Techno-Economic and Environmentally Conscious Deconstruction Project Planning and Decision Support (TEE-D-Plan)

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Abstract

For operational deconstruction project planning the principal, the engineering consultant, the deconstruction company and/or authorities are supported by a deconstruction plan of the specific project based on single activities. Usually, so called 'multi-mode resource-constrained project scheduling problems' (MRCPSP) are used to identify and define such a project plan. In this regard, alternative activity-related deconstruction techniques are displayed as modes. Decisions are regularly made due to quantitative economic objectives, such as minimisation of direct costs or the duration of the overall project. Project constraints due to economic parameters, such as maximum budget and maximum duration, and technical parameters, such as available resources, are modelled as renewable and non-renewable resources. Emissions and impacts on the local environment in general, their mitigation in particular and impact-influencing characteristics of the surrounding/neighbourhood are unconsidered in these models and in decision making to date.

In the dissertation a model for technical, economic and environmental deconstruction project planning and decision support (TEE-D-Plan) is developed and exemplarily applied. With this modular model for operational deconstruction project planning for the first time, local environmental impacts in the form of noise, dust and vibrations are integrated as objectives of decision making. The assessment of the deconstruction technique feasibility is completed with parameters, such as the deconstruction height above ground, which have an influence on the resulting local impacts as well. Economic assessment of the single deconstruction techniques is updated and enhanced by data from current literature, an expert survey and consultations. The economic assessment is validated by two realised deconstruction projects. For the first time, average human-sense-related emission and impact levels of noise, dust and vibrations of deconstruction activities can be quantitatively proposed with the help of a newly developed environmental assessment approach and newly collected primary data of experiments and expert survey and consultations.

With the help of TEE-D-Plan, project plans with activity-related deconstruction techniques for a specific building to be deconstructed are provided due to the preferences of the decision maker related to the mitigation of local environmental impacts and while considering the overall project duration and costs.

Zusammenfassung

Um Bauherren, Planungsingenieure, Rückbauunternehmer und/oder Behörden bei der Identifikation und Definition eines adäquaten Rückbauplans mit Techniken für die einzelnen Vorgänge für ein bestimmtes Rückbauprojekt zu unterstützen, können sogenannte „multi-mode resource-constrained project scheduling problems“ (MRCPSP) für die operative Rückbauplanung eingesetzt werden. Alternative Rückbautechniken der einzelnen Projektvorgänge werden dabei als Modi abgebildet. Die Entscheidungsfindung erfolgt hinsichtlich quantitativer ökonomischer Ziele, wie der Minimierung der direkten Kosten oder der Dauer des Gesamtprojekts. Projektbeschränkungen betreffs ökonomischer Größen, wie maximales Budget und maximale Dauer, und technischer Größen, wie verfügbare Ressourcen, werden als erneuerbare und nicht-erneuerbare Ressourcen modelliert. Lokale Immissionen im Allgemein und deren Minderung im Speziellen sowie Charakteristika des Umfeldes/der Nachbarschaft und deren Veränderungen bleiben in diesen Modellen und bei der Entscheidungsfindung bislang allerdings unberücksichtigt.

In der Dissertation wird ein Modell zur technischen, ökonomischen und ökologischen Rückbauplanung und –entscheidungsunterstützung (TEE-D-Plan) entwickelt und angewandt. Durch dieses modulare Modell für die operative Rückbauplanung werden zum ersten Mal lokale Immissionen in Form von Lärm, Staub und Erschütterungen als Zielkriterien in die Entscheidungsfindung integriert. Die Bewertung der technischen Durchführbarkeit von Rückbautechniken wird um Parameter wie die Abbruchhöhe, die am Ende auch die resultierenden Immissionen beeinflusst, ergänzt. Die ökonomische Bewertung einzelner Techniken wird auf Basis von Daten aus der Literatur und Expertenbefragungen aktualisiert und verbessert und durch zwei

Testprojekte validiert. Mittels eines Ansatzes der Umweltwirkungsabschätzung und neu erhobenen Primärdaten aus Experimenten und Expertenbefragungen können Lärm-, Staub-, und Erschütterungsimmissionen von Rückbauarbeiten in Form von prozentualen Auslastungen basierend auf der menschlichen Wahrnehmung erstmals quantitativ abgeschätzt werden.

Mit Hilfe von TEE-D-Plan werden Projektpläne mit Techniken für einzelne Vorgänge für ein bestimmtes Rückbauprojekt hinsichtlich der Präferenzen des Entscheiders zur Minderung von Immissionen und unter Berücksichtigung der Gesamtprojektdauer und -kosten vorgeschlagen.

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Indices and generic notations

Symbol	Meaning	Unit
a	All attachment	-
ab	Attachment for material sorting and crushing	-
ad	Attachment for deconstruction	-
b	Material	-
BS	Building scenario	-
bu	Basic unit	-
c	Costs	€
cw/CW	Crawler excavator resource	-
d	Deconstruction activity segment	-
diesel	Diesel	-
e	Emission	-
er	Emission reduction	-
ex	All contingencies	-
f	Function	-
fk	Factor/index	-
fu	Fuel	-
ful	Fuel and Lubricants	-
h	Hour	-
ha/HA	Hand tool resource	-
hy/HY	Hydraulic excavator resource	-
ia	Attribute	-
im	Impact	-
k	Building component	-
l	Noise level	dB(A)
le	Average noise emission level	dB(A)
lu	Lubricants	-
lim	Average noise impact level	dB(A)
lt/LT	Longfront excavator resource	-
M	Set of alternative execution modes	-
md	Method	-
ms	Alternative phase-related mode-series	-
MS	Set of alternative phase-related mode-series	-
mt	Contingency month/s	months
n	Number	-
o	Material-sorting activity segment	-
op	All operations	-
p	Duration	h
pc	Percentage	%

Symbol	Meaning	Unit
pc^{lim}	Percentage of average noise impact level	%
pc^{sim}	Percentage of average dust emission level	%
pc^{vim}	Percentage of average vibration impact level	%
po	Employee resource	-
PS	Project scenario	-
q	Material-crushing activity segment	-
r	Number of units of resource	-
R	Capacity of available (discrete) resources	-
rc	Noise calculation parameter	-
ref	Noise reflection	-
rf	Number of reflecting objects	-
s	Dust level	mg/m^3
sim	Dust emission level	mg/m^3
sp	Space	
SU	Surrounding scenario	
sz	Size of basic unit/s	kW
t	Time	h
v	Vibration level	mm/s
ve	Vibration emission level	mm/s
vf	Value function/value	-
vim	Vibration impact level	mm/s
w	Weighting vector	-
y	Score/value	%
z	Binary variable of activity/phase completion [0;1]	-
δ	Specific duration value	h/m3
κ	Specific hourly costs	€/h
κ^{ex}	Specific hourly contingency costs	€/h
ӄ	Costs unit rate per contingency month	€/mt
ҝ	Costs per litre	€/l
λ^{e}	Specific hourly average noise emission level value	average dB(A)/h
λ^{im}	Specific hourly average noise impact level value	average dB(A)/h
σ^{e}	Specific hourly average dust emission level value	average $(mg/m^3)/h$
Φ	Preference scenario	-
ψ^{e}	Specific hourly average vibration emission level value	average (mm/s)/h
ψ^{im}	Specific hourly average vibration impact level value	average (mm/s)/h

Model parameter

Symbol	Meaning	Unit
$ab_{j,m}$	Attachment for material sorting and crushing of activity j in mode m	-
ab_m	Attachment for material sorting and crushing required by mode m	-
A_{div}	Noise calculation parameter	average dB(A)/h
$ad_{j,m}$	Attachment for deconstruction of activity j in mode m	-
ad_m	Attachment for deconstruction required by mode m	-
$c_{g,msg}(sz, yr)$	Costs of project phase g in alternative phase-related mode-series ms_g influenced by the basic unit size sz and investment year yr [€]	€
$c_{j,m}(sz, yr)$	Costs of activity j in mode m influenced by the basic unit size sz and investment year yr [€]	€
$c_{dj,m}(sz, yr)$	Costs of deconstruction activity segment d_j of activity j in mode m influenced by the basic unit size sz and investment year yr [€]	€
$c_{oj,m}(sz, yr)$	Costs of material-sorting activity segment o_j of activity j in mode m influenced by the basic unit size sz and investment year yr [€]	€
$c_{qj,m}(sz, yr)$	Costs of material-crushing activity segment q_j of activity j in mode m influenced by the basic unit size sz and investment year yr [€]	€
c^{rep}	Initial cost for equipment (basic unit or attachment) on the basis of the price in the year 2014	€
c^{rep}_{yr}	Initial cost for equipment (basic unit or attachment) on the basis of the price in the year of investment yr	€
dc	Distance to the subject of protection [m]	m
Dc	Noise calculation parameter	average dB(A)/h
$D_{I,rc}$	Noise calculation parameter	-
d_j	Deconstruction activity segment of activity j	-
EF	Earliest completion time	h
ES	Earliest start	h
fk^e_{sz}	Factor of the emission level increase due to the variation of the basic unit size	-
fk^e_{hg}	Factor of the emission level increase due to the variation of the deconstruction height above ground	-
fk^{pp}_{yr}	Producer price index of construction equipment in year yr related to the base year 2014 = 100	-
g	Builing level-related deconstruction project phase	-
G	Number of project phases	-

Symbol	Meaning	Unit
hg	Height above ground	m
ht	Component height	m
i	Control variable	-
j	Activity	-
J	Number of project activities	-
j_g	Activity of deconstruction project phase g	-
J_g	Number of activities of deconstruction project phase g	-
L_{eq}	Time-average sound pressure level [dB(A)]	dB(A)
LF	Latest completion time	h
LIM	Maximal allowed average noise impact level [dB(A)]	dB(A)
$lim_{j,m}(dc,n^l,sz)$	Average noise impact level of activity j in mode m influenced by the distance from the emission source dc, number of equipollent, coherent noise levels r^l and basic unit size sz [dB(A)]	dB(A)
LS	Latest start	h
m	Mode	-
M_j	Set of alternative execution modes of activity j	-
ms_g	Alternative phase-related mode-series of project phase g	-
MS_g	Set of alternative phase-related mode-series of project phase g	-
n^l	Number of equipollent, coherent noise levels	-
n^{mt}	Number of contingency months	-
n^{year}	Number of usage years	-
nv^{exp}	Vibration calculation parameter	-
o_j	Material-sorting activity segment of activity j	-
$p_{g,msg}(sz)$	Duration of phase g in alternative phase-related mode-series ms_g [h]	h
$p_{j,m}(sz)$	Duration of activity j in mode m influenced by the basic unit size sz [h]	h
$p_{dj,m}(sz)$	Duration of the deconstruction activity segment dj of activity j in mode m influenced by the basic unit size sz [h]	h
$p_{oj,m}$	Duration of the material-sorting activity segment dj of activity j in mode m [h]	h
$p_{qj,m}$	Duration of the material-crushing activity segment dj of activity j in mode m [h]	h
$pc^{lim}{}_{g,msg}(dc,n^l,sz)$	Percentage of average noise impact level of project phase g in mode-series alternative msg influenced by the distance from the emission source dc, number of equipollent, coherent noise levels rl and basic unit size sz [%]	%
$pc^{sim}{}_{g,msg}(sz)$	Percentage of average dust emission level of project phase g in mode-series alternative msg influenced by the basic unit size sz [%]	%
$pc^{vim}{}_{g,msg}(dc,sz)$	Percentage of average vibration impact level of project phase g in mode-series alternative msg influenced by the distance from the emission source dc and basic unit size sz [%]	%

Symbol	Meaning	Unit
$pc^{ϰ(ami)}$	Percentage of amortization and interest per contingency month	%
pc^{amr}	Amortization rate per contingency month	%
pc^{int}	Interest rate per contingency month	%
pc^{iir}	Imputed interest rate of 6.5%	%
$pc^{ϰ(rpa)}$	Percentage repair costs rate per contingency month	%
$pos_j(g, ty)$	Position of activity j related to phase g and type of the component ty the activitiy is applied to	-
Pred(j)	Set of all immediate and transitive predecessors of activity j in the project network	-
q_j	Material-crushing activity segment of activity j	-
r^{cw}_{g,ms_g}	Number of units of crawler excavator resource cw of project phase g in alternative phase-related mode-series ms_g	-
$r^{cw}_{j,m}$	Number of units of crawler excavator resource cw of activity j in mode m	-
r^{cw}_{m}	Number of crawler excavator units cw required by mode m	-
R^{cw}/Rcw	Capacity of available crawler excavator resource cw	-
r^{ha}_{g,ms_g}	Number of units of hand tool resource ha of project phase g in alternative phase-related mode-series ms_g	-
$r^{ha}_{j,m}$	Number of units of hand tool resource ha of activity j in mode m	-
r^{ha}_{m}	Number of hand tool units ha required by mode m	-
R^{ha}/Rha	Capacity of available hand tool resource ha	-
r^{hy}_{g,ms_g}	Number of units of hydraulic excavator resource hy of project phase g in alternative phase-related mode-series ms_g	-
$r^{hy}_{j,m}$	Number of units of hydraulic excavator resource hy of activity j in mode m	-
r^{hy}_{m}	Number of hydraulic excavator units hy required by mode m	-
R^{hy}/Rhy	Capacity of available hydraulic excavator resource hy	-
r^{lt}_{g,ms_g}	Number of units of longfront excavator resource lt of project phase g in alternative phase-related mode-series ms_g	-
$r^{lt}_{j,m}$	Number of units of longfront excavator resource lt of activity j in mode m	-
r^{lt}_{m}	Number of longfront excavator units lt required by mode m	-
R^{lt}/Rlt	Capacity of available longfront excavator resource lt	-

Symbol	Meaning	Unit
$r^{po}_{j,m}$	Number of employee resource po of activity j in mode m	-
r^{po}_{m}	Number of employees po required by mode m	-
$sim_{j,m}(sz)$	Average dust emission level of activity j in mode m influenced by the basic unit size sz [mg/m3]	mg/m^3
SP	Maximal available space [0;1;2]	-
$sp_{j,m}$	Minimal required space sp of activity j in mode m [0;1;2]	-
sp_m	Minimal required space sp of mode m [0;1;2]	-
sz^{cw}	Size of available basic unit/s of crawler excavator resource cw [kW]	kW
sz^{ha}	Size of available basic unit/s of hand tool resource ha [kW]	kW
sz^{hy}	Size of available basic unit/s of hydraulic excavator resource hy [kW]	kW
sz^{lt}	Size of available basic unit/s of longfront excavator resource lt [kW]	kW
T	Latest possible completion time of the entire project	h
th	Component thickness [m]	m
u	Material volume [m3]	m^3
vf_{ia}	Value function/value of attribute ia	-
$vim_{j,m}(dc,sz)$	Average vibration impact level of activity j in mode m influenced by the distance from the emission source dc and basic unit size sz [mm/s]	mm/s
w_{ia}	weighting of attribute ia	-
y_{ia}	Score/value of attribute ia/plan value	%
yr	Investment report-year	year
$z_{g,msg}$	Binary variable: 1, if phase g is performed in alternative mode-series msg; 0, else	-
$z_{j,m,t}$	Binary variable: 1, if activity j in period t is performed in mode m; 0, else	-
$z_{j,t}$	Binary variable: 1, if activity j is performed in period t; 0, else	-

Symbol	Meaning	Unit
δ_d(m,b,sz)	Specific duration value to deconstruct the component influenced by the mode m, material type b and basic unit size sz	h/m3
δ_o(m,b)	Specific duration value to sort the component material influenced by the mode m and material type b	h/m3
δ_q(m,b)	Specific duration value to crush the component material influenced by the mode m and material type b	h/m3
$\kappa^{ex(ab)}$(m,sz,yr)	Specific hourly contingency costs per attachment material sorting and crushing influenced by the mode m, basic unit size sz and investment report-year yr	€/h
$\kappa^{ex(ad)}$(m,sz,yr)	Specific hourly contingency costs per attachment for deconstruction influenced by the mode m, basic unit size sz and investment report-year yr	€/h
$\kappa^{ex(cw)}$(sz^{cw},yr)	Specific hourly contingency costs per crawler excavator units cw influenced by the basic unit size sz and investment report-year yr	€/h
$\kappa^{ex(ha)}$(sz^{ha},yr)	Specific hourly contingency costs per hand tool units ha influenced by the basic unit size sz and investment report-year yr	€/h
$\kappa^{ex(hy)}$(sz^{hy},yr)	Specific hourly contingency costs per hydraulic excavator units hy influenced by the basic unit size sz and investment report-year yr	€/h
$\kappa^{ex(lt)}$(sz^{lt},yr)	Specific hourly contingency costs per longfront excavator units lt influenced by the basic unit size sz and investment report-year yr	€/h
κ^{fu}	Specific hourly fuel consumption costs	€/h
κ^{lu}	Specific hourly lubricants consumption costs	€/h
κ^{op}	Specific hourly operation costs	€/h
$\kappa^{op}{}_d$(m, sz)	Specific hourly operation costs to deconstruct the component influenced by the mode m and basic unit size sz	€/h
$\kappa^{op}{}_o$(m, sz)	Specific hourly operation costs to sort the component material influenced by the mode m and basic unit size sz	€/h
$\kappa^{op}{}_q$(m, sz)	Specific hourly operation costs to crush the component material influenced by the mode m and basic unit size sz	€/h
$\kappa^{po}{}_d$(m)	Specific hourly labour costs to deconstruct the component influenced by the mode m	€/h
$\kappa^{po}{}_o$(m)	Specific hourly labour costs to sort the component material influenced by the mode m	€/h
$\kappa^{po}{}_q$(m)	Specific hourly labour costs to crush the component material component influenced by the mode m	€/h
κ^{ami}	Cost unit rate of amortization and interest amount per contingency month	€/mt
κ^{ex}	Contingency costs unit rate per contingency month	€/mt
κ^{rpa}	Repair costs unit rate per contingency month	€/mt
κ^{diesel}	Diesel costs per litre	€/l

Symbol	Meaning	Unit
$\lambda^{e}{}_{d}$(m,b,sz,hg)	Specific hourly average noise emission level value to deconstruct the component influenced by the mode m, material type b, basic unit size sz and height above ground hg	average dB(A)/h
$\lambda^{e}{}_{o}$(m,b,sz,hg)	Specific hourly average noise emission level value to sort the component material influenced by the mode m, material type b, basic unit size sz and height above ground hg	average dB(A)/h
$\lambda^{e}{}_{q}$(m,b,sz,hg)	Specific hourly average noise emission level value to crush the component material influenced by the mode m, material type b, basic unit size sz and height above ground hg	average dB(A)/h
$\lambda^{im}{}_{d}$(dc,n^{l},m,b,sz,hg)	Specific hourly average noise impact level value to deconstruct the component influenced by the distance from the emission source dc, number of equipollent, coherent noise levels r^{l}, mode m, material type b, basic unit size sz and height above ground hg	average dB(A)/h
$\lambda^{im}{}_{o}$(dc,n^{l},m,b,sz,hg)	Specific hourly average noise impact level value to sort the component material influenced by the distance from the emission source dc, number of equipollent, coherent noise levels r^{l}, mode m, material type b, basic unit size sz and height above ground hg	average dB(A)/h
$\lambda^{im}{}_{q}$(dc,n^{l},m,b,sz,hg)	Specific hourly average noise impact level value to crush the component material influenced by the distance from the emission source dc, number of equipollent, coherent noise levels r^{l}, mode m, material type b, basic unit size sz and height above ground hg	average dB(A)/h
$\Delta\lambda^{er}$(dc)	Share in the hourly average noise emission level reduction effect due to the distance	average dB(A)/h
$\Delta\lambda^{er}$(n^{l})	Share in the hourly average noise emission level reduction effect due to the building-arrangement	average dB(A)/h
v	Fuel consumption per hour	l/h
$\sigma^{e}{}_{d}$(m,b,sz,hg)	Specific hourly average dust emission level value to deconstruct the component influenced by the mode m, material type b, basic unit size sz and height above ground hg	average (mg/m^3)/h
$\sigma^{e}{}_{o}$(m,b,sz,hg)	Specific hourly average dust emission level value to sort the component material influenced by the mode m, material type b, basic unit size sz and height above ground hg	average (mg/m^3)/h
$\sigma^{e}{}_{q}$(m,b,sz,hg)	Specific hourly average dust emission level value to crush the component material influenced by the mode m, material type b, basic unit size sz and height above ground hg	average (mg/m^3)/h
$\psi^{e}{}_{d}$(m,b,sz,hg)	Specific hourly average vibration emission level value to deconstruct the component influenced by the mode m, material type b, basic unit size sz and height above ground hg	average (mm/s)/h
$\psi^{e}{}_{o}$(m,b,sz,hg)	Specific hourly average vibration emission level value to sort the component material influenced by the mode m, material type b, basic unit size sz and height above ground hg	average (mm/s)/h
$\psi^{e}{}_{q}$(m,b,sz,hg)	Specific hourly average vibration emission level value to crush the component material influenced by the mode m, material type b, basic unit size sz and height above ground hg	average (mm/s)/h

