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The Use of Innovative Remediation Technologies in Brownfield Redevelopment Projects

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The Use of Innovative Remediation Technologies in Brownfield Redevelopment Projects

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ABSTRACT:

One of the working packages of the City of Stuttgart within the REVIT-project was the examination of the application of *innovative remediation techniques in brownfield redevelopment projects*. Before starting this research in detail, a useful definition for the phrase *innovative remediation technology* had to be found. In technical and scientific literature, the term *innovative remediation technology (IRT)* is a common description for a *new remediation technology*. Discussing the definition of IRT during a workshop with an international team of experts from Great Britain, the Netherlands, Swiss and Germany, it could be seen, that different ideas are associated with this term based on country-specific requests. As a result of this investigation, an IRT was defined as a technology in the development stage between a *state-of-science-* and a *state-of-the-art-technology*. A common use for IRT are pilot tests or pilot full scale applications. Due to this definition, the application of IRT in brownfield redevelpment projects might be difficult due to a number of uncertainties for pilot applications.

In a second step of this study the City of Stuttgart and reconsite - TTI GmbH examined several different brownfield redevelopment projects. The aim of this research was e. g. to identify of the site specific reasons for the application of a specific remediation technologies. As standard remediation technologies within brownfield redevelopment projects, *excavation and disposal* for the unsaturated zone and *pump and treat* for the saturated zone could be identified. In rare cases, other *techniques* like containments or immobilisation procedures have been applied in the unsaturated zone. According to the definition, these *alternatives* are not IRTs due to their high standard of proven applications. In the saturated zone, the application of *alternative remediation techniques* (e.g. Funnel & Gate, Air sparging) seams to be much more common, but also no IRT had been found in combination with brownfield redevelopment projects. Based on the IRT definition, their application could not be identified within the examined projects.

Introduction

The clean-up of contaminated land is seen as a significant obstacle to the redevelopment of real property, although a large number of different remediation technologies are available nowadays. Among these are also newly developed technologies, which are often described as *innovative remediation technologies (IRT)*. Considering the special site conditions in the area of brownfield redevelopment, it has to be clarified, which remediation technologies have been applied on brownfield redevelopment sites and whether the remediation techniques can be named *innovative*. To answer this question, the term *innovative remediation technology* must be defined. Up to now, no general definition for IRT exists, which makes the use of this term for a wide range of applications possible without giving a useful characterisation of the innovative character. Following several well-established definitions in other fields of technical applications, a definition of IRT has been developed for further use and reviewed by an international group of experts.

Based on an investigation of completed brownfields redevelopment projects, it is shown, which remediation technologies are applied in practice for land redevelopment. The main purpose was to find out the reasons for the choice of certain remediation options and the experiences concerning the practical implementation. For this reason, the city of Stuttgart carried out an inquiry together with the reconsite - TTI GmbH in order to analyze and assess brownfields redevelopment projects.

The results of this study and the definition of *innovative* were discussed during a REVIT-Workshop, held in January 2007 in Horrheim, Germany.

Innovative Remediation Technologies

Introduction

The term *innovative remediation technology* is well-established and commonly used although no general binding definition of the term is available. Several national and international experts have been contacted and current publications have been reviewed in order to define the term of IRT for further use.

In colloquial language, the term *innovative remediation technology* is used for a *new remediation technology*. Currently an expert committee of the German scientific-technical brownfields association ITVA is discussing the term *innovative remediation technology* related to its work on in-situ remediation technologies (Koschitzky 2006). It is planned to issue a report that will also contain a chapter of definitions, which will define terms such as *innovative*, *state of the art* and *acknowledged rules of technology* in order to clearly distinguish between conventional standard technologies of long standing and current *innovative* technologies.

