of reuse and the value of the existing materials. Within this context there is also a lack of consistent standards that include deconstruction. Hence, it is difficult to provide specifications for carrying out deconstruction and/or supervising the deconstruction process.

Besides, there are other organizational challenges due to logistics and scheduling. Demolition is usually on the critical path and contractors are under time pressure. Ironically a building may have sat derelict for years but as soon as a new project is planned for the site there is very little time to carefully deconstruct the building. Hence, deconstruction as a slower process to remove the building is not performed. Additionally, often space and cost constraints prohibit the use of sorting bins for different materials on site. Furthermore, infrastructure is needed to collect, transport, store, and prepare salvaged components. But this infrastructure is rarely available.

Moreover, there is often a lack of cooperation among all parties, including owner, designers, contractors, subcontractors, and waste haulers about resource stewardship. If any of the interested parties do not fully grasp the purpose of deconstruction, it can hinder the entire process. A thorough understanding of the project’s plan and goals are often not shared with all parties are not monitored.

3.5 Political/legal challenges

At present there are no legal requirements in any country for clients or contractors to consider deconstruction at the design stage. Furthermore, the obligatory use of recycling materials in the construction sector is not implemented in many countries yet except for concrete in Switzerland and the monetary incentives against landfilling are not high enough. Although many central and local governments are supportive of reducing waste, the issue of reuse is not in the focus of decision makers, such as politicians and clients. Sometimes it is even a threat to existing resource supply industries.

4. Leading national and global initiatives on deconstruction and construction materials management

Finishing the research in state of the art of demolition and reuse and recycling of construction materials, on-going national and global initiatives in the area of deconstruction and reuse/recycling of construction materials are summarized. The entities and stakeholders in charge of these initiatives and developments are associations, research centres and countries. The first type of initiatives is legal actions - such as specific regulations developed worldwide and related to construction material stewardship. Most of them are promoted by national governments. A summary of these initiatives based on the scope of this research is presented in Table 4 (own representation) for raw material extraction, material recycling process and use of recycled C&D material, respectively. The second type are global initiatives with a broader impact, for instance at the European level, such as the European Demolition Association (EDA (2015)). The promotion of European standards on demolition techniques and on recycling of demolition waste are major objectives of this institution.

Table 4: Regulatory initiatives at a national level related to material recycling processes, raw material extraction and the use of recycled C&D material based on the scope of this report

Country	***Specific regulation and content***
Canada	- *Canadian Standards Association CSA Z782-06:2012. guide for deconstruction, disassembly and adaptability of buildings* - *Construction and Demolition Debris Deposit Program of San Jose: regulation on deposits of construction and demolition debris* - *Provincial aggregates royalty fees: royalty fees per tonne of aggregate extracted for instance in Ontario, British Columbia, Alberta and Quebec* - *Environmental Protection Act (EPA) Regulation 102/94. Requirements for waste audit before demolition, source separation (recycling) program*
Denmark	*Tax on extracted raw materials(sand, gravel, stones, peat, clay and limestone) and on waste.*
Germany	- *Closed Substance Cycle Waste Management Act (KrW-/AbfG (2000)): basic principles for waste management and closed loop recycling strategies. Waste management hierarchy - the first goal is waste prevention and avoidance* - *Ordinance about waste treatment (NachwV (2006)): way and scope to proof waste disposal and recycling* - *General technical specifications in construction contracts - demolition and dismantling work (ATV DIN 18459(2012)): extraction, storage and transportation of deconstruction materials/components based on the European Waste Catalogue (EWC)* - *Planned “substitute building materials ordinance”. Actual draft as at October 31st 2012: nationwide regulations on mineral alternative construction materials produced out of/ resulting from recycled construction materials* - *Standard of “aggregates for concrete and mortar - part 100: recycled aggregates (DIN 4226-100 (2002)): quality of recycled aggregates and the composition of construction materials with portions of recycled aggregates (concrete and masonry)*
Israel	- *Green Building Standard: voluntary principles for on-site waste management and closed loop recycling strategies* - *EPA: Municipal Solid Waste Landfill Regulations. operation and management of municipal solid waste landfills* - *Mining and Quarrying laws and regulations: planning and operation of quarries, increase efficiency of raw material extraction, such as aggregates, sand and cement* - *Requests for proposals and promoting obligatory use of recycled C&D waste: promotion of policy aiming at obligating contractors to use recycled C&D waste in buildings projects and public infrastructure*
Netherlands	*The Dutch building materials decree: quality criteria for the application and re-use of stony materials and earth used as building materials (Eikelboom et al. (2001)). Reduction of waste material disposal and raw material extraction (Hendriks and Raad (1997)).*

Portugal	- *Guide for the use of coarse recycled aggregates in concrete (LNEC Specification E 471-2009):requirements for coarse recycled aggregates used in concrete (according EN 12620)* - *Law-decree Nr.73/2011, July 17th: mandatory use of recycled materials in public construction*
Sweden	- *Tax on natural gravel: substitution of natural gravel use (Söderholm (2011a), (2011b)).* - *Regional material inventories of natural gravel and alternative materials (Söderholm (2011b)).* - *Quality standards for road construction materials and tender bonus: to tender construction firms to use crushed rock instead of gravel (Söderholm (2011b)).*
Switzerland	*Recycling of aggregates (SN 640740, SN 640743 (1993)): obligatory recycling and use of RC concrete in new construction*
United Kingdom	*Taxes on aggregates: taxes on all extracted aggregates and imports (with the exception of recycled aggregates: sand, gravel and crushed rock used in construction)(Söderholm (2011b)).*
USA	- *Municipal C&D recycling rate requirements in Chicago and Washington* - *Municipal mandatory C&D recycling, materials separation and deconstruction and reuse requirements in Seattle, Portland and Chicago* - *C&D materials landfill ban in Massachusetts*

5. Conclusion

The analysis of the state of the art of demolition and reuse and recycling of construction materials shows that the leading institutions are very fragmented and leading processes are diverse. This reflects the actual structure of the construction and demolition industry, which is dominated by small and medium sized enterprises and includes diverse stakeholders and processes. Consequently, especially international activities are difficult to implement, as shown by the analysis of leading national and global initiatives.

The major aim of deconstruction and recycling of construction materials is, to drastically reduce the deployment and consumption of primary non-renewable construction materials. The identified challenges related to this aim show that current activities are highly driven by costs. Particularly, country specific regulatory initiatives are identified to meet these challenges.

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