Symbol	Meaning	Unit
$\psi^{im}{}_{d}$(dc,m,b,sz,hg)	Specific hourly average vibration impact level value to deconstruct the component influenced by the distance from the emission source dc, mode m, material type b, basic unit size sz and height above ground hg	average (mm/s)/h
$\psi^{im}{}_{o}$(dc,m,b,sz,hg)	Specific hourly average vibration impact level value to sort the component material influenced by the distance from the emission source dc, mode m, material type b, basic unit size sz and height above ground hg	average (mm/s)/h
$\psi^{im}{}_{q}$(dc,m,b,sz,hg)	Specific hourly average vibration impact level value to crush the component material influenced by the distance from the emission source dc, mode m, material type b, basic unit size sz and height above ground hg	average (mm/s)/h
$\Delta\psi^{er}$(dc,m,b,sz,hg)	Share in the hourly average vibration emission level reduction effect due to the distance	average (mm/s)/h

List of Abbreviations

AHP	Analytic Hierarchy Process
AoP	Area of protection
EIA	Environmental impact assessment
LCA	Life cycle assessment
LCIA	Life cycle impact assessment
LCI	Life cycle inventory analysis
MAUT	Multi-attribute utility theory
MAVT	Multi-attribute value theory
MCDA	Multi-criteria decision analysis
MRCPSP	Multi-mode resource constrained project scheduling problem
RCPSP	Resource-constrained project scheduling problems

1 Introduction[1]

1.1 Motivation and problem statement

Limited space and demographic and economic changes demand adaptions in the spatial distribution of buildings (Konertz and Wienberg (2016), Forsythe (2010), Shin et al. (2005)). Furthermore, tightened building standards, such as those related to energy efficiency, require the adjustment of building characteristics, which are often not realisable on old existing buildings or building parts (Just (2013, p. 103 Couto and Couto (2007)). Overall, the necessity of deconstructing buildings is becoming of great importance worldwide, especially in cities.

Deconstruction is the last building life cycle stage, also often called 'demolition'[2] (ISO 22263:2008-01, Thomsen et al. (2011), Sánchez and Lauritzen (2006)). Similar to building construction management, management of deconstruction activities requires expert knowledge (Thomsen et al. (2011); Kamrath and Hechler (2011)) and has a project character (Diven and Shaurette (2010)). However, deconstruction projects differ highly from new construction, especially

[1] Parts of this research thesis are related to the research project ISA (Immissionsschutz beim Abbruch), supported by the Deutsche Bundesstiftung Umwelt (DBU). Moreover, parts of this thesis had been published in advance in Kühlen et al. (2016), Kühlen et al. (2015a), Kühlen et al. (2015b) and Kühlen et al. (2014) (especially parts of chapters 2, 5 and parts of sections 4.3, 4.4 and 7.1). Fragments of the content of these sources, which are transferred to this document without reference, were prepared by the author of this thesis.

[2] In parts of the world, the terms 'deconstruction' and 'demolition' are used almost synonymously today. Here both terms describe the removal of a building/structure. In deconstruction environmental aspects, such as the recycling of building materials, are explicitly considered. Current regulations of these countries force the consideration of these environmental aspects in demolition as well. Hence, the differentiation between these terms is limited and in the following, deconstruction is used in general terms in this research.

regarding impacts on the local environment and human beings (Shaurette (2011)). Deconstruction activities are potentially the source of high impacts on the local environment in terms of noise, dust and vibrations (DA (2015, p. 28 et seq.), Diven and Shaurette (2010, pp. 66 et seq.), Mettke et al. (2008, pp. 176 et seq.)). These local impacts can cause hazards to the health of labour and neighbouring people (GLA (2014, pp. 2 and 3), Gabriel et al. (2010, pp. 4 et seq.)). Additionally, these impacts can harm the surrounding built environment, for instance through structural damage (DIN E 4150-3:2015-10). The distribution of deconstruction-related impacts and the relevance of impact extents (levels and exposure time/durations) for the local environment (building and people) are influenced by the characteristics of the neighbourhood around the deconstruction site. Furthermore, the extents of these impacts are the consequence of noise, dust and vibration emissions of the deconstruction process on site. These emissions highly depend on and vary with applied deconstruction technologies (DA (2015, p. 227 et seq.), Gabriel et al. (2010, pp. 16 et seq.), Toppel (2003, pp. 79 et seq.), DIN 18007:2000-05)) as well as on building characteristics, such as building materials (VDI 3790-3: 2010-01), Kühlen et al. (2016, pp. 28, 32 et seq.)). All these listed factors related to local environmental impacts, neighbourhood and building characteristics, as well as deconstruction techniques, can be addressed in the deconstruction planning phase. In this regard, planning and decision making tools can support the involved players (Lützkendorf (2000, p. 5)). In the course of sustainable development, the management and mitigation of emissions and related impacts on the local environment in planning and decision making of on site (de-)construction projects is already significant (BMUB (2015)). It might become even a key aspect of project quality in the future, encompassing the environmental dimension of deconstruction (and touching the social dimension) besides the technical and economic dimensions.

Problem statement

The environmental dimension in terms of local environmental impacts is currently insufficiently considered in deconstruction planning and decision making. This is verified, when looking at current practices as well as research in the field of deconstruction planning and decision making. As building deconstruction has a project character, project planning and decision making tools and methods are applicable. Current tools and software for operational construction/deconstruction project planning and decision making in practice, such as Microsoft Project[3] and Primavera[4], manly focus on economic issues and do not consider emissions and related local environmental impacts. The emphasis of recent research on operational level in this field is on the economic dimension as well. Environmental issues are considered, but the focus is on the disposal and recycling of building materials and related implications on costs and/or energy demand (Akbarnezhad et al. (2012), (2014), Cheng and Ma (2013), Sunke (2009), Aidonis et al. (2008), Schultmann and Sunke (2006), (2007), Schultmann (2003), (1998), Seemann (2003), Schultmann and Rentz (2002), (2001)). On a strategic planning level, environmental impacts are qualitatively addressed in practice, for instance in the form of checklists[5]. In research, noise, dust and vibration impacts are occasionally considered qualitatively, usually generally together with other environmental impacts in the context of decision making related to deconstruction projects (Anumba et al. (2008), Kourmpanis et al. (2008a), Abdullah (2003), Abdullah et al. (2003)). Via multi-criteria decision analysis (MCDA) methods, decisions

[3] Microsoft (2015): Office – Project. Online under: https://products.office.com/en-us/project/project-and-portfolio-management-software. Accessed on: 28.12.2015.
[4] Oracle (2015): Oracle's Primavera P6 Professional Project Management. Online available: www.oracle.com/applications/primavera/products/project-management.html. Accessed on: 28.12.2015.
[5] DA (Deutscher Abbruchverband) (2015): Checklists and guidelines. Online available: www.deutscher-abbruchverband.de/index.php?page=vorlagen-und-checklisten. Accessed on: 20.10.2015.

on the overall deconstruction project are made considering these environmental impacts qualitatively and/or aggregated. In this context, quantitative dimensions of distinct impacts and relevant influencing factors, such as neighbourhood and building characteristics and specific deconstruction techniques, are not considered. Nevertheless, the extent of impacts and related harm to the local environment in the form of health hazards and structural damages highly depend on the level of distinct impacts related to the exposure time and neighbourhood/surrounding characteristics (DIN 4150-2:1999-06, DIN 4150-3:1999-02; TA Lärm (1998); TA Luft (2002)). Moreover, the levels of the single deconstruction-related emissions and resulting environmental impacts are usually independent of each other and are greatly influenced by different building characteristics and specific deconstruction techniques, as mentioned above (DA (2015, p. 227 et seq.), Gabriel et al. (2010, pp. 16 et seq.), Toppel (2003, pp. 79 et seq.), DIN 18007:2000-05), VDI 3790-3: 2010-01), Kühlen et al. (2016, pp. 28, 32 et seq.)).

Besides these shortfalls in overall approaches of deconstruction project planning and decision making, there are also deficits in certain sub-steps of the planning and decision making process. There are deficits especially in the assessment of deconstruction-related local environmental impacts, including approaches for the quantification of emissions and the evaluation of local environmental impacts. And there is a lack of databases of respectively required data. Quantification of emissions (as a type of environmental intervention) and evaluation of environmental impacts due to human actions (impact assessment) are usually addressed by methods, such as Environmental Impact Assessment (EIA) or Life Cycle Assessment (LCA). EIA is rather a generic method for environmental assessment in which tools, such as LCA are applied. LCA includes diverse methods to analyse environmental interventions and assess related impacts. However, LCA regularly does not address in detail or not at all the emission and impact categories of noise, dust and vibrations. Furthermore, information and detailed data on emissions of noise, dust and vibrations (i.e. characteristic factors) and of neighbourhood influences on impact distribution and impact relevance for the local environment are necessary for deconstruction planning and decision making. This information and data is not available however, for instance in databases for environmental assessments, such as the widely recognised ecoinvent database[6] (Hischier et al. (2010, p. 13), EC-JRC (2011, p. 102)).

1.2 Objectives and research questions

Consequently, the main objective of this work is the development and exemplary application of a novel model-based approach to integrate emissions and neighbourhood-dependent local environmental impacts into the deconstruction project planning and decision making process. With the model application those deconstruction techniques are aimed to be identified, which mitigate local environmental impacts from deconstruction projects the most, dependent on the specific project and while considering economic objectives and the technical feasibility. Related to the issues brought up in the problem statement, the model-based approach has to contain the following three elements:

1. A framework of deconstruction planning for the assessment of emissions and local environmental impacts (noise, dust and vibrations), besides the economic and technical assessment of the deconstruction process.
2. Approaches and database for the quantitative environmental, economic and technical assessment of the deconstruction

[6] Website of the ecoinvent database: http://www.ecoinvent.org/database/database.html (last accessed 02.05.2016).

process, which allow the quantification of emissions and the evaluation of the resulting neighbourhood-dependent environmental impacts noise, dust and vibrations, as well as the assessment of technical feasibility and economic values.
3. Deconstruction project planning and decision support due to environmental (and economic) objectives, considering neighbourhood-, surrounding- and resource-dependent project constraints and preferences of the decision maker.

To reach the objectives, this thesis aims to answer the following research questions:

Major research question

‘How can the distinct emissions of noise, dust and vibrations caused by a building deconstruction project and the related neighbourhood-dependent impacts on the local environment be mitigated, while considering technical parameters and economic objectives?’

Research sub-questions

1. How do different building characteristics influence the proposed/adequate deconstruction plan due to the mitigation of distinct emissions and impacts in terms of applied deconstruction techniques and resulting emissions/ impacts?
2. How do surrounding conditions influence the levels of impacts?
3. How do different project constraints influence the proposed/adequate deconstruction plan due to the mitigation of distinct emissions and impacts in terms of applied deconstruction techniques and resulting emissions/ impacts?
4. Which economic and environmental objectives are conflicting?

5. How does the adequate deconstruction plan vary in the form of applied deconstruction techniques due to different economic and environmental objectives?

1.3 Structure of the thesis

To address the mentioned objectives and to answer the research questions the thesis is structured as follows:

Firstly, deconstruction project planning and decision making, respective relevant definitions and framework conditions are introduced in chapter 2.

Then, the current state of research in the areas of model-based deconstruction project planning and decision making and of model-based technical, economic and environmental assessment is critically reviewed in chapter 3. Consequently, the research gaps are underlined and related requirements for the research design of this thesis to close the gaps are set.

Subsequently, in chapters 4 to 6 the model of technical, economic and environmental deconstruction project planning and decision support is depicted. The development of Module 1, the database-based deconstruction planning for environmental assessment, is described in chapter 4 and 5. In this regard the model framework of deconstruction planning and the approaches for the technical, economic and environmental assessment are explained in detail in chapter 4. Thereafter, in chapter 5 the database structure and specific information of collection, editing and storing of required primary data is documented. Furthermore, Module 2, resource-, space and impact-constrained deconstruction project planning and decision support due to environmental objectives, is developed in chapter 6. It is based on a resource-constrained project scheduling problem, which is adapted by multi modes and specific project constraints. Additional, an iterative solution process based on a predefined fixed deconstruction activity sequence is applied to find the adequate plan due to minimise the local environmental impacts of a deconstruction project.

Chapter 7 shows the exemplary application of the developed model and evaluates the obtained results related to the research questions. This is the basis for the conclusion and outlook made in chapter 8. Finally, chapter 9 gives a summary of the whole thesis. Figure 1-1 illustrates the overview of structure of the present research thesis.

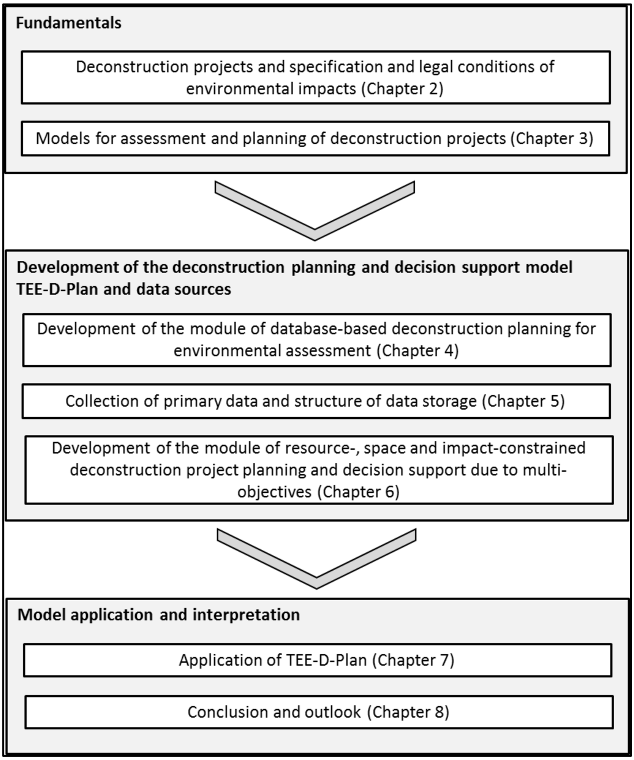


Figure 1-1: Overview of the thesis structure

2 Definitions and framework conditions for deconstruction project planning

In this chapter the process of deconstruction project planning and decision making is introduced. Therefore, respective relevant definitions and framework conditions are depicted. In section 2.1 deconstruction projects and phases and elements of deconstruction planning and decision making process are defined. The relevant emissions, local environmental impacts and respective mitigation methods examined in this research are specified in section 2.2. Finally, in section 2.3 the environment-related legal conditions significant for the research topic are presented.

2.1 About deconstruction projects

In the following section deconstruction projects, which are in the focus of this thesis, are defined. The definition encompasses the general terminology of deconstruction and the description of single project phases and of elements of the deconstruction planning and decision making process.

2.1.1 Definition of deconstruction

Throughout this work the term ‘deconstruction’ is used to denominate the last building life cycle stage. Other sources such as ISO 22263:2008-01 or OmniClass (2012) (Table 32) refer to this stage synonymously as ‘demolition’, ‘decommissioning’, ‘disassembling’ or ‘dismantling’. All of these terms describe the partial or complete removal of buildings and structures. However, the term 'deconstruction' implies the explicit consideration of environmental aspects, like recycling of building materials (Couto and Couto (2007), Schultmann (1998, p. 2)), as well as a better usage of space (Thomsen et al. (2011)). But as current regulations for instance in Germany generally require material recycling and minimisation of environmental impacts and as especially in cities space is scarce, a distinction between these different terms demolition, decommissioning, disassembling, dismantling and deconstruction is limited. As deconstruction has project character (Diven and Shaurette (2010, p. ix)), respective single project phases and involved players are described in the next section.

2.1.2 Deconstruction project phases and involved players

The deconstruction project can be split into four life cycle phases, as shown in Figure 2-1 (on the basis of Kühlen et al. (2016b), DA (2015, pp. 171 et sqq.)). Different players are involved and affected in these phases.

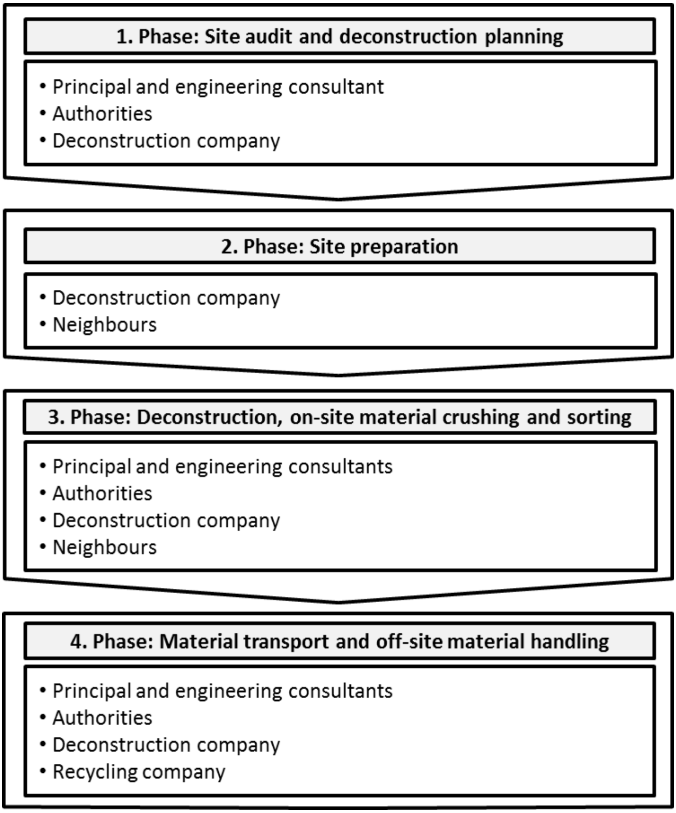


Figure 2-1: Life cycle phases of the deconstruction project[7]

Figure 2-1 shows that the principal, the engineering consultant, the deconstruction company and authorities are the main players in the first phase of deconstruction projects. According to Kühlen et al. (2016b) and DA (2015, pp. 171 et sqq.) within this phase the site is audited and the deconstruction project is planned. Usually the principal, the engineering consultant and depending on the building type often also authorities formulate the project framework conditions in the tender specifications in accordance with national

[7] On the basis of Kühlen et al. (2016b), DA (2015, pp. 171 et sqq.).

regulations. Competing deconstruction companies audit the building themselves and bid for the project. The accepted company plans the deconstruction project in detail based on distinct deconstruction, crushing and sorting techniques, depending on the building structure, available space onsite and available resources and in agreement with legal conditions. Consequently, deconstruction project planning and decision making, the focus of this thesis, applies to this first phase.