The term *innovative remediation technology* is also used in the name of a board of experts of the altlastenforum Baden-Württemberg e.V. dealing with remediation technologies. In the introduction to one of its publications it says: *"The Board for Innovative Investigation, Remediation and Monitoring Technologies […] has […] undertaken the task of identifying promising innovative technologies […], analysing the possibilities of application and presenting the results of this analysis in the form of up-to-date short status reports. […] Only technologies, which have reached a level of development that can be described as "fit for implementation in the field" will be considered."*

Within the framework of the EU funded project EURODEMO, a Canadian definition concerning the issue of innovation was introduced during a workshop in Vilnius, Lithuania on 14 September 2006: *"Innovation is the process of transforming knowledge into new products, processes and services which, in turn, generate new economic benefits. For this process to succeed, a complete system must be available that supports the movement of a new idea from initial concept, through research and development to a ready-for market product (Western Economic Diversification Canada, http://www.wd.gc.ca/innovation/)."*

Another expert reflected, that it would be possible to paraphrase *innovative* as *state-of-the-art* and the decision as to whether a specific technology can be called innovative or not would have to be taken individually in each case. Criteria for the decision could be the number of reference sites, where this technology has been applied and the general acceptance of the authorities. In principle, these criteria are independent from the *age* (e.g. time since the first application) of the technology in question. A technology developed years ago could still be described as innovative, if it has not been approved by the authorities yet, so that it is actually not available on the market.

However, authorities and investors (paying clients) exhibit a higher need for security – particularly if innovative technologies are employed – in order to minimize risks such as potential failure of the technology or rising costs (irrespective of the cause, which might be site investigation as well as remediation technology).

A different aspect is covered by the definition proposed by another expert, who takes into account the *principle of sustainability*: In terms of sustainability, innovative technologies are characterised by a reduced consumption of energy and resources and reduced waste production. Sustainable remediation technologies according to the Rio-Declaration are therefore characterised by minimized ecological footprints.

It still has to be determined, whether even a significant reduction of energy or resource consumption through innovative components as mentioned above would come under the heading of *innovative*. For instance, it is possible to halve the energy consumption of conventional soil vapor extractions through the use of thermal in-situ methods (Hiester & Schrenk 2005).

Derivation of a Definition

An approach to define IRT in contrast to conventional remediation technologies could be based on the fact, that this term denotes technologies, which have not been considered state-of-the-art for long time. According to the free encyclopaedia WIKIPEDIA, state of the art is *"a technical term that describes the technical possibilities at a certain point in time, based on reliable and proven knowledge of science and technology. […] It is the level of development of an up-to-date technology, which allows the practical application of this technology with a sufficient reliability concerning the meeting of defined targets. Nevertheless, at this level sufficient long-term experience is still missing and only experts are familiar with the technology in detail. For this reason, civil engineering standards usually require the meeting of "acknowledged-rules-of-technology" instead of state-of-the-art technology. In the context of patent law, "state-of-the-art" denotes technologies, which are already made available to the public, i.e. which have been published in any form. The most important requirement for obtaining a patent is that an invention is novel, i.e. that it clearly differs from the state-of-the-art. Consequently, "state of the art" is a fundamental term of patent law. In patent specifications, frequently the term "state-of-the-art" or the synonym "prior art" is referred to in order to describe the current level of technology, followed by a description of the innovation."*

In Germany, a definition of state-of-the-art technology is also given in the Federal Imission Control Act § 3 (6):

"State-of-the-art in the legal sense is that level of development of up-to-date technologies, which is generally considered as sufficient to ensure the suitability of these technologies for the following goals: limitation of emissions into air and water, guarantee of plant safety and environmentally safe waste disposal and avoidance of any other impact on the environment to achieve a high level of environmental protection. For the determination of state-of-the-art technologies, particularly the criteria shown in the appendix have to be taken into account."

In the appendix to the Federal Immission Control Act the following criteria are listed regarding § 3 Abs. 6: *„For determining the state-of-the-art, while considering the cost-benefit relationship of potential techniques and the precautionary principle, the following criteria have to be taken into account (in each case relating to plants of a certain type only):*
1. Application of technology minimising waste production.
2. Application of technology using materials with a low risk potential.
3. Promotion of the recycling and reuse of materials used and waste produced with a particular technology.
4. Scientific and technological progress.
5. Type and amount of emissions produced and their impact on the environment.
6. Time needed for the start-up of a new or existing plant; time needed for the implementation of a better technology that is available on the market.
7. Consumption of resources and types of resources used for a particular technology (including water); efficiency of energy use.
8. Necessity to minimize the overall impact of emissions and to avoid or reduce the risks for man and environment as far as possible.
9. Necessity to prevent accidents and to minimize their consequences for man and environment.
10. Information published by the European Commission in connection with (Art. 16 Abs. 2 of the Council Directive 96/61/EC of the 24 September 1996 concerning integrated pollution prevention and control) or published by international organisations.
A definition similar to the one given in the Federal Immission Control Act can be found in the Federal Water Act § 7 "Requirements for the discharge of wastewater".
Based of these findings and discussions, the following definition for an innovative remediation technology was suggested:
An innovative technology for the remediation of soil or groundwater contamination is defined as a technology in the transition phase between the state-of-the-art and acknowledged-rules-of-technology.
Criteria for the classification can be found in the corresponding appendix of the Federal Immission Control Act.
This definition was presented and discussed in January 2007 with experts from GB, Netherlands, Switzerland and Germany during an international REVIT-Workshop. The workshop showed, that it is difficult, in fact almost impossible, to find a common definition due to the individual points of view and the different conditions in the European countries. Most of the German experts agreed with this definition, but the experts from the other European countries disagreed with this suggestion of the definition, because their understanding of the term state-of-the-art is different. Another fact is, that the terms "state-of-science", "state-of-the-art" and "acknowledged-rules-of-the-art" as criteria for differentiation are not commonly used in other countries.
Common sense in context of a definition was that an innovative technology is between the step of state-of-the-science and the step state-of-the-art, but there is no clear border dividing innovative and non-innovative technologies. A combination of different remediation technologies was described not as an innovative solution, but as an intelligent solution.
The period of time, in which a remediation technology can be defined as *innovative*, is shown schematically in Figure 1.
<Figure 1 goes here>
Figure 1 Definition of *innovative remediation technology* (IRT) in the chain of technological development

The consequence of this definition is that a lot of remediation technologies, which are assessed as innovative technologies, are not really innovative technologies. But it was agreed, that the question whether a technology is innovative or not, plays no role for the choice of a remediation technology. It is more important to choose the best available technique for a site.

Results of the Investigation about Brownfields Redevelopment Projects

Investigation Procedure

The data collection concerning brownfield redevelopment projects was carried out by analyzing publications in scientific journals and conference proceedings and by an online inquiry conducted by the city of Stuttgart. The collection of 35 projects that originated from that inquiry has been analyzed by the reconsite - TTI GmbH in collaboration with the city of Stuttgart. Projects that were interesting with regard to this study were singled out from the collected data. During the investigation, further information about other projects emerged; those projects were also incorporated into the investigation. In total, information from 50 projects has been reviewed.
With the help of schematic record sheets, the projects were characterized in a uniform way. For this, the projects were analyzed by employees of the city of Stuttgart and then transferred on the record sheets. The record sheets of each particular project were sent to the concerned project managers (environmental authorities, engineering consultants, property owners etc.) to clarify remaining questions. The results of this data preparation were examined critically by the reconsite - TTI GmbH. This examination partly resulted in further need of clarification about details. The analysis and the compilation of the study by the reconsite - TTI GmbH was carried out based on the completed record sheets.

Results

Remediation Technologies applied for Brownfields Redevelopment

In total, 50 projects were collected for this study. Of all these projects, 40 were analyzed and the results of these projects were used for the study. Of those 40 projects, 14 projects were analyzed in detail.
The results show that only a few remediation technologies are applied more widely for

brownfields remediation. The standard procedure in the unsaturated zone is in most cases *excavation & disposal;* in the saturated zone it is *pump & treat*. In some cases, alternative remediation technologies were used. The following Table 1 shows an overview of the technologies that were applied. In general it has to be noted, that in many of the analyzed brownfields redevelopment projects, several different remediation technologies were used at the same site due to the heterogeneity of the contaminants found there. For this reason, the number of remediation applications given is higher than the total number of projects.