In the second phase the site is prepared related to occupational health and safety conditions and the site facilities are installed by the deconstruction company. In this regard, neighbours can be tangent to the preparation as well.

The main players in the third phase in Figure 2-1, which covers the actual deconstruction process on site, are the principal, the engineering consultant, authorities, the deconstruction company and neighbours. Here the deconstruction company performs the planned techniques of deconstruction, pre-crushing and pre-sorting on site. The principal, the engineering consultant and authorities regularly has to control this on-site process with respect to contractual and legal conditions. Furthermore, within this phase the major impacts on the local environment are caused, which can affect neighbours. Hence, the focus of planning in this research, which includes planning and decision making considering impacts on the local environment, is on this third deconstruction project phase.

Finally, in the fourth phase the deconstruction materials are transported from site to off-site disposal and recycling plants. This is usually done by the deconstruction or recycling company. At the plant materials are further crushed, sorted and reprocessed with the aim to gain recycling materials. The principal, the engineering consultant and authorities regularly have to control this material handling processes with respect to contractual conditions and legal, often regionally differing regulations. Nevertheless, as these processes are performed off the deconstruction site, this phase is not in the focus of this research.

Consequently, the major players of the focal two phases are the principal, the engineering consultant, authorities, the deconstruction company and neighbours. The major economic, technical and environmental and social interests of these players related to the deconstruction process on site and relevant legal condition types related to these interests are summarised in Table 2-1 on the basis of DA (2015, pp. 171 et sqq.) and Kühlen et al. (2014, pp. 22 et sqq.).

Table 2-1: Major interests of players related to the deconstruction process on site and relevant legal condition types related to these interests[8]

<table>
<tr><th rowspan="2">Players</th><th colspan="6">Current major interests related to the on-site deconstruction process and relevant legal condition types related to these interests</th></tr>
<tr><th colspan="2">Economic</th><th colspan="2">Technical</th><th colspan="2">Environmental and social</th></tr>
<tr><td rowspan="3">Principal and engineering consultant</td><td rowspan="3">Project budget</td><td rowspan="3">National contractual regulations</td><td rowspan="3">Technical restrictions of building statics</td><td rowspan="3">National contractual regulations and technical guidelines</td><td>Local environmental impacts</td><td>National regulations on impacts on the local environment, contractual regulations, technical guidelines</td></tr>
<tr><td>Work safety</td><td>National regulations on labour law and health and safety, guidelines</td></tr>
<tr><td>Material quality</td><td>National and regional regulations on hazardous materials, material recycling and disposal</td></tr>
<tr><td rowspan="3">Authorities</td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td>Local environmental impacts</td><td>National regulations on impacts on the local environment</td></tr>
<tr><td>Work safety</td><td>National regulations on labour law and health and safety, guidelines</td></tr>
<tr><td>Material quality</td><td>National and regional regulations on hazardous materials, material recycling and disposal</td></tr>
<tr><td rowspan="3">Deconstruction company</td><td rowspan="3">Costs of the deconstruction site: site facilities, resources and equipment</td><td rowspan="3">National contractual regulations</td><td rowspan="3">Technical restrictions of building statics and equipment</td><td rowspan="3">National contractual regulations and technical guidelines</td><td>Local environmental impacts</td><td>National regulations on impacts on the local environment, contractual regulations, technical guidelines</td></tr>
<tr><td>Work safety</td><td>National regulations on labour law and health and safety, guidelines</td></tr>
<tr><td>Material quality</td><td>National and regional regulations on hazardous materials, material recycling and disposal</td></tr>
<tr><td>Neighbours</td><td></td><td></td><td></td><td></td><td>Local environmental impacts</td><td>National regulations on impacts on the local environment</td></tr>
</table>

As shown in Table 2-1, especially the principal, the engineering consultant and the deconstruction company have economic and technical interests. These are generally regulated in national contractual regulations, such as the German construction contract procedures (VOB) due to demolition and dismantling work (DIN 18459:2015-08) and especially technical aspects are further specified

[8] On the basis of DA (2015, pp. 171 et sqq.) and Kühlen et al. (2014, pp. et sqq.).

in technical guidelines, for instance DIN 18007:2000-05. Work safety and material quality are interests of the principal, the engineering consultant and the deconstruction company and are addressed in national regulations, which are described in section 2.3.2. Moreover, they are further specified in regional regulations and national guidelines[9]. Local environmental impacts are of major interest to all players. They are addressed in national regulations, which are further specified in section 2.3.1. Additionally, they are brought up as qualities in contractual regulations and technical guidelines, mentioned above.

Besides the relevant involved players, the planning of the on-site deconstruction process includes the specification and scheduling of distinct applied deconstruction techniques, besides material crushing and sorting. In the following deconstruction techniques are characterised for this research.

2.1.3 Deconstruction methods and techniques

The deconstruction method describes the way in which single building components are removed. In the scope of this research, each building component is removed by applying one deconstruction method. Different components of one building can be removed by the same or by different methods. Hence, one method or a combination of methods is applied to a building within a deconstruction project (DA (2015, pp. 227 et seq., 257 et seq.), DIN 18007:2000-05). In Table 2-2 standardized deconstruction methods, on the basis of DIN 18007:2000-05, are listed, as they will be employed in the context of this thesis.

[9] Respective national guidelines are for instance Gabriel et al. (2010); BMVBS BMV (2008).

Table 2-2: Standardised deconstruction methods[10]

#	Method name	Method description
1	Gripping	Removal/crushing of building components out of masonry and wood.
2	Wrecking	Removal/crushing of building components out of concrete, reinforced concrete and masonry.
3	Pushing	Felling of a building component out of masonry and wood.
4	Pulling	Felling of a building component out of concrete, reinforced concrete, masonry, wood or steel.
5	Ripping	Removal of foundation plates/ground slabs.
6	Mortising	Removal/crushing of building components out of concrete, reinforced concrete and masonry.
7	Press-cutting	Removal/crushing of building components out of concrete, reinforced concrete and masonry.
8	Cutting	Removal/crushing of building components out of steel.
9	Splitting	Separation/parting of building components out of concrete, reinforced concrete and masonry.
10	Dismounting	Disassembling of (usually complete) building components for reuse.
11	Blasting	Collapse of a complete building.
12	Bumping	Loosening of (very thick) building components out of concrete, reinforced concrete and masonry.
13	Drilling	Preparation for blasting.
14	Sawing	Separation/parting of building components.
15	Oxygen cutting	Separation/parting of (very thick) building components out of reinforced concrete and steel.
16	Hydroblasted cutting	Separation/parting of building components out of concrete, reinforced concrete and masonry.
18	Stripping	Stripping of single layers of building components.
19	Deconstruction by hand	Removal/crushing of building components by hand-held equipment.
Grey-colored: deconstruction techniques not further examined in this study		

Depending on the method, specific equipment in the form of support frames and attachments are used within the deconstruction project. In the context of this research, the combination of method and equipment is called deconstruction technique.

In conjunction with those methods listed in Table 2-2, the hydraulic excavator (equipped with different attachments) is the most used

[10] On the basis of DIN 18007:2000-05.

support frame (see methods 1, 3-8 in Table 2-2). In general, 83% of building deconstruction projects are performed with a hydraulic excavator (Kühlen et al. (2016, p. 23), DA (2015, pp. 257 et seq.), Weimann et al. (2013, p. 100)). Hence, the focus of this research is on those deconstruction methods performed with a hydraulic excavator. Additionally, wrecking with a cable excavator (method 2) and deconstruction by hand (method 19) are included in the examinations of this research.

2.2 Emissions and environmental impacts

Emissions, local environmental impacts and respective mitigation methods relevant to answer the research questions are specified in this section.

2.2.1 Emission- and impact-related definitions

As mentioned in section 1.1, deconstruction activities are the source of emissions, causing local environmental impacts in terms of noise, dust and vibrations on the immediate neighbourhood (DA (2015, pp. 28 et seq.), Diven and Shaurette (2010, pp. 66 et seq.), Mettke et al. (2008, pp. 176 et seq.)). Figure 2-2 illustrates the scope and understanding of impacts in the context of this research, which is further defined in the following sections.

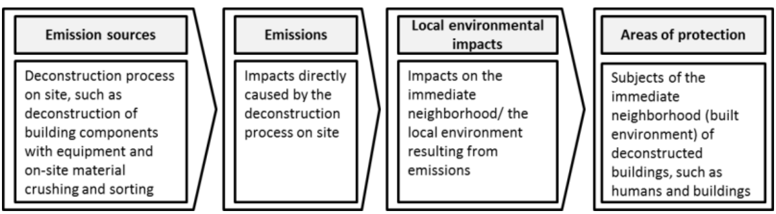


Figure 2-2: Scope and understanding of emissions and impacts in this study

2.2.1.1 Emission sources and emissions

According to EC-JRC (2011, p. xiii), emissions are one form of 'human intervention in the environment, either physical, chemical or biological'. In the Federal Immission Control Act of Germany 'air pollution, noise, vibration, light, heat, radiation and similar phenomena originating from an installation' are specified as emissions (§ 3 para.3 BImSchG). As especially noise, dust (as a form of air pollution) and vibrations are relevant impacts caused by deconstruction projects (DA (2015, p. 28 et seq.), Gabriel et al. (2010, pp. 4 et seq.), DIN 18007:2000-05), the focus of this thesis is on these emissions and impacts, which are further described in section 2.2.2. Possible emission sources of noise, dust and vibrations related to the deconstruction process on-site are listed in Table 2-3 (Kühlen et al. 2014, p. 14). As indicated in Table 2-3 (x), in this research the emphasis is on emissions which can be directly mitigated through planning of deconstruction projects on an operational level. This encompasses the deconstruction of single building components differing due to the selected techniques (1) and the technique-related scope of required material handling actions on site (2). The other emission sources of deconstruction processes on site (3-5) are not directly related to the selected deconstruction technique. Hence, the level and duration of emissions of these sources are assumed to remain constant for one deconstruction project (independently of the technique) and are not further examined within this research.

Table 2-3: On-site deconstruction process-related emission sources[11]

#	Possible emission source (with varying emission levels and durations)	Sources considered in this research
1	Deconstruction of building components with equipment, performed in different deconstruction techniques	x
2	Handling of deconstruction material on-site (i.e. (pre-)separation, (pre-)crushing)	x
3	Loading and unloading of deconstruction material	-
4	Equipment at rest and operation of power units	-
5	Abrasion of wearing parts	-
6	Cleaning and preparation of equipment and surfaces	-

Emission sources can be classified on the basis of dust emission source criteria of VDI 3790-1:2015-07 (Table 1, pp. 8, 9). As summarised in Table 2-4, emission sources of the deconstruction process on-site can in general be assigned to the class of **'diffuse emission sources'** according to VDI 3790-1:2015-07 (Table 1, pp. 8, 9).

[11] Kühlen et al. (2014, p. 14).

Table 2-4: Classification in diffuse and defined emission sources[12]

Criteria	Emission source class		Emission sources of the deconstruction process
Spatial emission source structure in particular	Diffuse	Larger spatial scale in particular	Depending on the position of the building component to be deconstructed above ground and the position of the equipment, the emission source in general has a large spatial scale, as emissions occur at different places at the same time, such as at the component, at the equipment and on the ground.
	Defined	Clearly defined source location in particular	
Emission mechanism	Diffuse	Uncontrolled release of emissions by the influence of external forces and physical properties	Emissions are uncontrolled released due to building material properties and external forces of the equipment.
	Defined	Forced release of emissions by a measurable volume flow	
Time response of emissions	Diffuse	Emission rate frequently highly fluctuates over time	Due to frequently changing conditions on site (building statics, component materials, equipment operations) the emission mass flow highly fluctuates.
	Defined	The emission rate is usually constant	
Influence of the surroundings on the emission	Diffuse	Usually intense	The influence of surrounding conditions on the propagation path between the emission source on the deconstruction site and the area of protection is usually intensified by the surrounding built environment and weather conditions.
	Defined	Usually not influenced	

In addition to the classification in diffuse and defined emission sources in Table 2-4 (on the basis of VDI 3790-1:2015-07 (Table 1, pp. 8, 9)) the spatial scale of the emission source relative to the dimensions of the examination area has a quantifiable influence on the distribution of noise and vibrations. In contrast to the classification criteria 'emission source structure in particular' (see Table 2-4), this characteristic is called 'emission source structure in general' in this study. According to DIN 18005-1:2002-07, ISO 9613-2:1999-10 and DIN 4150-1:2001-06, point and line sources can be generally

[12] On the basis of VDI 3790 Sheet 1 (2015, pp. 8, 9)

distinguished. Point sources have minor relative spread. According to DIN 18005-1:2002-07 and ISO 9613-2:1999-10, a noise source is defined as a point source, when its maximal spread is less than half of the distance between the source centre and the examination area (namely the subject of protection). Line sources are defined as constant over a greater distance/length, such as the constant noise source of a public highway. As the emission sources examined in this research are deconstruction of single building components and material handling actions on site, they can best be described as point sources.

2.2.1.2 Local environmental impacts and subjects of protection

The term ‘local environmental impacts’ is used for results of emissions according to the definition of environmental impacts of EC-JRC (2011, p. xiii) in this research. Environmental impacts are also often called ‘immissions’ and are defined as ‘air pollution, noise, vibration, light, heat, radiation and similar effects on the environment, which affect human beings, animals and plants, the soil, the water, the atmosphere as well as cultural assets and other material goods’ (§ 3 para.2 BImSchG).

The position, where the impact is measured, the allowed level of impact and the protection requirements depend on the ‘area of protection’ (AoP) (EC-JRC (2011, p. xii), Guinée et al. (2002, p. 109)). These areas are regulated. Relevant AoPs related to deconstruction projects are in general ‘human heath’ and the ‘man-made environment’ (EC-JRC (2011, p. xii), Guinée et al. (2002, p. 109)). Human health regards for instance to employees on site and residents of the neighbourhood, which consequently are called the subjects of protection. The man-made environment concerns for example buildings of the neighbourhood, which thus state subjects of protection as well.

2.2.2 Relevant emissions and impacts

In the following sections noise, dust and vibrations as relevant emissions and impacts caused by deconstruction projects (DA (2015, pp. 28 et seq.), Diven and Shaurette (2010, pp. 66 et seq.), Mettke et al. (2008, pp. 176 et seq.)) are defined.

2.2.2.1 Noise

According to EC-JRC (2011, p. 103), Guinée et al. (2002, Part 2, p. 68, Part 3, p. 230), § 3 para.1 to para.3. BImSchG and para.2 TA Lärm (1998), noise is defined as an environmental impact of sound, which can be hazardous with even long-term consequences to the health of humans[13] and ecosystems of the neighbourhood. Health impacts of noise were already scientifically confirmed in the 1970s to provide recommendations for policy makers (Health Council of the Netherlands (1971)[14], U.S. EPA (1974)[15]). Furthermore, studies show evidence of impacts for instance on birds and other animals (Brumm (2004)).

Deconstruction methods associated with relevant noise emissions are for instance wrapping, mortising, and sawing (DIN 18007:2000-05). Noise emission sources of deconstruction projects in the scope of this research (see Table 2-3) are located directly at the building component to be deconstructed (1), where falling component pieces strike (2) and at the equipment engine (3) (Figure 2-3 (Kühlen et al. (2014, p. 23, Figure 3))). In terms of subjects of protection, the impacts of noise on the local environment are assigned to buildings

[13] Auditory effects, such as hearing impairment, non-auditory physiological effects, i.e., ischemic heart diseases and hypertension, and psychological effects, such as sleep disturbance, depression and annoyance (Cucurachi et al. (2012); Giering (2010)).

[14] Health Council of the Netherlands (1971) Committee on Noise Annoyance and Noise Abatement. Geluidhinder [Noise Annoyance]. The Hague.

[15] U.S. EPA (1974) Information on levels of environmental noise requisite to protect public health and welfare with an adequate margin of safety. EPA/ONAC 550/9-74-004.Washington.

(with residents) of the neighbourhood close to the deconstruction site (4) (Figure 2-3 (Kühlen et al. (2014))).

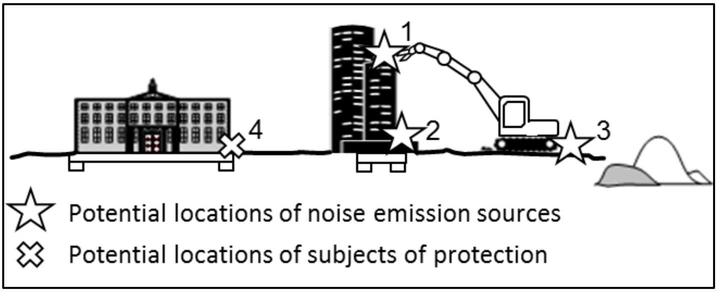


Figure 2-3: Potential locations of noise emission sources and of subjects of protection related to local environmental impacts (cross section)[16]

Noise is related to a change of pressure in the air, caused by compressed air through a sudden movement of an object. Noise is quantified by the physical quantity called sound pressure (p, normally measured in pascal (Pa)). The sound pressure level (L_p) (see Equation 2-1 (Sinambari and Sentpali (2014, p. 97, Equation 2.251))) is a logarithmic measure, commonly indicated in decibel (dB), to describe the intensity of noise. It is derived from the difference between compressed (p) and uncompressed air (p_0). This difference is also called amplitude.

Equation 2-1: Sound pressure level (L_p)

$$\mathrm{L}_p = 20 \cdot log_{10}\left(\frac{p}{p_0}\right) \text{ [dB]}$$

Besides L_p, the level of sound perceived by humans is influenced by the frequency (measured in Hertz (Hz)). The human ear is sensitive to frequencies between 16 Hz and 16,000 Hz (Sinambari and Sentpali

[16] Kühlen at al. (2014, p. 23, Figure 3).

(2014, p. 208)). To consider this frequency influence in noise level definition, frequency weighting filters are defined based on normal equal-volume-level curves according to DIN ISO 226: 2006-04 (Figure 2-4).

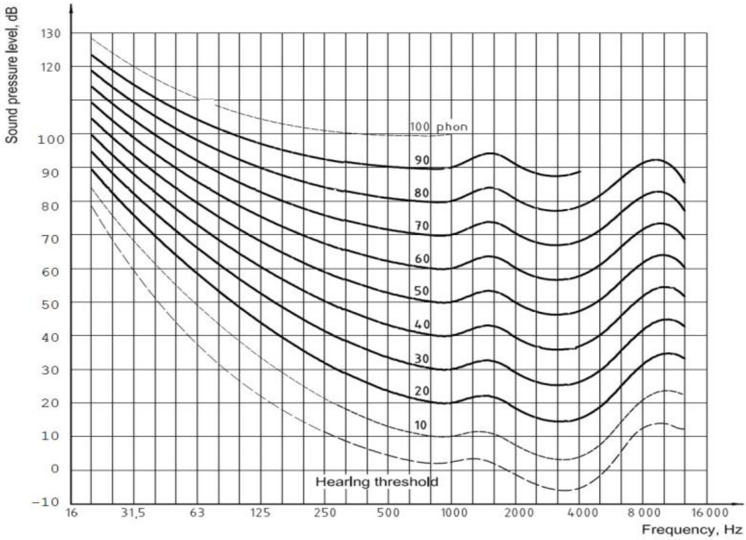


Figure 2-4: Normal equal-volume-level curves for pure tones under free-field listening conditions[17]

The normal equal-loudness-level curve of the hearing threshold in Figure 2-4 illustrates the sound pressure levels at different frequencies related to the natural human sense. This curve corresponds to the A-weighting filter according to DIN EN 61672-1:2014-07, which generally is expressed in A-weighted decibels (dB(A)) (Figure 2-5).