In general, technologies for the remediation of the unsaturated zone (soil remediation) and technologies for the remediation of the saturated zone (groundwater remediation) have to be distinguished. Some of the technologies can be used for both zones.

<Table 1 goes here>

Table 1: Overview of remediation technologies applied in the analyzed projects.

Unsaturated Zone (Soil Remediation)

For many of the projects, the remediation of the unsaturated zone was carried out by excavation of the contaminated soil and either on-site containment of the material (containment technology) or disposal or on-site/off-site treatment and subsequent disposal. Excavation and disposal was used for 29 of the 40 projects (about 70 %).

In this context, the term (waste) disposal encompasses the reuse and the destruction of wastes (§ 3 KrW-/AbfG Abs. 7). The material was "reused" e. g. on landfill sites for surface modelling and landfill road construction. In the analyzed projects, manifold reasons were given for choosing the option excavation and disposal:

- For many projects, the demanding deadlines didn't allow for long-term remediation measures, due to the fact that the marketing of real property already had started,
- the low costs for the disposal of contaminated soil, e.g. 12 €/t,
- need for a definitely clean site, as the site will be used as residential area in future, resulting in correspondingly high demands concerning environmental standards,
- the excavation area was used for the foundation of buildings and for underground structures, or an excavation was required anyway due to dismantling of buildings on the site,
- clearly defined point sources of contamination or e.g. filled up bomb craters

However, cost-effective disposal (e.g. landfill costs) should be regarded critically, as disposal costs only constitute a part of the total remediation costs. The depth of the contaminant source and the resulting additional expenditure for the excavation (e.g. large volumes needed for slopes, sheeting, special excavation methods (e.g. large hole boring)), the accessibility (e.g. open space or below a building), the surroundings (e.g. industrial area, city center area) and last but not least occupational health and safety issues on the building site and the periphery (e.g. pollutants escaping into air, building noise, truck transports, black/white plant) can be of decisive importance for the total remediation costs of a particular project.

Besides the disposal of excavated, contaminated soil on landfills at some of the analyzed brownfields sites, an off-site soil treatment of the contaminated excavation material was carried out and the material was subsequently disposed of. Soil treatment influences the disposal route (e.g. disposal with or without prior processing); however, the application of technologies on the site itself is usually not affected. Soil washing (ex-situ), thermal treatment (ex-situ) and biological treatment (ex-situ) were employed in the analyzed projects as well.

Containment measures were employed at some of the brownfields projects analyzed. They were applied for the containment of contaminated areas on-site or for landsfills constructed on-site and pits. The containment of contaminants leads to a disruption of the exposure pathways.

On abandoned sites, surface sealing was carried out for instance through sealing by construction. Examples of this are the construction of a parking lot over contaminated zones or the construction of new buildings. The sealing as a consequence of construction leads to a reduction in the amount of leachate. For instance, at one site, the remediation goal was defined as a reduction of infiltration to ≤ 12 %. For several areas on this site, a complete surface sealing was necessary.

Methods for containment by surface sealing were developed first for landfills and meet the acknowledged rules of technology concerning emission protection and preventive groundwater protection. They are well-tried methods that are described in relevant rules and regulations (LANDFILL ORDINANCE - DEPV, TECHNICAL INSTRUCTIONS ON MUNICIPAL WASTE – TASI). Surface sealing methods can limit the future use of the site. On one of the examined sites, just buildings without a basement and with a surface foundation only are permitted, such as industrial buildings.