[17] DIN ISO 226:2006-04.

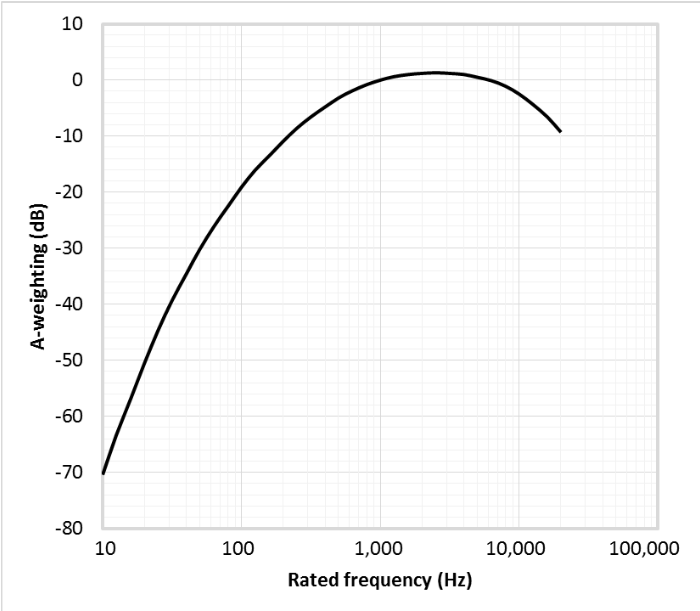


Figure 2-5: Curve of A-weighted frequencies[18]

The A-weighting filter is nationally and internationally most common and is generally used in relation to the measurement and definition of industrial or environmental noise (DIN EN 61672-1:2014-07). Hence, in the context of this thesis the term noise is related to A-weighted noise, considering the human sense of noise, and the noise level is indicated by dB(A).

2.2.2.2 Dust

Dust describes small, solid particles distributed in the air, but which have a higher density than air. There are three main ways to quantify the dust level. Firstly, the dust level can be described by the concentration of dust in the air, which is the mass of dust related to a

[18] Own illustration on the basis of table 3 of DIN EN 61672-1:2014-07, p. 21.

volume of air (mg/m³). Secondly, the dust level can be defined as the amount of dust in the air in terms of number of dust particles related to a volume of air (number/m³). Thirdly, it can be the dust mass depositing on a defined area during a certain time interval ($mg/(m^2\ t^1)$). Most specifications and regulations, which address dust emissions and impacts[19], quantify the dust level by the dust concentration in the air (mg/m³). Hence, in the context of this research the dust level is indicated by this concentration.

According for instance to DIN ISO 4225:1996-08 and TA Luft (2002), all particulate matters up to 75µm in diameter, encompassing suspended and deposited dust result in total dust. Furthermore, it is distinguished between total dust and micro dust (PM10). PM10 are dust particles with an aerodynamic diameter of 10µm or less (TA Luft (2002), U.S. EPA (1997, p. 4)). Especially micro dust can be hazardous for human beings, as it can cause long term health problems. Respectively, micro dust is defined as 'air pollution', besides 'smoke, soot, gases, aerosols, steam or odorous substances' under § 3 para.4 BImSchG. Besides micro dust, those particles of total dust which are too big to be inhaled can have negative impacts on the local environment including human health. They can cause irritations of eyes, throat and nose, lead to damages to property by deposits on buildings and cars and can effect surrounding wildlife (DA (2015, pp. 29 et seq.), GLA (2014, pp. 2 and 3)). Furthermore, from the work safety point of view the dust concentration in the air is classified in inhalable (E-dust) and alveolar (A-dust) dust (TRGS 900 (2015), TRGS 402 (2014)). E-dust is defined as all particulate matters inhalable through the mouth and nose. According to DIN EN 481:1993-09 it includes dust particles with an aerodynamic diameter up to 100µm. Until 1993 E-dust was called total dust in TRGS 900 (Mattenklott and Höfert (2009)). Hence, in this thesis the term dust is related to total dust in the air and it is assumed

[19] For instance the following European and German national regulations: RL 1999/30/EG, RL 89/427/EWG, TA Luft (2002) and the different Technical Rules (TRGS).

that the total dust concentration correlates with the concentration of E-dust.

Besides the size of dust particles, dust types are classified according to the material, such as organic dust from wood, mineral dust of concrete and metallic dust from metals. Depending on the material, the harmfulness of dust for humans varies. Related to the material, harmful dust can be grouped into asbestos (TRGS 517 (2015), TRGS 519 (2014)), mineral dust out of quartz (TRGS 559 (2010)) and carcinogen dusts according to TRGS 905 (2014). Carcinogen dusts can be further specified in dust of metals and wood and especially fibrous dusts out of mineral wool (TRGS 521(2008)).

During the deconstruction process on site mainly mineral dust (TRGS 559 (2010)) or mixed dust, including sand, lime, gypsum, cement and/or concrete, is generated (BG Bau (2007), DA (2015, pp. 29, 97)). But also those harmful dusts of other materials, encompassing for instance asbestos, mineral wool, different metals and wood, often result from building deconstruction (TRGS 519 (2014), TRGS 521 (2008)). All dust caused by deconstruction projects, independent of the material, is called dust in this study.

The diffusivity of emission sources of deconstruction projects in general is highlighted in section 2.2.1.1. Especially dust emission sources in the scope of this research (see Table 2-3) are highly diffuse. They are often uncontrolled and fluctuate over time, as they are influenced by characteristics of the deconstruction process, such as the structure of the building to be deconstructed and the equipment (see Table 2-4 on the basis of VDI 3790 Sheet 1 (2015, pp. 8, 9)). The key locations of dust emission sources correlate with those of noise emissions (1-3) in Figure 2-3. The local environmental impacts are highly affected by weather and surrounding conditions. In terms of subjects of protection, the impacts of dust on the local environment are assigned to buildings of the neighbourhood, where residents or neighbouring buildings are affected, close to the deconstruction site. Hence, the location correlates with the location assigned to noise impacts (4) in Figure 2-3.

2.2.2.3 Vibrations

According to § 3 para.1 to para.3. BImSchG, DIN 4150-2:1999-06 and DIN E 4150-3:2015-10, vibrations can be dangerous to human health and can cause damages to the built environment. Vibrations are mechanical oscillations of solid matters and are defined by frequency (measured in Hertz (Hz)) and amplitude, similar to noise. The level of hazard for humans and buildings depends on the frequency of occurrence and the frequency range of vibrations. Especially vibrations with frequencies between 0.1 Hz and 50 Hz can be harmful for humans and can cause damages to buildings (DIN 4150-2:1999-06, DIN E 4150-3:2015-10).

Deconstruction methods associated with relevant vibration emissions are for instance, mortising, blasting and in general methods causing big falling pieces/objects of buildings, such as wrecking and pulling (DIN 18007:2000-05). In general, the deconstruction process causes vibrations of lower frequency (Kühlen et al. (2014, pp. 122, 123, Figure 32)), hence all vibrations caused by deconstruction projects, are called vibration in this study.

Vibration emission sources of deconstruction projects in the scope of this research (see Table 2-3) are in general located at the baseplate of the building to be deconstructed (1), where falling component pieces strike (2) and at the engine of equipment (3) (Figure 2-6 (Kühlen et al. (2014, p. 27, Figure 5))). In terms of subjects of protection, the impacts of vibrations on the local environment are assigned to buildings (including residents) of the neighbourhood close to the deconstruction site (4) (Figure 2-6 (Kühlen et al. (2014))).

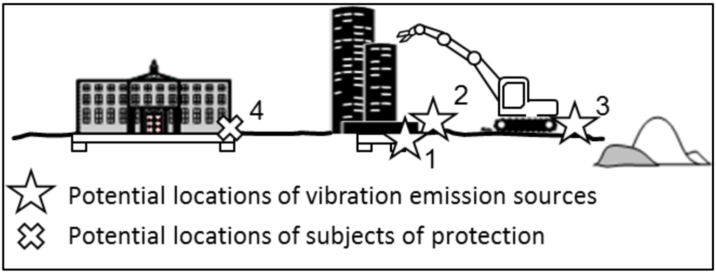


Figure 2-6: Potential locations of vibration emission sources and of subjects of protection related to local environmental impacts (cross section)[20]

2.2.3 Emission and impact mitigation methods

Similar to construction projects (Chen and Li (2006), p. 28), methods to mitigate the identified emissions and local environmental impacts on subjects of protection caused by deconstruction projects can be assigned to three categories. These categories are

1. 'Technology',
2. 'Management' and
3. 'Planning'.

The fourth category of mitigation methods according to Chen and Li (2006), p. 28, 'building materials' is not applicable for deconstruction projects. On the one hand, materials of building components and other building characteristics, such as the height of the building components to be deconstructed[21] (VDI 3790-3:2010, pp. 20, 21; Kühlen et al. (2016)), influence the level of emissions. But on the other

[20] Kühlen at al. (2014, p. 27, Figure 5).
[21] This is the vertical distance between ground surface and the building component/building level to be deconstructed. It varies over the deconstruction project phase (DA (2015), p. 24). In the following this building component characteristic is also called 'deconstruction height above ground'.

hand, these building characteristics are fixed values within one deconstruction project and cannot be adapted to mitigate emissions.

Technological methods address the actual mitigation of emissions and impacts by choosing different deconstruction methods respectively techniques and protective measures. Management and planning methods are combined to the one category ‘managerial methods’ in this study, as planning is the second process group of the five major process groups of project management according to (PMBOK (2013)).

2.2.3.1 Technological methods

In terms of technological methods, there are three method groups to mitigate the identified local environmental impacts on subjects of protection caused by deconstruction projects. The first group of technical impact mitigation is the reduction of emissions at the emission source by different deconstruction methods (see Table 2-2) and techniques respectively. Secondly, the impact on the propagation path between the emission source and the subject of protection can be decreased by protective measures on the propagation path. Thirdly, the impact at the subject of protection is limited by protective measure at the subject of protection, such as the human being itself or the neighbouring building. Nevertheless, emissions caused by deconstruction projects, can be singly mitigated by different deconstruction methods/techniques, as these technological methods reduce the emission source. Hence, the focus of this study is on the first group of technological methods to reduce emissions by different deconstruction methods/techniques.

2.2.3.2 Managerial and planning methods

The Project Management Institute (PMI) defines in PMBOK (2013) the following five major process groups of project management:

1. Initiating,
2. Planning,
3. Execution,
4. Monitoring and controlling and
5. Closing

As outlined in section 2.1.2, the focus of this research is on the planning phase. Hence, the focus of this research is on the second project management process group of managerial methods and on planning to reduce emissions and impacts. According to PMBOK (2013) the planning process group includes decision making. Within the context of this research, planning and decision making are managerial methods to prepare the mitigation of emissions. To mitigate the local environmental impacts on subjects of protection via the reduction of deconstruction project emissions by managerial methods, in this thesis a planning and decision support model is developed. This planning and decision support model is for those players mainly involved in the planning phase of deconstruction projects, including the principal, engineering consultant, the deconstruction company and authorities (see section 2.1.2).

2.3 Environment-related legal conditions

This section gives an overview of the statutory framework due to the control of the local environmental impacts noise, dust and vibrations caused by deconstruction projects. Within this context, the German national legal conditions are exemplarily introduced. It can be distinguished between regulations addressing the control of impacts on the neighbourhood, the local environment in general and those related to employees. Due to the focus of this research, regulations are relevant which address the control of impacts on the neighbourhood, including buildings and their residents as subjects of protection. These focal regulations are described in section 2.3.1. For completeness, regulations related to employees as subjects of protection and on respective protective measures are shortly introduced in section 2.3.2.1. Regulations on material recycling and hazardous substances are listed in section 2.3.2.2, as they are important in the environmental-related legal framework and highly influence deconstruction project planning.

2.3.1 Control of local environmental impacts

Consistent with the focus of this thesis, the statutory framework to control impacts on the neighbourhood, the local environment in general, is presented and analysed in the following using the example of Germany.

2.3.1.1 Noise

Regulations referring to noise distinguish between noise impacts on the neighbourhood and on employees on site as subjects of protection (DA (2015), p. 40, figure 1.21). In Germany, noise impacts on the local environment are mainly addressed by the national regulations BImSchG (2015), AVV Baulärm (1970), TA Lärm (1998) and 32. BImSchV (2015). BImSchG (2015) includes general regulations to protect the local environment from harmful impacts. As described in section 2.2.2 emissions and impacts are generally defined in § 3 BImSchG. Furthermore, according to BImSchG deconstruction sites are facilities requiring no approval. Within this context, for instance § 22 BImSchG states that avoidable emissions have to be avoided and those which are unavoidable have to be minimised. The general regulations of BImSch (2015) are further specified in the other national regulations. The most important regulation to evaluate the impact of construction noise on the local environment is AVV-Baulärm (1970). In case specific issues are not or only partly regulated in AVV-Baulärm (1970), the often more precise control definitions of TA Lärm

(1998) can be additionally applied to protect the local environment against noise impacts and to check the compliance with BImSchG (2015)[22] (Krämer (2013)). For instance, in TA Lärm peak and average values of sound levels related to a workday of 8 hours are defined to evaluate noise impacts on the local environment. In 32. BImSchV (2015) operation hours of equipment depending on the characteristics of the neighbourhood such as residential areas and generally sensitive areas, are regulated (§ 7 und § 8 32. BImSchV). The principle and engineering consultant have to consider the compliance with these regulations in the tender documents. Additionally, specific national and international standards and guidelines, including DIN ISO 9613-2:1999-10, DIN 18005-1:2002-07 and DIN 18005-1 supplement 1:1987-05 can be adducted for the evaluation of noise impacts on the local environment.

2.3.1.2 Dust

Similar to noise regulations, regulations referring to dust can be classified due to subjects of protection in terms of impacts on the local environment and on employees (Kühlen et al. (2014), p. 24).In Germany dust impacts on the local environment are mainly addressed by BImSchG (2015) in general and the 'Technical Instructions on Air Quality Control', TA Luft (2002) more specific. Even though TA Luft (2002) does not explicitly refer to construction and deconstruction projects, the instructions are applied to evaluate dust impacts on the local environment, independent of the impacts on employees. The instructions define allowed levels of dust concentrations in the air related to the dust particle sizes and the reference period. For instance, for PM10 the allowed average annual concentration is 40 µg/m³, while the average concentration of one day (24 hours) can be 50 µg/m³, if this concentration is not exceeded 35 times a year (para. 4.2.1 TA Luft).

[22] Especially the compliance with § 22 BImSchG.

2.3.1.3 Vibrations

Regulations referring to vibrations distinguish between impacts on the local environment, especially on the surrounding built environment and on humans within these buildings, and on employees on site as subjects of protection (Kühlen et al. 2014, p. 26). Besides BImSchG (2015), in Germany the decision of the Federal States Committee for pollution control (LAI (2000)) addresses vibration impacts on the local environment more specific. LAI (2000) includes for instance the evaluation of vibration impacts and refers to more specific standards. The German standards DIN 4150 Parts 1 to 3 (DIN 4150-1:2001-06, DIN 4150-2:1999-06, DIN E 4150-3:2015-10) address vibrations of construction works in particular. Part 1 describes preliminary proceedings to determine vibration impacts. Part 2 evaluates vibration impacts on humans in buildings and in part 3 vibration impacts on the surrounding built environment are assessed.

2.3.2 Regulations on other environment-related subjects

For the sake of completeness regulations related to employees as subjects of protection and on de-/construction material recycling and hazardous substances are presented in this section.

2.3.2.1 Work health and safety

There are various national regulations related to employees as subject of protection, addressing health and safety of labour linked to noise, dust and vibration impacts in Germany. General issues on control and documentation of health and safety on construction/deconstruction sites are set in BaustellV (2004) and ArbStättV (2015). Specific constraints on levels of impacts of noise and vibrations on labour are defined in LärmVibrationsArbSchV (2010). The technical guidelines TRLV Lärm (2010) and TRLV Vibrationen (2015) complete

LärmVibrationsArbSchV (2010). Furthermore, the evaluation of noise expositions at work is addressed by BGV B 3 (1997) and VDI 2058-2:1988-06 and VDI 2058-3:2013-04. VDI E 2057-1:2015-12 and VDI 2057-2:2016-03 and the international standard ISO 2631-1:1997-05 and ISO 2631-2:2003-04 evaluate the exposure of vibrations on the human body at work. A specific regulation on dust at work is GefStoffV (2015), which regulates classification, labelling and handling of hazardous substances, including different dust types, to protect labour. The diverse technical guidelines mentioned in section 2.2.2.2 complete this ordinance (TRGS 402 (2014), TRGS 517 (2015), TRGS 519 (2014), TRGS 521 (2008), TRGS 559 (2010), TRGS 900 (2015), TRGS 905 (2014)).

2.3.2.2 Material recycling and hazardous substances

Elements of the German regulatory framework on material recycling and hazardous substances relevant for deconstruction projects are introduced in the following. KrW-/AbfG (2016) ranks measures of waste management in a five-stage waste hierarchy. Waste avoidance has the highest priority followed by reuse, recycling, other utilisation (especially energetic utilisation and backfill) and disposal (§6 para.1 KrW-/AbfG). The draft of the planned ErsatzbaustoffV (status: 23.07.2015) defines limits of specific substances in recycled construction materials. Moreover, AVV (2016) classifies wastes according to their hazardousness. Within this context, disposal of different environmentally compatible deconstruction materials is regulated in GewAbfV (2012). NachwV (2015) specifies disposal of contaminated materials. Additionally, waste disposal acts of the single German federal states usually further specify the aspects of these ordinances.

Following this depiction of definitions and framework conditions for deconstruction project planning and related impacts on the local environment, in the next chapter the current state of research is respectively analysed due to model-based environmentally conscious deconstruction project planning and decision making.

3 Methods of modelling and assessing the planning and decision making process of deconstruction projects

This chapter summarises the current state of research related to the major research question: 'How can the distinct emissions of noise, dust and vibrations caused by a building deconstruction project and the related neighbourhood-dependent impacts on the local environment be mitigated, while considering technical parameters and economic objectives?'.

The interdependencies between distinct emissions and impacts on the local environment, technical parameters and economic objectives of deconstruction projects are highly complex. Consequently, a model-based approach is chosen to answer the research question. By answering the sub-questions (section 1.2), requirements for the model, which is newly developed within this research, are identified in the following. Strengths and weaknesses of existing approaches and relevant and partly missing data are elaborated. Requirements for adequate approaches and data for the new model are derived in this chapter. In conclusion, adequate approaches have to be redeveloped when necessary and required missing data have to be collected.

To analyse

- firstly, the influence of different building characteristics on the proposed/adequate deconstruction plan due to the mitigation of distinct emissions/impacts (sub-question 1) and

- secondly, the influence of surrounding conditions on the level of distinct impacts (sub-question 2),

the framework of the model of deconstruction planning for environmental assessment, besides economic and technical assessment, have to have specific characteristics. Hence, existing models for deconstruction project planning and decision making are analysed in section 3.1. Based on the analysis the framework characteristics are identified. Additionally, alternative deconstruction plans have to be technically, economically and environmentally assessed. Therefore, in sections 3.2 and 3.3 approaches to quantitatively assess the technical feasibility as well as economic and environmental planning parameters of the deconstruction process are discussed and selected. Furthermore, respectively required data and data sources for the assessment are examined and identified.