Due to the high building costs and the running costs (maintenance of reverse flow gradient), containment techniques constitute an economical alternative only for complex pollution cases and large areas or volumes. Sealed areas can be formed to dams or mounds by piling up contaminated material. Former commercial or industrial areas can take over the function of structuring the scenery due to these landscaping measures

Typically, maintenance has to be considered for all containment measures. This often includes a continuous treatment of the groundwater or the water from the insulated zones

The insulated zones are comparable to landfill structures and can extend into the saturated zone (below groundwater level) as well.

Apart from surface sealing and incapsulation methods, methods for the immobilization of contaminants are of special importance. These were employed on-site in two of the analyzed projects and off-site in one project (treatment plant). Immobilization methods are employed predominantly in the case of contamination with heavy metals (LUA NRW 2005). At the sites, where immobilization was used, treated soil was reintroduced on-site, in parts below roads and noise protection banks. These sites are going to be used as residential areas in future, which argues favourably for the acceptance of these methods.

Saturated Zone (Groundwater Remediation)

All remediation technologies in the saturated zone share the characteristic that they have to be operated over a longer period of time. During the operation time, the remediation facilities or installations (e.g. wells, funnel & gate) usually have to be accessible. For brownfields redevelopment, this characteristic results in the problem that remediation times for hydraulic measures in the saturated zone are difficult to estimate and the site owner is left with financial insecurities.

In the saturated soil zone, the following technologies were employed at the analyzed project sites:

- Pump & treat (P&T): The time needed for remediation with P&T technology is normally several years to decades. For this reason, P&T is often employed for protection instead of remediation of the site. An application with fixed remediation times and goals is only feasible in special cases. P&T can be identified as a standard technique.
- Air sparging technology was employed at a former gas station area during the brownfield remediation of a military site due to geological boundary conditions (depth of contamination in a hard sandstone, low yield of groundwater wells).
- Groundwater circulation wells (GCW)/Vacuum vaporized wells (UVB): A vacuum vaporized well was employed for the pollutant source remediation of a gas station at another military site. Advantages for the application of this technology at that particular site were the low costs in comparison to an excavation of the pollutant source and the improved treatment of the capillary fringe compared to a hydraulic technology (P&T). At the site, the remediation area could not be used for other purposes during the remediation process of seven years.
- Microbiological remediation methods in the saturated zone were applied in two projects.
- Funnel & gate systems were used at two sites. At one site the criteria for the choice of method were among others the prevention of contaminant transport into a second aquifer.

According to the definition of innovation these technologies are not innovative; they are classified as alternative technologies in relation to the "standard" pump & treat.

Criteria for the Choice of Remediation Technologies

An assessment of the investigated projects with respect to criteria given for the choice of remediation technologies, shows that the remediation costs, the future use, the time required for remediation and the technical reliability of the remediation technology are decisive for the choice of the method applied. In Table 2, the most important criteria are summarized.

<Table 2 goes here>

Table 2 Criteria for the choice of remediation technologies

The results of this assessment make it clear, that in general technical and economic criteria are essential for the choice of a remediation technology.

In numerous projects, the option *excavation & disposal* was investigated as standard method during the planning process. In cases where alternative technologies were preferred, the option *excavation & disposal* was discarded due to technical and economic reasons, meaning the contamination dimensions or the location of the contaminant led to a disproportionately high technical and economic effort. On those sites, more cost effective remediation technologies or other alternative technologies were employed.

In some cases, the technical feasibility of innovative technologies was decisive for their application, because a successful remediation was technically not possible with the standard methods excavation & disposal or P&T. Examples for this are the use of the funnel & gate method or microbiological remediation techniques.

In addition to technical feasibility, the predicted remediation costs – as shown above – were decisive for the choice of remediation technology. Costs were mentioned as a criterion (as shown in Table 2) by the interviewed persons, without giving numbers for the remediation options considered. The criterion costs was one of the reasons for the use of alternative technologies as well.

The time required for remediation proved to be another important criterion for the choice of remediation technology in some projects. In these projects, the option *excavation and disposal* or containment measures were employed in the unsaturated zone due to time constraints. In the saturated zone, the use of air sparging can be mentioned as an example. Conventional pump & treat technology would have resulted in a distinctly longer remediation time.