To gain an adequate deconstruction project plan due to impact mitigation and to analyse

- firstly, the influence of different project constraints on this deconstruction plan (sub-question 3),
- secondly, the conflicts between economic and environmental objectives (sub-question 4) and
- thirdly, the variations in this deconstruction plan due to different economic and environmental objectives (sub-question 5),

deconstruction project planning and decision support due to different objectives/preferences and under project-dependent restrictions have to be provided. Hence, characteristics of existing models for deconstruction project planning and decision making are analysed in section 3.4. Within this context, qualities of project-related constraints and qualities of the objective function/s to select the deconstruction plan/s due to environmental objectives are nominated respectively.

Moreover, approaches of multi-objective decision support are examined and selected.

Section 3.5 summarises the characteristics and availability of data for modelling and assessing the deconstruction project planning and decision making process to answer the research question/s.

3.1 Modelling deconstruction planning for environmental assessment

In the following, the framework characteristics of existing models for deconstruction project planning and decision making are analysed. The framework conditions for modelling deconstruction planning for environmental assessment, besides economic and technical assessment, are identified. This is the basis to answer sub-questions 1 and 2.

Within this context, the consideration of the single emissions of noise, dust and vibrations and related impacts on the local environment is in the focus of the analysis. Furthermore, organisational actions and changes of the actual performance/productivity are circumstantial as the emphasis of this research is on environmental impacts from a technical perspective. Hence, the performance of employees in the form of a productivity rate is assumed to be fixed. On deconstruction sites usually there are only a few employees and/or they have comparable qualifications. Hence, in this research it is assumed that all deconstruction activities are performed by the same employees or by employees with the same qualification. Moreover, no learning effects are considered. Hence, for the purpose of this research, planning methods of traditional project management are applicable and performance-oriented planning approaches are not further analysed in the following.

3.1.1 Level of detail for environmentally conscious deconstruction planning

Model-based approaches for planning and decision making of (de-) construction projects differ according to the level of detail of the required information and the quality[23] of planning and decision making objective(s). There are strategic and operational approaches to model the planning procedure, which are introduced in the following sections.

3.1.1.1 Strategic planning and decision making related to the overall project

Literature on strategic project planning in terms of strategic decision support for the overall project is vast. Some current approaches of strategic project planning are applied to deconstruction projects and can give decision support for planning the overall deconstruction strategy (Abdullah (2003), Abdullah et al. (2003), Abdullah und Anumba (2002), Anumba et al. (2008), (2003), Coelho and de Brito (2013), Kourmpanis et al. (2008a), (2008b), Liu et al. (2005), Endicott et al. (2005), Liu et al. (2003)). These approaches provide information in terms of planned magnitudes for strategical decision objectives and are based on quantitative and qualitative project analysis. Coelho and de Brito (2013), Endicott et al. (2005) and Liu et al (2003) quantitatively compare deconstruction strategies with the help of case studies. Coelho and de Brito (2013) evaluate several overall project strategies, which combine deconstruction and material handling, based on costs, durations and quantitative values of global environmental impacts in the form of climate change, acidification, summer smog, nitrification and heavy metals. In this respect, the strategies are analysed by scenarios. Liu et al (2003) singly focus on deconstruction project costs of different strategies. Kourmpanis et al.

[23] The objectives can be for instance qualitative or quantitative.

(2008a), (2008b) and Liu et al. (2005) qualitatively evaluate three different strategies for the overall deconstruction project with respect to deconstruction material management options. In Kourmpanis et al. (2008b) and Liu et al. (2005) the different deconstruction strategies and deconstruction material management options are outlined, but no decision support in terms of a specific strategy is provided. Whereas, Kourmpanis et al. (2008a) applies the multi-criteria decision analysis (MCDA) method PROMETHEE II to provide decision support regarding a specific combination of one overall deconstruction strategy and one deconstruction material management option due to different strategic economic, environmental, technical and social criteria. Within this context, environmental impacts in the form of noise, dust and vibrations, besides technical and economic aspects, are considered in decision making. Nevertheless, decision is made on strategic level for the overall project and no information on and solution for single project activities is provided. Furthermore, the single economic, environmental and technical decision criteria are qualitatively assessed. Besides Kourmpanis et al. (2008a), Abdullah (2003), Abdullah et al. (2003), Abdullah und Anumba (2002), Anumba et al. (2008), (2003) provide strategic project decision making approaches for the overall deconstruction project. They use a two-step approach. Firstly the hierarchical MCDA method Analytic Hierarchy Process (AHP) is applied to select adequate deconstruction strategies due to different qualitative economic, environmental, technical and social decision criteria. Within this context, noise, dust and vibrations are qualitatively considered as criteria in decision making, besides other environmental, economic, technical and social criteria. Secondly, these selected adequate strategies are quantitatively, economically assessed in terms of cost.

3.1.1.2 Operational planning and decision making based on single activities

Operational project planning and decision making implies detailed planning of the project, usually of single project activities. Hence, the deconstruction process has to be modelled bottom-up, based on quantitative data of single project activities and their relations to each other. These models require detailed, activity-related, quantitative information on time, costs and resources, such as employees and equipment. In general, they give decision support due to economic objectives in terms of minimising the overall project duration or costs. Within this context, the model outcome is usually activity-related information, for instance information on required resources and their allocation and detailed time and cost estimates.

In the context of building deconstruction projects, there are only few research studies, which provide operational project planning approaches (Akbarnezhad et al. (2012), (2014), Cheng and Ma (2013), Sunke (2009), Aidonis et al. (2008), Schultmann and Sunke (2006), (2007), Schultmann (2003), (1998), Seemann (2003), Schultmann and Rentz (2002), (2001)). Most of these approaches make detailed planning of single deconstruction activities possible (Sunke (2009), Schultmann and Sunke (2006), (2007), Schultmann (2003), (1998), Seemann (2003), Schultmann and Rentz (2002), (2001)). Some of them include case study-based, quantitative, activity-related data of duration times, costs and resources usage (Schultmann (2003), (1998), Seemann (2003), Schultmann and Rentz (2002), (2001)). Akbarnezhad et al. (2012), (2014) and Cheng and Ma (2013) include simulation approaches in operational deconstruction planning, which analyse different deconstruction scenarios due to material recycling, whereas single project activities are not planned. Finally, Aidonis et al. (2008) provides operational decision support for single deconstruction project stages in terms of the two options demolition and selective deconstruction with the help of a mixed-integer linear programming model. The objective function maximises the profit from selling deconstruction products/‘waste’ minus the costs of the deconstruction process. In each stage it is decided, if the next stage is selective deconstructed or if the total rest of the building is demolished. Hence, there is one deconstruction technique related to the single project stages and one technique related to the deconstruction of the overall building (rest). Consequently, as in Akbarnezhad et al. (2012), (2014) and Cheng and Ma (2013), single project activities are also not planned. Moreover, alternative deconstruction techniques are not considered. Further analysis of the existing approaches of operational deconstruction project planning on single deconstruction project activities (Sunke (2009), Schultmann and Sunke (2006), (2007), Seemann (2003), Schultmann (2003), (1998), Schultmann and Rentz (2002), (2001)) is carried out later within this chapter regarding diverse criteria, as the operational level of detail and planning of single project activities is chosen for this research (see section 3.1.1.3).

3.1.1.3 Selected level of detail

The level and duration of distinct emissions of noise, dust and vibrations correlates with the method/technique and duration of the single, usually hourly changing deconstruction project activities and vary throughout the working day (DA (2015, p. 227 et seq.), Gabriel et al. (2010, pp. 16 et seq.), DIN 18007:2000-05). Emission levels and durations are also related to the activity order, e.g. activity parallelisation. For instance, in general twice the amount of dust is released when two machines are working compared to one machine and the noise level increases 3 dB(A) for two equally loud sound sources, which equals an increase in loudness perception of about 0.2 (on the basis of Sinambari and Sentpali (2014, p. 212, Equation 6.4)). Hence, to reach the major research objective, the level of detail of operational planning and decision making is chosen. Furthermore, detailed planning of and decision making on single deconstruction project activities is required. Consequently, the existing models of operational deconstruction planning and decision making on single deconstruction project activities (Sunke (2009), Schultmann and Sunke (2006), (2007), Seemann (2003), Schultmann (1998), (2003), Schultmann and Rentz (2002), (2001)) are examined due to additional required framework characteristics of modelling deconstruction planning for environmental, economic and technical assessment.

3.1.2 Model framework characteristics for operational planning

The extent of deconstruction related environmental impacts in the form of noise, dust and vibrations depends mainly on:

- Alternative deconstruction techniques (technique modes) applied to single deconstruction project activities (DA (2015, p. 227 et seq.), Gabriel et al. (2010, pp. 16 et seq.), Toppel (2003, pp. 79 et seq.), DIN 18007:2000-05). They influence the level and duration of emissions;
- Sizes of basic units used to perform the activity (EU 2000/14/EC, Kühlen et al. (2016, p. 28)). They have an impact on the level and duration of emissions;
- Deconstruction activity sequences (activity parallelisation) depending on available resources, namely the availability of equipment (number of basic units) used to perform the activity. They effect the level and duration of emissions (e.g. on the basis of Sinambari and Sentpali (2014, p. 212, Equation 6.4));
- Building characteristics, such as building shell materials and the height above ground of the building level and respectively of the component to be deconstructed (VDI 3790-3: 2010-01), Kühlen et al. (2016, pp. 28, 32 et seq.)). They have an impact on the level and duration of emissions as well;

- Characteristics of the deconstruction site surroundings, such as the neighbouring building structures and the environment in-between buildings.[24] They influence the level of impact on the immediate neighbourhood.

Hence, these influencing factors have to be part of the framework of the deconstruction planning model for environmental assessment. In the following sections, the existing models and research studies of operational planning and decision making of deconstruction projects, identified in section 3.1.1.3 are analysed according to their provision of these influencing factors.

3.1.2.1 Activity performance alternatives and parallelisation

Current models of operational deconstruction project planning and decision making consider alternatives to perform single project activities by a set of multiple feasible modes related to each activity (Sunke (2009), Schultmann and Sunke (2006), (2007), Seemann (2003), Schultmann (2003), (1998), Schultmann and Rentz (2002), (2001)). Consequently, different deconstruction techniques and activity parallelisation can be modelled as multi modes respectively. There are the two major quantitative mathematical methods to identify the most suitable feasible modes in operational deconstruction planning and decision making: optimisation and simulation in terms of scenario analyses. These two methods and their implementation in the identified relevant research approaches are further examined in section 3.4 in the context of gaining a deconstruction project plan due to impact mitigation.

[24] Noise: DIN 18005-1:2002-07, DIN 18005-1 supplement 1:1987-05, DIN ISO 9613-2:1999-10; Dust: VDI 3782-1:2016-01, VDI 3783-13:2010-01 VDI 3945-1:1996-03, VDI 3945-3:2000-10; Vibration: DIN 4150-1:2001-06, DIN 4150-2:1999-06, DIN E 4150-3:2015-10.

3.1.2.2 Building characteristics

The few current models of multi-mode operational deconstruction project planning and decision making include building characteristics, such as different building component types and materials. Within this context, the selection of feasible deconstruction technique modes applicable for single project activities is based on these building characteristics (Sunke (2009), Schultmann and Sunke (2007), (2006), Seemann (2003), Schultmann (1998), (2003); Schultmann and Rentz (2002), (2001)) Hence, in these planning models the project is modelled based on physical characteristics of the building, whereas the single project activities are assigned to the single building components. These models do not distinguish between different deconstruction heights above ground (hg[25]) by considering the vertical position of building components. Nevertheless, this (hg) for instance can influence the emission level (VDI 3790 Sheet 3 (2010, pp. 20, 21), Kühlen et al. (2016)) and is important for the suitability of certain deconstruction techniques (DA (2015), Toppel (2003)). Furthermore, these models do not provide information about the influence of building characteristics, such as building component materials and (hg), on the level of distinct emissions of noise, dust and vibrations, caused by deconstruction activities. Hence, this data is not available to date.

3.1.2.3 Site surroundings

None of the currently existing models of operational project planning and decision making include characteristics of the surroundings/neighbourhood of the deconstruction site. These characteristics could be properties of neighbouring building structures and the environment in-between buildings. Hence, related model properties to include site surroundings/neighbourhood characteristics in planning and decision making of deconstruction projects do not

[25] In the following the deconstruction height above ground is also abbreviated ‘hg’.

exist until now. Relevant specific information and data of surrounding-conditions-depending influences on the impact level on the immediate neighbourhood, resulting from emissions of noise, dust and vibrations caused by deconstruction projects, are currently not available.

3.1.3 Research gaps in modelling deconstruction planning for environmental assessment

In general, to date no model of deconstruction planning exists, which includes all the identified required model framework conditions for deconstruction planning for environmental assessment, besides economic and technical assessment. Hence, to reach the research objective/s and to answer the research sub-questions 1 and 2, a new module of the overall model with the essential framework conditions for deconstruction planning for environmental assessment has to be developed. This new module, which is called Module 1 in the following, is developed with VBA and Access within the present research. It is modelled in the level of detail of operational project planning, based on single deconstruction project activities. The single project activities are assigned to the single components of the building shell. Physical characteristics of these single building shell components, such as building materials and (hg), are included in the model. Activity performance alternatives in terms of deconstruction techniques and activity parallelisation are modelled as modes. Furthermore, different deconstruction site surroundings are considered by modelling respective impact-influencing characteristics.

Besides these necessary model framework characteristics, Module 1 has to provide approaches to quantitatively assess the technical feasibility as well as economic and environmental planning parameters of the deconstruction process to answer sub-questions 1 and 2 as parts of the major research question. Hence, adequate approaches to provide quantitative assessment of technical, economic and environmental parameters have to be selected for the implementation into the model. Furthermore, Module 1 has to store and provide specific deconstruction-related information and data for the technical, economic and environmental assessment. Hence, methods to collect, edit, store and provide this data and information have to be selected. Therefore, in sections 3.2 and 3.3 firstly, approaches for technical, economic and environmental assessment are reviewed. Secondly, the data properties are defined and available data in literature, required primary data and respective sources/collection approaches are identified.

3.2 Technical and economic assessment in the planning process and required data

To reach the research objective/s, the assessment of the technical feasibility and of economic parameters has to be integrated into Module 1 of the deconstruction planning model. In the following, first technical parameters, relevant for deconstruction projects, and related assessment approaches are identified. Costs are the quantitative economic object variable looked at in this study. Hence, secondly economic assessment approaches for calculating deconstruction project costs are reviewed.

3.2.1 Delimitation of considered technical parameters

For the selection of alternative deconstruction techniques to define the sets of feasible modes for each deconstruction activity (see section 3.1.2.1), several parameters of technical feasibility are relevant. Based on DA (2015), Toppel (2003) and DIN 18007:2000-05 the following four parameters are considered in this research to define the technical feasibility of building component-related deconstruction activity technique modes:

- Component type suitability,
- Component material suitability,
- Maximum component material thickness and
- Maximum deconstruction height above ground.

3.2.2 Selected technical assessment method

Information and data of the technical feasibility of deconstruction methods related to building component types and materials as well as material thickness and deconstruction heights is available in DA (2015), Toppel (2003), DIN 18007:2000-05. The technical feasibility of deconstruction methods related to building component types and materials is considered in Schultmann (1998), (2003) and Schultmann und Rentz (2002), (2001), Seemann (2003). Only feasible methods related to the component type and material are part of the mode set of an activity.

For the technical assessment in this research, technique modes of single deconstruction project activities have to be evaluated due to the four identified relevant parameters of technical feasibility. In general a distinct decision for or against a certain deconstruction technique and method respectively is made according to all feasibility parameters. Therefore, a sequential application of relational operators is selected for technical assessment with subsequently application of the Boolean logic (true/false) related to technical comparative values.

3.2.3 Delimitation of considered costs

On the basis of the life cycle phases of the deconstruction project shown in Figure 2-1 and according to LFU. (2001, pp. 11, 12), costs of the following undertakings related to a specific project can be distinguished:

- Project planning,
- Site preparation and site facilities,
- Deconstruction process on site,
- Material transportation and material disposal and recycling

The existing research studies on operational deconstruction project planning also contain economic assessment in terms of costs. Within this context, Sunke (2009), Schultmann and Sunke (2007), Schultmann (2003), (1998), Seemann (2003), Schultmann and Rentz (2002), (2001) consider costs of equipment and employees related to the actual deconstruction process on site and related to material transportation and material disposal and recycling. And Schultmann (2003), (1998), Seemann (2003), Schultmann and Rentz (2002), (2001) even provide specific costs related to the material volume based on case studies. Nevertheless, these specific costs are more than 10 years old. Furthermore, different equipment sizes, which can influence the duration and emissions of deconstruction projects, are not considered in these studies.

The focus of this study is on the on-site deconstruction process, including the actual deconstruction of the building, pre-crushing and – sorting of material on site. Hence, costs related to the actual deconstruction process phase on site are included in the economic assessment and the costs of the other phases are assumed fixed and are not calculated.

Costs of the deconstruction process can be defined as manufacturing costs in the context of cost estimation in business administration. The calculation of manufacturing costs is part of industrial cost accounting. Within this context, the quantitative usage of single production factors can be determined by cost type accounting and it is distinguished between direct and indirect costs (Fichtner (pp. 58, 59)). In construction projects the calculation of manufacturing costs is part of the construction cost calculation on bid sum. According to Girmscheid and Motzko (2013, p. 154), the construction cost calculation on bid sum encompasses the steps illustrated in Figure 3-1.

	Direct costs of single production factors of single construction activities
+	indirect costs of the construction site
=	production costs
+	indirect expenses
+	construction interest
=	manufacturing costs
+	mark-up for risks and profit
=	net bid sum
+	turnover tax
=	bid sum including turnover tax

Figure 3-1: Steps of construction cost calculation on bid sum[26]

As the economic assessment aims to support planning and decision making of the deconstruction process based on single project activities, it is reasonable to focus here on production costs. Indirect expenses related to the general existence of the deconstruction

[26] Own illustration on the basis of Girmscheid and Motzko 2013, p. 154.

company, construction interest for probable pre-financing of construction works and mark-ups for risks and profit (see Girmscheid and Motzko 2013, pp. 237-247) are assumed to be fixed in this research and are not included in the economic assessment.

In Germany the basis for the estimation of costs related to buildings in the planning phase states DIN 276-1:2008-12. In this regard, the costs of deconstruction projects are assigned to the cost category 200 as part of site preparation for new buildings. As illustrated Figure 3-2 DIN 276-1:2008-12 distinguishes between different stages of cost estimation depending on the planning phases assigned to the service phases (LP) of the HOAI (2013)[27] (Bielefeld and Wirths (2010, p. 240)). These cost estimations depending on the service-phase-related planning phases display the point of view of the principal and the engineering consultant. From the point of view of the (de-) construction company, the different cost estimation stages can be assigned to the status of the placing of order (Jacob et al. (2011, p. 11)).

[27] The HOAI is the German Fee Structure for Architects and Engineers.

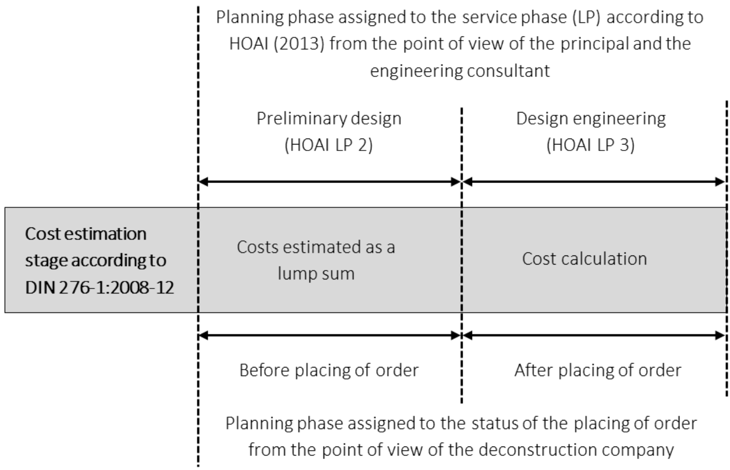


Figure 3-2: Stages of cost estimation from the point of view of the different players[28]

Depending on the planning phase and the respective cost estimation stage, the level of detail of planning and of cost estimation approaches differ. Approaches of production cost estimation are introduced in section 3.2.4. In section 3.2.5 the appropriate approach for the economic assessment in this research is selected.