The future use of the site was important for some projects only. On these sites, *excavation and disposal* was employed; either because the excavated areas were used for building foundations or because the future use as a residential area made it necessary to have a site without *rest damage*.

Deficits of Data Collection

Basically, the quality of the collected information always depended on the data source and therefore on the position of the interviewed persons (expert, executive company, state authorities planner, geologist, etc.). For some projects:

- no complete information was available, as the projects were completed several years ago,
- the contact persons could answer the questions only from memory, which inevitably led to an impairment of the quality of data,
- information could not be collected entirely, as the contact persons were not allowed to give away information on details due to business discretion.

Conclusions

The analysis shows that the number of soil remediation projects is significantly larger than the number of groundwater remediation projects.

The option *excavation & disposal* was employed frequently for brownfields redevelopment and constitutes the preferred method for remediation. In more than 70 % of analyzed cases (see Table 1), an excavation of polluted material was used.
One advantage of the method *excavation & disposal* is the possibility to clean up contamination cases with widely varying contaminant mixtures (e.g. halogenated VOCs, BTEX, fuel contaminants, PAH, heavy metals) in one treatment step with conventional building technology, if required extended by black/white area. Moreover, this method can be used directly for the dismantling of old facilities, such as subsurface tanks. These synergetic effects do usually not occur with all other methods, as they are focused exclusively on the treatment of soil or groundwater. Other methods are mostly conceived for or only efficient with distinct groups of pollutants. The removal of contaminant mixtures is usually not possible with these methods.
In brownfields redevelopment projects, excavation for the removal of contaminant sources can generally be combined with construction work (e.g. underground parking or foundations). If the site investigation is sufficient, these processes can be adjusted already in the planning stage, so that synergetic effects can be used.
For this study, no information could be collected about the status of further developments in the field of off-site remediation methods. It can be assumed that technical developments for off-site remediation technologies are going to influence brownfields redevelopment, if they allow a reduction of costs compared to conventional methods and render alternative disposal methods compared to landfill possible. As many landfills in Germany are going to be shut down, this disposal route, which has been used extensively during the last years, is going to be closed. Corresponding changes in the market segment for the disposal of excavated soil can therefore be expected during the next years.
For the remediation of contaminations in the unsaturated zone, containment by surface sealing, vertical barriers and immobilization methods are employed as alternatives. The first two technologies are well-tried methods developed in the area of landfill construction.
The analysis of the projects shows, that there are no examples of employed IRT for the treatment of the unsaturated zone in brownfield redevelopment projects. The standard technology for the unsaturated zone in these projects is *excavation and disposal*. All other remediation technologies have to be described as alternative due to the definition of innovative.
This result for the unsaturated zone as demonstrated by the projects was already predicted during discussions with project managers in engineering consultant companies, environmental authorities and site owners during the search for projects.
In the saturated zone, *pump & treat* (P&T) is used as a standard technology for groundwater remediation, but a number of alternative remediation technologies were applied in brownfield redevelopment projects as well. Due to the frequently predicted, long operation times for P&T (and as a consequence thereof uncertainties about reaching the remediation goals and keeping to the predicted remediation cost budget), remediation of the saturated zone in brownfields redevelopment projects is often carried out by alternative technologies. Among these can be numbered: passive groundwater remediation methods (funnel & gate), the air sparging method and microbiological remediation technologies.