3.2.4 Production cost estimation approaches and respective data

On the basis of the two cost estimation stages outlined in Figure 3-2, it can be distinguished between two production cost estimation approaches, cost estimation on the basis of cost-indices and the cost of single production factors.

[28] Own illustration on the basis of Bielefeld and Wirths (2010, p. 240), Jacob et al. (2011, p. 11).

3.2.4.1 Cost-index approach

The cost-index approach is usually used in the earlier planning phase related to the stage 'cost estimated as a lump sum' (see Figure 3-2). In this regards, the level of planning is less detailed than in the cost of single production factors (Drees and Paul (2015, p. 308), Leimböck (2015, pp. 181-183)). According to DIN 276-1:2008-12, a cost-index describes costs related to a reference unit. Different reference units can be possible. DIN 277-1:2016-01 describes probable units, such as building areas (€/m^2) and cross volumes (€/m^3). Furthermore, units can be building elements (masonry wall (€/wall)) or project activities related to a geometric unit (deconstruction of masonry (€/m^2)). Cost-indices related to deconstruction projects are for instance available from the German information centre of construction costs (BKI). Yearly, statistical costs-indices related to building types (BKI (2015a)), building elements (BKI (2015b)) and construction/deconstruction activities and service items (BKI (2015c)) are provided. However, only BKI (2015b) and BKI (2015c) include deconstruction works. These deconstruction work cost-indices of the BKI consider different material types and building components, but they are independent of specific deconstruction methods/techniques and equipment types and sizes.

3.2.4.2 Cost of single production factors

Calculation of costs of single production factors is usually used in the later planning phase related to the stage 'cost calculation' (see Figure 3-2). Production factors of the on-site deconstruction process are resources, mainly in the form of employees, equipment and resources to operate and repair equipment. Related costs can be differentiated into cash-based costs[29] and imputed costs[30]. Cash-based costs are costs related to real expenditures. In the context of this thesis, cash-

[29] Pagatorische Kosten.
[30] Kalkulatorische Kosten.

based costs are labour cost and operation-related equipment costs, which can be assigned to the single deconstruction project activities. Imputed costs are investment-based costs and contingency reserves. In this research imputed costs are equipment contingency costs, which cannot be directly assigned to single deconstruction activities.

In the following paragraphs the calculation of costs of the single production factors of the on-site deconstruction process is described in detail by distinguishing labour, equipment contingency and operation-related equipment costs.

Calculation of labour costs

Labour costs of construction/deconstruction projects are usually calculated with the help of an average salary ASL[31]. The fundamentals of this average salary are shown in Figure 3-3 (Kattenbusch et al. (2012, p. 40), Girmscheid and Motzko (2013, p. 182).

Average basic (standard) labour wage	
+	additional labour costs
=	average salary A
+	social costs
=	average salary AS
+	probable non-wage labour costs
=	average salary ASL

Figure 3-3: Fundamentals of average salary[32]

[31] In literature and in the German construction industry the calculated salary is called average salary ASL.
[32] Own illustration on the basis of Kattenbusch et al. (2012, p. 40), Girmscheid and Motzko (2013, p. 182).

The average salary (A) (see Figure 3-3) is the sum of an average hourly basic (standard) labour wage and additional hourly labour costs. The average hourly basic labour wage is drawn from the number of employees on site and their qualification-depending hourly wages. In Germany basic hourly labour wages are standard wages according to labour agreements. These agreements are based on the federal framework conditions for labour agreements in the construction industry (BRTV (2014)). The federal agreements define hourly wages for six different wage groups. According to DA (2015, p. 181) a deconstruction activity is usually performed by a pair of employees, one operator, who is assigned to the fourth wage group, and one skilled worker assigned to the third wage group of §5 BRTV. Furthermore, in contrast to construction, a general foreman is not regularly on site. Hence, the average hourly basic labour wage is drawn from the two hourly basic wages[33] of 18.64 €/h (fourth wage group) and 17.07 €/h (third wage group) according to §2 section 9 of the German labour agreement on wages of the construction industry (TV Lohn/West (05.07.2014)).

Additional labour costs for instance encompass awards for long hours and difficult work conditions. In general, long hours are excluded in this research. But as service and maintenance of equipment basic units[34] is usually performed by the operator by doing overtime, an award of 10% based on the hourly basic operator wage is added (Girmscheid and Motzko (2013, p. 219)), resulting in 1.86 €/h. Moreover, as deconstruction activities usually state difficult work conditions and occasionally for instance breathing protection is required and vibration impacts occur, 1.65 €/h are assumed as additional labour costs according to §6 BRTV.

[33] The hourly basic wages include a mark-up due to construction works of 5.9% according to §2 section 9 TV Lohn/West.
[34] See as well paragraph 'operation-related equipment costs' of this thesis.

The average salary (AS) is the average salary (A) plus social costs. Social costs include all legal, negotiated and organizational social wages and costs. It is a percentage rate of the average salary A and usually around 90% (Girmscheid and Motzko (2013, p. 180)).

The average salary (ASL) is the average salary (AS) plus probable non-wage labour costs. Non-wage labour costs incur for instance for the refund of travel expenses and subsistence allowances (Girmscheid and Motzko (2013, p. 181)). Especially, travel expenses usually occur related to deconstruction projects, as the work place is outside the company’s headquarter. According to §7 BRTV an employee receives travel expenses of 0.20 € per kilometre. In this study an average distance to site of 10 km (20km return) is assumed, which results in travel expenses of 4 €/working day (with 8 hours per working day).

Equipment contingency costs

Equipment contingency costs are investment-based equipment costs and contingency reserves for probable equipment repairs. Investment-based equipment costs include amortization and the interest rate of equipment basic units and attachments (Girmscheid and Motzko (2013, p. 213), Drees and Paul (2015, p.67); Leimböck et al. (2015, pp. 47-50)). Due to cumbersome and often costly and time-consuming transport of basic units, they usually stay on site and are kept available during a deconstruction phase across single activity durations. Hence, the contingency costs of basic units should be calculated as contingency costs for the duration of the deconstruction of one building level. Amortization, interest rate and reserves for probable equipment repairs of equipment attachments can be assigned to the single deconstruction project activities, as their transport between different deconstruction sites/projects throughout project duration is probable.[35]

The register of construction equipment (BGL (2015)) includes size-related/engine-power-related monthly unit rates of contingency costs (κ^{ex}) of different equipment basic units and attachments valid across Europe. In the following, the two parts of the contingency costs unit rate, amortization and interest amount and repairs, are further described.

Firstly, BGL (2015) includes a fraction of the amortization and interest amount per contingency month (κ^{ami}). The unit rate fraction is based on a fraction of the percentage of amortization and interest per contingency month ($pc^{\kappa(ami)}$) and the average replacement value (c^{rep}) of the basic unit or attachment (Equation 3-1) (BGL (2015), p. 19).

Equation 3-1: Unit rate of the amortization and interest amount per contingency month

$$\kappa^{ami} = \mathrm{pc}^{\kappa(ami)} \cdot \mathrm{c}^{rep} \text{ [€/mt]}$$

This average replacement value (c^{rep}) states the equipment investment, the initial cost for the equipment on the basis of the price in the year 2014. A translation of the average replacement value to other years of investment (c^{rep}_{yr}) is performed via the producer price index of construction equipment related to the base year 2014 (fk^{pp}_{yr}) (Equation 3-2) (BGL (2015, p. 19)[36].

[35] In this research, costs for transport are not considered. Costs for the change of equipment attachments are considered by additional costs due to additional global time units.

[36] According to the producer price index for construction equipment (Destatis (2016, p. 189)) and the base year change by the Association of the German Construction Industry (BGL (2015, p. 18).

Equation 3-2: Average replacement value in year yr

$$c_{yr}^{rep} = \mathrm{c}^{rep} \cdot \frac{fk_{yr}^{pp}}{100} \text{ [€]}$$

With

c^{rep} average replacement value of BGL (2015)

fk^{pp}_{yr} producer price index of construction equipment in year yr related to the base year 2014 = 100

The percentage of amortization and interest per contingency month ($pc^{\kappa(ami)}$) (Equation 3-3) is drawn from a linearly calculated amortization rate (pc^{amr}) (Equation 3-4) and an interest rate (pc^{int}) (Equation 3-5) based on an imputed interest rate of 6.5% (pc^{iir}) (BGL (2015), p. 19).

Equation 3-3: Percentage of amortization and interest per contingency month

$$\mathrm{pc}^{\kappa(ami)} = \mathrm{pc}^{amr} + pc^{int} \text{ [\%]}$$

Equation 3-4: Fraction of monthly amortization in percentage of the average replacement value

$$\mathrm{pc}^{amr} = \frac{100}{n^{mt}} \text{ [\%]}$$

With

n^{mt} number of contingency months

Equation 3-5: Average fraction of monthly interest in percentage of the average replacement value

$$\mathrm{pc}^{int} = \mathrm{pc}^{iir} \cdot \mathrm{n}^{yr} \cdot \frac{100}{2 \cdot n^{mt}} \text{ [\%]}$$

With

$\mathrm{pc}^{\mathrm{iir}}$ imputed interest rate of 6.5%

$\mathrm{n}^{\mathrm{year}}$ number of usage years

For this research, the fraction average values of contingency months and hence the fraction average values of the amortization and interest unit rate per contingency month ($\varkappa^{\mathrm{ami}}$) according to BGL (2015) are taken.

Secondly, BGL (2015) includes a unit rate ($\varkappa^{\mathrm{rpa}}$) of repair per contingency month. This repair rate is based on the percentage of repair per contingency month ($\mathrm{pc}^{\varkappa(\mathrm{rpa})}$) and the average replacement value ($\mathrm{c}^{\mathrm{rep}}$) (Equation 3-6) (BGL (2015), p. 22).

Equation 3-6: Unit rate of repair per contingency month

$$\varkappa^{rpa} = \mathrm{pc}^{\varkappa(\mathrm{rpa})} \cdot c^{rep} \text{ [€/mt]}$$

With

$\mathrm{pc}^{\varkappa(\mathrm{rpa})}$ repair costs rate in percentage of the average replacement value per contingency month

$\mathrm{c}^{\mathrm{rep}}$ average replacement value of BGL (2015)

As BGL (2015) states discrete equipment sizes/engine powers (sz_1, sz_2) and respective unit rates of contingency costs (ϰ^{ex}_1, ϰ^{ex}_2), a continuous function is assumed between these unit rates. Hence, the contingency cost unit rate (ϰ^{ex}) is interpolated and extrapolated for equipment sizes/engine powers in-between and for smaller or greater equipment sizes/engine powers (sz) respectively with the help of Equation 3-7 (BGL (2015, p. 24)).

Equation 3-7: Interpolation/extrapolation of contingency cost unit rates

$$\text{ϰ}^{ex} = \text{ϰ}_1^{ex} + (\text{ϰ}_2^{ex} - \text{ϰ}_1^{ex}) \cdot \frac{(sz - sz_1)}{(sz_2 - sz_1)} \text{ [€/month]}$$

With

ϰ^{ex} sought unit rate of contingency costs

ϰ^{ex}_1 unit rate of contingency costs of the adjacent smaller equipment size/engine power

ϰ^{ex}_2 unit rate of contingency costs of the adjacent greater equipment size/engine power

sz equipment size/engine power of the available equipment (in kW)

sz_1 size/engine power of the adjacent smaller equipment (in kW)

sz_2 size/engine power of the adjacent greater equipment (in kW)

Whereby, for extrapolation ϰ^{ex}_1 and ϰ^{ex}_2 are the unit rates of contingency costs and sz_1 and sz_2 are the discrete equipment sizes/engine powers of the two smallest respectively greatest equipment sizes/engine powers (BGL (2015), p. 24).

Based on these data and assuming 170 service hours per month (Leimböck et al. (2015, p. 49), BGL (2015, p. 22)), hourly specific values of equipment contingency costs can be calculated.

Operation-related equipment costs

Operation-related equipment costs include costs of equipment operating resources, such as fuel and lubricants, of operation as well as of service and maintenance of equipment basic units and equipment attachments (Girmscheid and Motzko (2013, pp. 213, 218, 219), Drees and Paul (2015, p.67)). Hence, operation-related equipment costs should be assigned to the single deconstruction project activities.

According to BGL (2015, p. 15) a specific value of fuel consumption per activity hour (ν) (in l/h) can be calculated based on the characteristic engine power of the basic unit (sz) in kilowatts (kW). Fuel consumption of construction equipment is generally expected between 80-170 g/kWh (including operational interruptions). In this research, the average value of 125 g/kWh is assumed. Usually construction equipment runs with diesel. Customs conversion factor of diesel density is 0.84 kg/l. Hence with Equation 3-8 the specific value of fuel consumption per activity hour (l/h) is calculated.

Equation 3-8: Specific value of fuel consumption per activity hour

$$\nu = sz \cdot \frac{125}{1000 \cdot 0.84} \text{ [l/h]}$$

With specific diesel costs per litre (κ^{diesel}) (in €/l), specific fuel consumption costs per activity hour (κ^{fu}) can be estimated (Equation 3-9).

Equation 3-9: Specific fuel consumption costs per activity hour

$$\kappa^{fu} = \nu \cdot \kappa^{diesel} \text{ [€/h]}$$

Due to highly changing prices of one litre diesel throughout weeks and months, in this study the average price of one litre diesel in the year 2015 in Germany is presumed. Hence κ^{diesel} is put to 1.17 €/l, which is the average value based on monthly prices of one litre diesel in Germany within the year 2015[37].

The costs of lubricants consumption usually accounts for 10-12% of fuel costs (BGL (2015), p. 15). Hence, lubricants consumption costs per activity hour (κ^{lu}) are calculated as 11% of fuel consumption costs per activity hour (κ^{fu}) in this research ($\kappa^{lu} = 0.11 * \kappa^{fu}$ [€/h]).

Equipment operation costs and equipment service and maintenance costs are calculated as labour costs in terms of the salary of the operator (Girmscheid and Motzko (2013, p. 219)) and are described above (see paragraph "estimation of labour costs").

All cost of single production factors described above, labour costs and equipment investment-based and operational costs, are duration-/time-dependent. Hence, for the calculation of costs, the durations of the single deconstruction activities are required from the project schedule. Requirements related to the calculation of the deconstruction project schedule due to the research objective/s are further examined in section 3.4.

3.2.5 Selected economic assessment method

The appropriate cost estimation approach for the economic assessment of this thesis has to calculate costs assigned to single deconstruction project activities. Both introduced production cost estimation approaches, cost-indices and cost of single production factors, provide this.

[37] Average costs based on monthly gross consumer prices of one litre diesel in Germany within the year 2015 (Mineralölwirtschaftsverband (2016)).

Moreover, for decision support related to the major research question, it is necessary to distinguish between alternative deconstruction techniques. Hence, the estimation of distinct costs of on-site deconstruction activities performed with different deconstruction techniques is required. Here, cost-indices are not suitable and more detailed information related to single techniques is necessary. The approach of costs of single production factors provides costs of labour and distinct investment-based and operational costs of diverse equipment (basic unit and attachments) used to perform different techniques. Hence, the approach of costs of single production factors is appropriate and selected for the economic assessment in this thesis.

3.3 Environmental assessment in the planning process and required data

Besides technical and economic assessments, the assessment of environmental deconstruction plan parameters has to be integrated into Module 1 of the planning model to reach the research objective/s by answering the major research question. Environmental objectives in the context of this study are mitigations of distinct emissions of noise, dust and vibrations and related neighbourhood-dependent impacts on the local environment, caused by individual deconstruction projects. Hence, for the environmental assessment, potential emissions and related impacts on the local environment of specific deconstruction projects are supposed to be estimated/ quantified based on the modelled deconstruction project plan.

Environmental assessment, taking into account the environmental implications of decisions related to projects before decisions are made, is regulated by the directive 2014/52/EU of environmental impact assessment (EIA) (EIA directive) in Europe. This European directive is implemented and substantiated at national level. For instance, in Germany the national law for EIA is the UVPG (2015). The related administrative regulation UVPVwV (1995) includes further details for implemetation. In this regulation it is differentiated between three categories of environmental consequences, consequences related to watercourses, related to soil properties and related to the air quality. In the context of air quality the regulation refers to the BImSchG. As mentioned in chapters 2.2 and 2.3, this act specifies noise, dust and vibrations as relevant emissions and environmental impacts.

The environmental evaluation and comparisons of process alternatives of a specific project, leading to these different emissions and their effects on the environment at the location, are usually the focus in so called ‘project EIA's’ (Glasson et al. (2005, p. 15), Cornejo (2004)). Hence, EIA is a major management and evaluation instrument to support decision making on environmental aspects of projects (Manuilova et al. (2009)). Furthermore, EIA concentrates on the assessment of actual and local environmental issues (Tukker (1999)). However no specific method is used and provided in EIA to assess the effects on the environment (Manuilova et al. (2009), Stahl (1998, p. 56)). Rather than a single tool in itself, EIA is referred to as a procedure/a generic instrument to compare the environmental effects of alternatives in which tools, such as Life Cycle Assessment (LCA), are applied (Cornejo et al. (2005), Tukker (1999)).

LCA is a standardised tool for environmental assessment from a life cycle perspective based on a generic environmental evaluation framework. Principles, framework conditions for and requirements of LCA are standardised and summarised in DIN EN ISO 14040:2009-11 and DIN EN ISO 14044:2006-10. In this respect, LCA is structured into four stages, as shown in Figure 3-4.

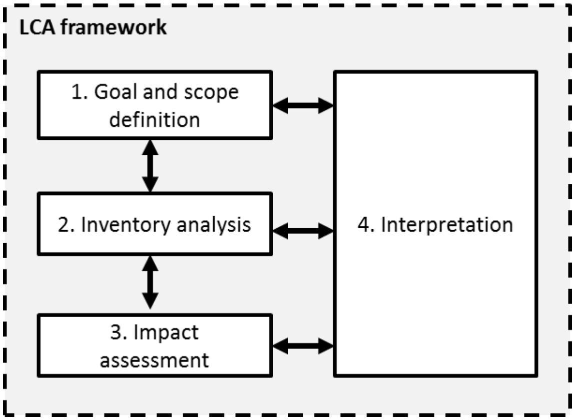


Figure 3-4: Stages of LCA[38]

The central elements of LCA are the life cycle inventory analysis (LCI) (stage 2) and the life cycle impact assessment (LCIA) (stage 3) (DIN EN ISO 14040:2009-11). Manuilova et al. (2009) state that in general adoptions of specific LCIA methods developed for LCA can be used for EIA. Moreover, IAQM (2014) in particular applys risk assessement for EIA of deconstruction sites.

In the following, existing approaches for environmental assessment and available data are examined with respect to answer the research question. Available approaches, data and required data characteristics for modelling emissions related to the topic of this thesis are analysed in section 3.3.1. Due to the above mentioned probable adaption of LCIA methods for EIA, an analysis of available methods and data in LCIA related to the relevant environmental effects in this study, namely noise, dust and vibrations, as well as the deconstruction-specific risk assessment approach for EIA of IAQM (2014) are examined in section 3.3.2.

[38] Own illustration on the basis of DIN EN ISO 14040:2009-11, p. 17.