Requirements for remediation technologies in brownfields redevelopment

In order that alternative remediation technologies (compared to the standards *excavation & disposal* and *pump & treat)* can be employed efficiently in brownfields redevelopment, the following requirements concerning the criteria named in Table 2 can be derived:

- alternative technologies have to be cost-efficient, i.e. they have to be at least equal to the standard technologies, or preferably more favourable with respect to costs and efficiency. At accessible remediation sites (unsaturated soil zone without buildings), alternative remediation technologies compete directly with excavation & disposal, with the latter offering the additional possibility of using the excavated areas for subsurface construction (basement, underground parking).
- Using alternative remediation technologies, remediation goals should be reliably obtainable in a certain period of time. The required operation time should be assessable well in order to make the integration of the remediation process into construction plans possible. For brownfields redevelopment projects, normally remediation times in the order of weeks to a few months will be of interest.
- The interfaces between remediation technologies and other construction processes in a brownfields redevelopment project should be controllable in the same way as with the standard techniques.
- Compared with standard remediation technologies, innovative and alternative remediation technologies need usually more time for the final design which might include batch or pilot tests as well. An early start of the remediation, e.g. during deconstruction and independent from the subsequent reuse of a brownfield site would permit a more efficient use of alternative remediation techniques in brownfield redevelopment projcts.

All in all, alternative remediation technologies need to be equal to the standard method technically as well as economically. Another possibility is the way of legislation. In Great Britain, a considerably larger number of different remediation technologies are used, because excavation & disposal is too expensive due to the landfill directive. Additionally, the selection of a remediation technique is based on sustainable criteria. Furthermore, the acceptance of the treatment of contaminated soil is very high. In the Netherlands, alternative remediation technologies are more widely used than in Germany.

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LIST OF TABLES AND FIGURES

Tables

Figures

Table 1 Overview of remediation technologies applied in the analyzed projects

	Technology	**Number of appl.**
Unsaturated Zone	Dig & Dump	29
	Soil washing	1
	Thermal Ex-situ Treatment	2
	Biological on-site treatment	1
	Biological off-site treatment	6
	Soil vapor extraction	1
	Surface sealing	6
	Containment structures	5
	Containment by sealing with buildings	3
	Immobilization	2
Unsaturated and Saturated Zone	Vertical barrier	1
	Mixed-in-place vertical barrier	1
	Microbiological in-situ methods	2
	Vacuum vapor extraction	1
Saturated Zone	Pump & Treat	7
	Air sparging	1
	Funnel & Gate	2
	Number of applications	***71***
	Number of projects	***40***

Table 2 Criteria for the choice of remediation technologies

Criterion	**Number of times mentioned**
Technical reliability of the technology	26
Costs	12
Time needed	7
Future use	3

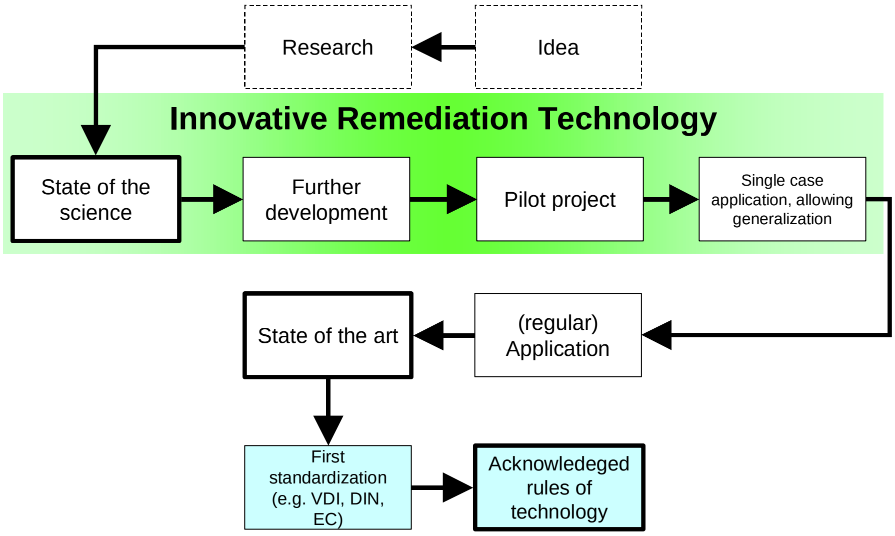

Figure 1 Definition of innovative remediation technology (IRT) in the chain of technological development