3.3.1 Modelling of emissions and related data

For EIA in this thesis, first emissions of noise, dust and vibrations related to deconstruction projects have to be estimated/quantified. In this context, specific values of the respective emissions and related to particular reference units are required for the quantification of emissions. For instance, for LCI in general, characteristic factors in the form of classification numbers and specific values related to reference units is gathered from existing databases, such as from the internationally, widely recognized 'ecoinvent' database[39] and from the German 'Ökobaudat'[40]. Nevertheless, to date these databases to estimate emissions for instance for LCI, do not include data in the form of classification numbers or specific values of emissions of noise, dust and vibrations at all (Hischier et al. (2010, p. 13), EC-JRC (2011, p. 102), and especially also not related to deconstruction projects.

To model the emissions of noise, dust and vibrations related to different deconstruction methods a respective database of specific values of emissions has to be developed within this thesis. The required properties of data for the development of specific values of emissions for this database are defined in section 3.3.1.1. For the development of specific values, available data from literature is examined in section 3.3.1.2 and methods of primary data collection executed in this thesis are introduced in section 3.1.1.3.

3.3.1.1 Data properties

Specific values related to reference units are required for the quantification of emissions. In this study the reference units are the single process activities of deconstruction projects assigned to particular building components (see section 3.1.2.2) and relating to

[39] Website of the ecoinvent database:
http://www.ecoinvent.org/database/database.html (last accessed 02.05.2016).
[40] Website of the Ökobaudat database: http://oekobaudat.de/datenbank/browser-oekobaudat.html (last accessed 02.05.2016).

one hour. These activities usually have durations between one hour to a few hours. Applicable data of emissions of noise, dust and vibrations has to be related to these reference units and to those factors, identified to mainly influence the duration and level of their emissions (see section 3.1.2). Hence, respective data has to be related to:

- Alternative deconstruction techniques (technique modes) applied to single deconstruction project activities (DA (2015), Kühlen et al. (2016), DIN 18007:2000-05);
- Sizes of basic units used to perform the activity (EU 2000/14/EC, Kühlen et al. (2016));
- Deconstruction activity sequences (activity parallelisation) depending on available resources, namely the availability of equipment (number of basic units) used to perform the activity (Kühlen et al. (2016));
- Building characteristics, such as building shell materials and the height above ground of the building level and respectively of the component to be deconstructed (VDI 3790 Sheet 3 (2010, pp. 20, 21), Kühlen et al. (2016)).

Furthermore, related data has to allow quantification of emissions due to different emission levels.

3.3.1.2 Available data

In this section available data in literature[41] is analysed according to the defined data properties in the previous section 3.3.1.1.

DA (2015, pp. 227 et seq, 257 et seq.), Toppel (2003, pp. 79 et seq.), DIN 18007:2000-05), Mettke et al. (2008, pp. 181ff) provide data on the distinct emissions of noise, dust and vibrations of different

[41] Within this context, data of the research this thesis is related to is excluded from the literature review.

deconstruction methods. Nevertheless, this data is qualitative (yes/no statements) and no general quantification of emissions is possible.

A small amount of quantitative data of noise emissions exists related to specific building materials and to a few deconstruction techniques[42] in Krämer et al. (2004) and Krämer et al. (1998). Furthermore, little quantitative data of measured noise, dust or vibration impacts is documented in Mettke et al. (2008, noise (pp. 181 et seq.), dust (pp. 196 et seq.), vibrations (pp. 205 et seq.)). Within this context, data is generally based on single case studies with no fixed framework conditions. Hence, it cannot be inferred to universal valid emission levels and the values of the different cases cannot be compared for instance due to different deconstruction methods. Moreover, measured impacts, e.g. the noise impacts (Mettke et al. (2008, noise (pp. 181 et seq.), relate to different deconstruction strategies for the overall deconstruction project. Finally, data of one case focusses on one distinct impact and noise, dust and vibrations are not examined in combination. Little universal valid quantitative data of noise emission levels is available for selected equipment, which can be used for deconstruction activities (database on noise emissions for outdoor equipment of the European Commission[43], Dittrich et al. (2016), 2000/14/EC; Hammad et al. (2014, Table 1 on the basis of BS 5228[44])). Limited semi-quantitative data of dust emission levels exists related to different materials (but very little building materials) in VDI 3790-3: 2010-01. This universal valid quantitative data is limited to only one emission in terms of noise or dust and is usually independent of the deconstruction height above ground.

[42] As defined in section 2.1.3, the technique is a combination of deconstruction method and equipment.

[43] Website of the noise emissions for outdoor equipment database of the European Commission: http://ec.europa.eu/growth/tools-databases/noise-emissions-outdoor-equipment/index_en.htm (last update: 05.04.2016, accessed: 05.05.2016).

[44] BS 5228: British Standards: Code of Practice for Noise and Vibration Control on Construction and Open Sites - Part 1: Noise, BS 5228, British Standards Institution., 2009.

In summary, in literature available data is generally limited. Furthermore, this limited data has not the required quality to develop the intended specific values of noise, dust and vibration emission levels of the database for emission modelling for EIA. Existing data is not quantitative or semi-quantitative/classified, universal valid and related to the defined reference units of deconstruction projects. Relevant emissions of noise, dust and vibrations are not examined in combination. Additionally, data is often limited to only one of the four identified mainly emission-influencing parameters, such as method/technique, equipment size and number and building characteristics (material and deconstruction height above ground).

3.3.1.3 Research gaps and primary data collection

As applicable data is currently not available, in this research primary data is collected for the development of classification numbers and specific values of levels of the distinct emissions, which are included in a database for emission modelling related to deconstruction projects. This primary data has to be quantitative or semi-quantitative/classified data of the relevant distinct emissions related to the defined reference units of deconstruction projects, including the identified mainly emission-influencing parameters. Hence, quantitative/semi-quantitative data of hourly noise, dust and vibration emission levels related to single process activities of deconstruction projects assigned to particular building components by distinguishing between different deconstruction techniques or component materials is gathered. Therefore, the two methods of primary data collection

- experiments and
- an expert survey together with expert consultations

are applied in this thesis.

3.3.2 Analysis of local environmental effects

After distinct potential emissions of noise, dust and vibrations related to deconstruction projects on the basis of single process activities are estimated/quantified, related potential effects on the local environment have to be assessed. Within this context, available methods and data of impact assessment in LCIA are examined for probable adaption for EIA. Furthermore, the deconstruction-specific risk assessment approach for EIA related to risks of dust impacts of IAQM (2014) is look at.

3.3.2.1 Effect assessment methods

To date only a few LCIA methods exist to address environmental effects in terms of noise and odour. The few studies for assessing noise impacts in LCA focus primarily and almost exclusively on road transport, causing noise impacts on human health by road vehicles. They singly include the so-called endpoint impact categories, such as ‘damage to human health’[45], usually related to one year as global and regional environmental indicators (Cucurachi et al. (2012); Franco et al. (2010); Althaus et al. (2009a), (2009b); Lam et al. (2009); Meijer et al. (2006); Müller-Wenk (2004); Müller-Wenk (2002), Lafleche and Sacchetto (1997)). Hence, these methods are generally not applicable to other subjects, such as deconstruction projects, and for local and temporary impact assessment with local and short-time environmental indicators. Guinée et al. (2004, Part 3, pp. 613, 614) recommend using the method described by Heijungs et al. (1992) as the baseline characterisation method for noise. Here all sound produced is multiplied by a characterisation factor of 1 (Heijungs et al. (1992, p. 43). But this method evaluates noise exposures related to one year. Furthermore, the method is location-independent and ignores the fact that some sound emissions may not cause any

[45] EC-JRC (2010, Figure 15, p. 108).

nuisance and others may cause great nuisance depending on the environment. Cucurachi et al. (2012) describe a general framework to include noise impacts in LCA, but again based on the annual global, regional and usually year-related endpoint impact categories as environmental indicators.

The limited available LCIA methods to assess dust in the form of fine particulate matters (PM10) and ultrafine particles (PM2.5) in the air are general approaches (Notter (2015), van Zelm et al. (2013)) or refer to road traffic impacts (Meijer et al. (2006)). All these methods are end-point approaches, referring to annual global and regional exposure to human health and focus on fine and/or ultrafine particulate matters.

In the context of dust impact assessment, IAQM (2014) applies a risk assessment approach for EIA. This approach is especially applied to deconstruction. The risk of dust impacts is a combination of the 'potential dust emission magnitude', determined by the scale and nature of deconstruction, and the 'sensitivity of the area'. It is destinguished between 3 risk levels, low, medium and high. However, risk of dust impacts is assessed for one overall deconstruction project as one activity type on construction sites. The approach does not provide detailed data and a detailed and quantitative analysis of (dust) emissions and related impacts of single deconstruction activities/techniques.

3.3.2.2 Research gaps in effect assessment

Consequently, in general existing methods are not applicable for a quantitative and specific evaluation of deconstruction techniques based on the hourly effects of noise and total dust (see section 2.2.2) on the local environment. Furthermore, vibrations are not considered at all in these approaches. Hence, to answer the research question, an EIA approach with new established assessment methods and respective defined environmental indicators for noise, dust and vibrations is required and therefore developed in the present research.

3.3.3 Selected environmental assessment method

In summary, EIA is applied for the environmental assessment in this thesis. In this regard, firstly a database is generated for emission modelling of the on-site processes of deconstruction projects. Therefore, primary data is collected through experiments and an expert survey together with expert consultations for the development of specific values of levels of the distinct emissions. Secondly, for assessment of the effects of deconstruction projects on the local environment, a new approach is developed. This approach includes newly-established assessment methods and respective defined environmental indicators to model average hourly emission/impact levels of noise, dust and vibrations.

To achieve the research objective/s and to gain a deconstruction project plan due to emission and impact mitigation, the characteristics for modelling deconstruction project planning and decision support due to different objectives/preferences and under project-dependent restrictions have to be identified in the following sections. To this end, firstly the identified existing approaches of operational deconstruction project planning and decision support (see section 3.1.1.3) are further analysed in section 3.4.1. Secondly, current approaches of multi-objective decision support are reviewed in section 3.4.2. This is also the basis to answer research sub-questions 3, 4 and 5.

3.4 Resource-, space and impact-constrained deconstruction project planning and decision support due to environmental objectives

3.4.1 Planning and decision making under project-dependent restrictions

As mentioned in section 3.1 (section 3.1.2.1), there are the two major approaches of operational (de-)construction project planning and decision making: optimisation and simulation in terms of scenario analyses. These approaches are further analysed due to planning and decision making under project-dependent restrictions in the following.

3.4.1.1 Optimisation

Optimisation models are a formal description of a decision or planning problem, including at least one alternative and a valued objective function, which is minimised or maximised. Hence, optimisation models in general offer one (near-)optimal solution for the planning and decision making problem related to the objective criterion/criteria. The 'resource constrained project scheduling problem' (RCPSP) based on mixed-integer linear programming is the optimisation method for operational planning and decision making of projects. The method describes the project by a set of scheduling constraints (e.g. resource constraints) and an objective function. As a result an (near-)optimal project plan is provided with information on the allocation of activity-related resources and on the activity sequence, usually connected to the objective of minimising the overall project duration (Hartmann and Briskorn (2010)). Moreover, the 'multi-mode resource constrained project scheduling problem' (MRCPSP) is an adaption of RCPSP, additionally including activity performance alternatives in terms of modes, also called 'time-resource-tradeoffs’ or resource-resource-tradeoffs’ (Alcaraz et al. (2003), Hartmann (2001)). Most of the current research studies of operational deconstruction project planning and decision making apply this method (Sunke (2009), Schultmann and Sunke (2007), (2006), Schultmann (1998), (2003), Schultmann and Rentz (2002), (2001)). Current MRCPSP approaches are generally NP-hard combinational optimisation problems, which are computational highly complex and hence restricted to a small number of activities and resources and to usually linear-scaled objective variables (Gomes et al. (2014)).

3.4.1.2 Simulation

Simulation models in terms of scenario analysis for planning and decision making imply a step-wise mathematical approach with no analytical algorithm. Diverse scenarios of the project process are generated by selective variation of certain model parameters, such as activity performance alternatives/modes and project-constraints. In general, simulation models are used to analyse consequences of selective variations. Each scenario offers an output related to objective criterion/criteria. Based on the comparison of these outputs a decision can be made for project planning by fixing selected model parameters, such as activity performance alternatives/modes. In summary, the aim of simulation is not to find an adequate or (near-)optimal solution but to analyse consequences of variations as basis for a solution. A few research studies apply simulation on operational level to deconstruction projects (Akbarnezhad et. al, (2012) und (2014), Cheng and Ma (2013), Seemann (2003)). Whereas, singly Seemann (2003) includes a simulation approach in operational deconstruction planning based on single project activities (see section 3.1.1.2).

3.4.1.3 Properties of the objective function and scenario selection

All identified optimisation models related to deconstruction project planning (see section 3.4.1.1) include multi-modes. The modes indicate feasible deconstruction techniques applicable for single, throughout-the-day-changing deconstruction project activities in the form of time-resource-tradeoffs. Hence, modes in these approaches refer to different resources and imply different costs and durations. Different equipment sizes are not analysed. Decisions are made on economic objective/s, such as minimum costs and duration of the overall project. Furthermore, Sunke (2009), Schultmann and Sunke (2007), (2006) additionally considering recycling options/recovery rates of building component materials and related energy-saving effects due to different deconstruction activities. In this regard, the objective function is reformulated into the maximisation of the overall project recovery rate or energy-savings respectively. Besides a solution in terms of an (near-)optimal project schedule related to the overall project objective/s, the models propose one selected mode for each project activity. In general, costs and durations are calculated based on the single activities/activity modes. Costs across single activity durations, such as the contingency costs of basic units (see section 3.2.4.2) are related to the overall project duration, if considered (Schultmann (1998)). Costs of a project phase across single activities, which is shorter than the overall project duration, are not calculated. Furthermore, impacts on the local environment in terms of noise, dust and vibrations are not considered in any of these models. Chen and Li (2006) consider local environmental impacts. They present a resource constrained project scheduling problem (RCPSP) for operational construction planning and decision making considering local environmental impacts related to single activities. However, the focus is on construction projects/activities and multi modes are not included in the optimisation. Local environmental impacts in terms of noise, dust and vibrations are aggregately, equally-weighted examined related to project activities by assuming linear scaling and time-independence of this aggregate variable of the environmental impact. Hence, it is not considered that impacts of noise, dust and vibrations have different dimensions, are partly non-linearly scaled (e.g. noise) and have time-dependent average impact level values. Additionally, it is not payed attention that emissions and impacts are independent of each other, not necessarily correlating with each other and can even conflict. Furthermore, the temporal resolution of the model is working days. Project activities are coarsely defined and assigned to working days, not varying throughout the day.

3.4.1.4 Properties of constraints

The performance of single deconstruction project activities in changing modes implies different required space on site, differing usage of resources, such as equipment and employees, and different impacts on the local environment. To reach the research objective/s with the help of model-based deconstruction project planning and decision making, the modelling of project-dependent restrictions in the form of resource-, space- and impact-related project constraints is required. In Sunke (2009), Schultmann and Sunke (2007), (2006) Schultmann (1998), (2003), Schultmann and Rentz (2002) resource constraints due to equipment and employees are modelled as renewable resources. These renewable resources are constrained on a periodic basis, whereas non-renewable resources (e.g. financial budget) are limited on the basis of the whole project duration (Schultmann (1998), (2003), (Schultmann and Rentz (2002)). Space- and impact-dependent constraints are not considered in these studies. Chen and Li (2006) model an impact-dependent constraint in form of a maximum pollution value as the limit of a ‘pseudo’ renewable resource. Space-dependent constraints are not considered, but related information is available in DA (2015).

3.4.1.5 Research gaps in project planning and decision making

The analysis of current research of operational deconstruction project planning and decision making approaches shows, that to date no adequate model exists, which includes exclusively all of the following identified required model qualities due to specific characteristics of the objective function/scenario selection and resource-, space and impact-related restrictions:

- Resource-, space- and impact-related project constraints have to be modelled.
- Deconstruction technique alternatives in the form of multi modes have to be modelled for single trough-out-the-day-changing activities.
- Costs across single activity durations, distinct non-linear scaling of noise impacts and time-dependent average impact level values have to be considered in the objective function/solution process.
- An adequate deconstruction project plan has to be provided, including one technique mode for each project activity out of the set of technical feasible modes.

As the new model of this research should find and provide an adequate deconstruction project plan, MRCPSP approaches are more suitable than simulation models. Nonetheless, current MRCPSP approaches have to be adapted to include the identified, above mentioned required model qualities.

Besides these model qualities, the distinct, different-scaled and partly conflicting environmental objectives have to be evaluated independent of each other and based on preferences of the decision maker. Within this context, the consideration of the single environmental objectives separately as well as of three or two environmental objectives simultaneously can be imagined. Hence, multi-objective decision support approaches are analysed in the following section 3.4.2.

3.4.2 Multi-objective decision support

The results of the independent assessment of environmental impacts, which are partly conflicting as well as different and partly non-linear scaled, can be considered in combination to reach the research objective/s. Especially, it might provide a better understanding of conflicts between economic and specific environmental objectives (sub-question 4). Furthermore, with respect to the sensitivity of the neighbourhood of the deconstruction site, varying and combined evaluation of specific environmental objectives should be possible. Therefore, methods of multi-objective and neighbourhood-dependent decision making, methods of so called Multi-Criteria Decision Analysis (MCDA) are reviewed in the following. There are two general classes of Multi-Criteria Decision Analysis (MCDA), namely Multi-Attribute Decision Making (MADM) and Multi-Objective Decision Making (MODM) (Triantaphyllou et al. (1998)).

3.4.2.1 Classes of Multi-Criteria Decision Analysis (MCDA)

Multi Attribute Decision Making (MADM)

The major difference between MADM and MODM is that in the former an adequate solution is selected from a discrete (finite) set of known solution options/alternatives by considering multiple objective attributes simultaneously. As here the term ‘attribute’ is used equivalent to ‘criteria’, the class MADM is also often called MCDM (Multi Criteria Decision Making) and denotes the same concept (Triantaphyllou et al. (1998)).

Multi Objective Decision Making (MODM)

In MODM a continuous (infinite) set of solution options/alternatives is given and the problem is solved by selecting from this continuous set by simultaneously considering multiple objective functions (Bertsch, 2008, p. 12). The target levels of objectives need to be specified precisely in making decisions. For solving this type of problems, methods like goal programming (GP) are used (Chang (2007)).

For this research MADM is the appropriate class of MCDA, as the different alternative deconstruction techniques to perform single activities of a deconstruction project are known and form a discrete and finite set of decision options. From this discrete set one adequate deconstruction technique alternative is selected for each project activity. Hence, in the following, approach types of MADM are further examined in terms of the research requirements.

3.4.2.2 Approach types of MADM

Two major types of MADM approaches are distinguished in current research, namely ‘classical’ approaches, such as multi-attribute value theory (MAVT) and multi-attribute utility theory (MAUT), and outranking approaches, such as PROMETHEE (Preference Ranking Organisation Method for Enrichment Evaluations) (Brans et al. (1984); Brans and Vincke (1985)) and ELECTRE (Elimination Et Choix Tradusaint la Réalité) (Roy, 1991). In both approach types preferences between different criteria/objective variables (‘inter-criteria preferences’) (Valentin Bertsch, 2008, p. 18) are modelled by weighting factors. Nonetheless, the actual modelling of these inter-criteria preferences differs within these two approach types.

Outranking MADM-approaches

In outranking approaches the inter-criteria preferences of decision makers, the weighting factors, are regularly not known. The purpose of these approaches is the structuring of the decision problem for transparency. Discrete alternatives are partially (relatively) compared based on specific preference functions of criteria/objective variables. Following these partial comparisons of alternatives related to the single criteria/objective variables, weighting factors are determined. In this regard, the weighting factors are usually an outcome of a process of approval between different involved decision makers. The result of the outranking method is a ranking of the possible discrete alternatives based on their relative performance scores (Bouyssou and Vincke (1997), Brans and Vincke (1985)).

'Classic' MADM-approaches

In 'classic' approaches the inter-criteria preferences of decision makers are known. A utility function is provided for each discrete alternative. Within this context, for each alternative an overall utility value is calculated based on partial utility values related to the single criteria/objective variables and the known inter-criteria preferences in the form of weighting factors. The result of the 'classic' method is the proposal of the most adequate alternative drawn from a ranking of the possible discrete alternatives based on their absolute performance scores (Geldermann und Lerche (2014, p. 11, 12), Bertsch (2008, p. 12, 13). In this research the preferences of the decision maker are known. For instance, depending on the sensitivity of the neighbourhood of the deconstruction site, the distinct environmental criteria/objective variables are differently weighted. Furthermore, the model should propose one solution in terms of an appropriate deconstruction method related to each deconstruction activity. Hence, 'classic' MADM-approaches are suitable for this research.

The Multi-Attribute Utility Theory (MAUT) facilitates modelling and handling of uncertainties related to the underlying data of decision making. Nevertheless, the application of this approach in practice is problematic, due to its complexity (Bertsch, 2008, p. 14).

The Multi-Attribute Value Theory (MAVT) is a ‘classic’ MADM-approach where the decision making process is based on data, assumed to be deterministic. MAVT is widely known approach with a transparent and comprehensible decision logic, which is often practically applied (Geldermann und Lerche (2014, p. 12), Bertsch (2008, p. 14)).

3.4.2.3 Selected multi-objective decision support method

To enable the implementation of the results of this research into the actual planning and decision making process of deconstruction projects in future, a practically-applicable approach is essential. Moreover, within this context, it is important that the decision logic is transparent and comprehensible for the decision maker and additional involved stakeholders. Hence, MAVT is the selected method of multi-objective decision making in this research. Therefore, the underlying data of decision making is assumed to be deterministic and in this regard no uncertainties are considered.

In MAVT, as a ‘classic’ MADM-approach, the relative importance between criteria is known. These known preferences of decision makers due to criteria/attributes are depict as weighting factors, summarised in a weighting vector. Sometimes the distinct environmental criteria/objective variables are differently weighted depending on the sensitivity of the neighbourhood of the deconstruction site. Different weighting methods are possible to determine and model this (neighbourhood-dependent) relative importance between environmental criteria and to calculate weighting factors. On the one hand, a criterion/objective variable can be directly weighted with respect to its importance related to the other criteria/objective variables. Hence, weighting factors are determined on a one-level hierarchy of criteria/objective variables. On the other hand, weighting factors can be defined with the help of an attribute tree, a multi-level hierarchy of criteria/objective variables (Bertsch, 2008, p. 14). Respective common methods are the Analytic Hierarchy Process (AHP) introduced by Saaty (1980) and Analytic Network Process (ANP). In AHP the decision problem is structured by a multi-level hierarchy of criteria/objective variables. For instance, a three-level hierarchy would contain an overall objective, sub-objectives/criteria and measurable sub-sub-objective variables. On each level of the hierarchy respective criteria/(sub-)objective variables are evaluated due to their relative importance to each other. The sum of weighting factors within one level is 1. Final weighting factors are determined by multiplicative aggregation of respective weighting factors of the different levels (Hanne (1998, pp. 17, 18)). In AHP the (sub-)criteria/objective variables within one level are considered to be independent of one another. Furthermore, the discrete alternatives are considered to be independent of each other as well. In contrast, in ANP (Saaty (2001, pp. 83 et seq.) horizontal dependencies are explicitly modelled by a network of (sub-)criteria/objective variables, instead of an hierarchy, where only vertical dependencies are considered. Hence, dependencies between (sub-)criteria/objective variables or dependencies between alternatives can be mapped (Peters and Zelewski (2008)).

In this research, a two-level hierarchy of criteria/objective variables is required to provide decision support. Where the overall environmental effect is the main criterion/objective variable and noise, dust and vibrations are independent sub-criteria/sub-objective variables. Hence, there is independency on each level of the decision hierarchy and the discrete, independent deconstruction techniques represent the decision alternatives.

3.4.3 Selected multi-objective deconstruction project planning and decision support

To reach the research objective/s and to answer the research *sub-questions 3 to 5*, a second new module of the overall model has to be developed. Based on the output of Module 1, this second module, which is called Module 2 in the following, has to provide resource-, space and impact-constrained deconstruction project planning and decision support due to environmental objectives. As Module 1, Module 2 is developed with VBA and Access by including the following model components:

Alternative deconstruction techniques in the form of multi modes are modelled for each usually hourly changing activity. Therefore, sets of feasible deconstruction techniques, solution spaces for each activity, are identified for the single building component-related deconstruction project activities according the technical feasibility parameters (see section 3.2.1).

Resource-, space- and impact level-related restrictions are included in the objective function/selection process. Thus, existing approaches for the consideration of constraints in project planning and decision making are adopted for this research. Consequently, resource-, space- and impact level-related restrictions are modelled as renewable resources.

The distinct non-linear scaling of noise impacts and contingency costs of basic units (see section 3.2.4.2), which have to be calculated for a project phase duration across several activities, are considered. Therefore, alternatives of deconstruction project phases are calculated related to the building levels.

The distinct, differently-scaled and partly conflicting environmental objectives are evaluated independently of each other and based on preferences of the decision maker. For multi-objective evaluations MAVT is applied.

The deconstruction project plan due to minimised environmental emissions and impacts is provided. The plan includes the adequate technique mode for each project activity out of a set of technical feasible techniques. Hence, the objective function/solution process of existing approaches of project planning and decision making under project-dependent restrictions is adopted for this research.

3.5 Preliminary concluding remarks

The focus of this research is the integration of emissions and neighbourhood-dependent local environmental impacts in deconstruction project planning and decision making. To answer the research question ‘How can the distinct emissions of noise, dust and vibrations caused by a building deconstruction project and the related neighbourhood-dependent impacts on the local environment be mitigated, while considering technical parameters and economic objectives?’ a model of technical, economic and environmental deconstruction project planning and decision support is developed in chapter 4.

The model consists of the two modules:

- Module 1: Database-based deconstruction project planning for environmental assessment.
- Module 2: Resource-, space and impact-constrained deconstruction project planning and decision support due to multi-objectives.

To model the framework for Module 1, which has to be partly newly developed, the framework characteristics are identified in section 3.1.

Operational planning and decision making has to be based on single deconstruction project activities and their relation to each other by the adoption of existing approaches. Building-physics-related modelling of the deconstruction project plan has to be based on building shell component-related activities by a partly newly developed approach. Deconstruction technique alternatives and activity parallelisation have to be modelled as activity modes by the adoption of existing approaches. Different deconstruction site surroundings have to be modelled with their impact-influencing characteristics by a newly developed approach.

To technically, economically and environmentally quantitatively assess the deconstruction plan within Module 1, partly new to develop assessment approaches are identified and selected in section 3.2 and section 3.3. Technical feasibility of deconstruction methods and techniques respectively should be assessed by a partly newly developed sequential application of relational operators. Economic assessment of deconstruction activities should be performed by the estimation of duration-based costs of single production factors. Environmental assessment of deconstruction activities in terms of noise, dust and vibrations should be executed by newly developed approaches of EIA. To collect and edit specific information and data for the assessment in Module 1, required data and respective secondary and primary data sources are identified in section 3.2 and section 3.3. Technical assessment requires the development of technical feasibility parameters of deconstruction methods and techniques respectively. Necessary basic information and data are mostly available in the literature. Economic assessment requires the development of economic specific values in terms of specific duration values and hourly costs of single resources related to the single deconstruction activities. Necessary basic information and data are mostly available in the literature. Environmental assessment requires the development of environmental specific values in terms of specific hourly emission level values of noise, dust and vibrations related to deconstruction activities. Additionally, information about resulting neighbourhood-dependent emissions and impacts on the local environment is essential. Necessary primary data of distinct noise, dust and vibration emissions have to be collected through experiments with on-site measurements and through an expert survey and consultations. Basic information on resulting impacts can be deducted from literature.

To store and provide the specific information and data for the assessment in Module 1, a database with the developed technical feasibility parameters as well as economic and environmental specific values is assembled.

To model deconstruction project planning and decision support due to the multi-objectives and based on project-dependent restrictions and preferences of the decision maker, in section 3.4 firstly qualities of the objective function/selection process are identified. The objective function/selection process has to include resource-, space and impact-related constraints by adoption of existing approaches. It has to allow distinct non-linear scaling of noise impacts by adoption of existing approaches. Furthermore, the objective function/selection process has to provide a deconstruction project schedule including one adequate technique mode for each project activity by adoption of existing approaches. Secondly, an approach of multi-objective decision support is selected. In the objective function/selection process the distinct, different-scaled and partly conflicting environmental objectives have to be evaluated independently of each other and based on preferences of the decision maker by applying an existing approach.

4 Development of the deconstruction planning and decision support model TEE-D-Plan

In chapters 4 to 6 the model for technical, economic and environmentally conscious deconstruction project planning and decision support (TEE-D-Plan) is developed with respect to the above identified model requirements. With the newly developed model and a novel generated database the exposed research gaps of a missing adequate model of deconstruction project planning and decision making and of missing specific information and data should be filled. Therefore, existing model types of operational planning and decision making based on single deconstruction project activities are further developed. The model types are enhanced with respect to the identified necessary model characteristics to propose methods to mitigate the distinct emissions and related neighbourhood-dependent impacts on the local environment in the planning phase. At the same time, economic parameters and technical feasibility have to be considered. Furthermore, existing data in literature is extended by primary data, collected through experiments and an expert survey and consultations to develop a database for the model. In terms of deconstruction project planning and decision support, new knowledge is gained of specific emissions of noise, dust and vibrations of deconstruction projects according to single activities and related neighbourhood-dependent influences on resulting impacts on the local environment. Hence, besides new developments in relation to the method and new data, original contributions from the user perspective are made.

First the identified model requirements are summarised in section 4.1. Then an overview of the model is given in section 4.2, based on the model core, including two modules, Module 1 and 2, and the model input and output data, integrated into a user interface. In sections 4.3 to 4.6 Module 1, database-based deconstruction planning for environmental assessment, is described. Firstly, the framework of Module 1 is presented in section 4.3, followed by the modelling of technical and economic assessment in section 4.4 and environmental assessment in section 4.5. In chapter 5 the database-structure and primary data collection for the basic data of Module 1 is depicted. Finally, in chapter 6 Module 2, resource-, space- and impact-constrained deconstruction project planning and decision support due to multi-objectives, is described.

4.1 Model requirements

The major objective of TEE-D-Plan is to answer the research question 'How can the distinct emissions of noise, dust and vibrations and related neighbourhood-dependent impacts on the local environment caused by projects of building deconstruction be mitigated, while considering technical parameters and economic objectives?'.

Therefore, the following model requirements, identified in chapter (2 and) 3, have to be realised within this research, which can be assigned to the deduced research sub-questions:

To answer sub-questions 1 and 2:

1. How do different building characteristics influence the proposed/adequate deconstruction plan due to the mitigation of distinct emissions and impacts in terms of applied deconstruction techniques and resulting emissions/impacts?

2. How do surrounding conditions influence the levels of impacts?

First the model framework of Module 1, database-based deconstruction planning for environmental assessment, has to be modelled. The realisation is described in section 4.3 and includes the following elements of TEE-D-Plan:

- A building shell model of the physical characteristics of the single building shell components is modelled to store the information of the deconstruction object.
- Impact-influencing effects of settlement structures are modelled to calculate impact distribution due to the site surroundings.
- Alternative deconstruction plans of the process on site with building component- and time-related activities, activity-related technique modes/ decision alternatives [46]and a predefined deconstruction sequence are modelled to calculate the technical, economic and environmental plan values.

Secondly, alternative deconstruction plans have to be technically, economically and environmentally assessed. The realisation is described in sections 4.4 and 4.5 and includes the following elements of TEE-D-Plan:

- Relational operators (adjacency matrices with technical comparative values) due to the technical suitability related to physical characteristics of the single building shell components are applied sequentially to perform the technical assessment in the model.

[46] Alternatives are usually called 'decision alternatives' in the context of MCDA. In the context of project scheduling problems the term 'modes' is used, which is also used in the following of this research.

- Costs of activity-and building-level-related resources[47] of the activity modes are calculated (economic plan values) for the quantitative economic assessment.
- Activity-and building-level-related environmental impact assessments (EIA) of the activity modes are performed (environmental plan values) for the quantitative environmental assessment.

Thirdly, data for the assessment is required. The realisation is described in chapter 5 and includes the following elements of TEE-D-Plan:

- Database-based storage and provision of data and information for and from the technical, economic and environmental assessments is developed.
- Activity-related specific values and classification numbers for the technical, economic and environmental assessments are developed based on primary data and literature.

To answer sub-questions 3 to 5:

3. How do different project constraints influence the proposed/adequate deconstruction plan due to the mitigation of distinct emissions and impacts in terms of applied deconstruction techniques and resulting emissions/impacts?
4. Which economic and environmental objectives are conflicting?
5. How does the deconstruction plan vary in the form of applied deconstruction techniques due to different economic and environmental objectives?

[47] Costs of resources are calculated based on the costs of single production factors, including labour costs, imputed equipment costs and equipment operation costs.

Constrained deconstruction project planning and decision support is provided due to different environmental and economic objectives. The realisation is described in chapter 6 and includes the following elements of TEE-D-Plan:

- Basic resource-constrained project planning method is set up with 'renewable resources' to model deconstruction project planning and decision support with resource-dependent project constraints.
- The basic method is adapted by 'time-resource-tradeoffs' and further 'renewable resources' to consider alternative deconstruction techniques and space- and impact-level-dependent project constraints in deconstruction project planning and decision support.
- Building-level-related economic and environmental plan values based on a predefined deconstruction activity sequence are used to consider costs across single activity durations, distinct non-linear scaling of noise impacts and time-dependent average impact level values in the objective function/selection process.
- Iterative solution processes/objective functions based on the predefined activity sequence is/are performed to provide a solution in the form of a deconstruction project plan/schedule[48] with one technique mode for each project activity out of the set of technical feasible modes.
- Multi-Attribute Value Theory (MAVT), as an approach of Multi Attribute Decision Making (MADM), is applied to the independent conflicting environmental (multi) objectives/ objective preferences of the decision maker to evaluate alternatives of level-wise deconstruction project plans.

[48] In the following, the term 'plan' is used for both, 'plan' and 'schedule'.

In general, the model is transparently described for clear and easy understanding of the planning and decision support process.

4.2 Model overview: TEE-D-Plan

Based on the model requirements outlined above, the model TEE-D-Plan is developed, programmed in Visual Basic for Applications (VBA) and implemented in Microsoft Access 2010 in this study. In the context of current research, TEE-D-Plan is a research-objective-oriented further development of existing model types of operational planning and decision making based on single deconstruction project activities in combination with a newly developed database containing primary data (see chapter 3). Figure 4-1 shows how TEE-D-Plan fits into the operational deconstruction project planning phase to answer the research question/s.

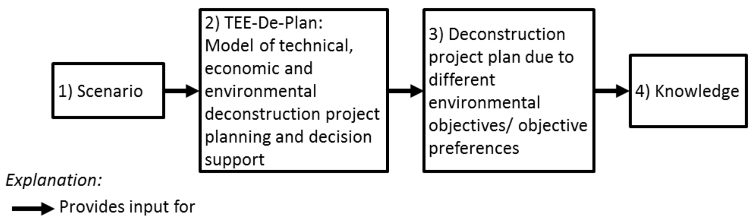


Figure 4-1: TEE-D-Plan embedded into the operational deconstruction project planning phase to answer the research question/s

For different scenarios (1) of buildings to be deconstructed, surrounding settlement characteristics and project restrictions in terms of available resources, space and allowed impact levels, TEE-D-Plan (2) provides a deconstruction project plan (3) due to the environmental objectives/the environmental preferences of the decision maker. The plan encompasses the appropriate activity- and time-related deconstruction techniques (modes). The deconstruction project plan is visualised as a bar chart based on the single activities of the deconstruction process and histograms of levels of the economic and specific environmental plan values over time. With this information knowledge (4) is gained to answer the research question. The knowledge/findings could be interesting primarily for principals, engineering consultants, deconstruction companies as well as for public authorities[49]. As shown in Figure 4-2, the model TEE-D-Plan consists of the Modules 1 and 2 (the core of TEE-D-Plan) and a user interface, which enables the input of the scenarios (1) and the output of the deconstruction project plan (3).

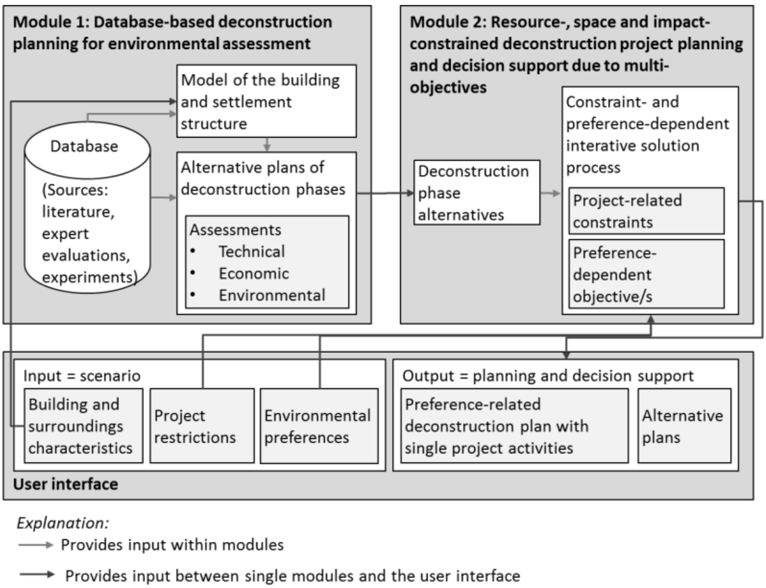


Figure 4-2: Elements of the overall model structure

After a short description of the general elements of the overall model, in the following the core of TEE-D-Plan, Module 1 and 2, is described in detail in sections 4.3 to 4.5 and chapters 5 and 6.

[49] Compare involved players defined in section 2.1.2.

(1) Scenario

An overall scenario of TEE-D-Plan is defined as the building to be deconstructed, the surrounding settlement structure and resource, space and impact level restrictions. The building to be deconstructed (building scenario) includes all building levels and the single components of the building shell. The components are differentiated by their type in terms of profile and horizontal and vertical position and their material. The building scenario especially affects technically possible deconstruction techniques, the set of technical feasible modes per deconstruction activity, and emission levels. The surrounding settlement structure (surrounding scenario) encompasses impact-influencing characteristics of the surrounding built environment. Therefore, the surrounding scenario affects impact distribution. Resource-, space- and impact-level-related restrictions (project scenario) state project constraints due to available resources of the deconstruction company, space on site and noise impact level limits depending on the neighbourhood usage type around site. The project constraints scenario especially affects technically possible deconstruction techniques and emission levels. The information of the overall scenario is inserted by the user based on the database via input forms in MS Access.

(2) TEE-D-Plan core

Module 1, database-based deconstruction planning for environmental assessment consist of a database, a building shell model, impact-influencing effects of settlement structures and level-wise deconstruction phase plans. The database of MS Access contains generic information on characteristics of deconstruction processes and buildings. The information is based on primary data, collected through an expert survey and consultations and experiments and existing data in literature. Besides basic data for user input, activity mode-related specific values and classification numbers for the technical, economic and environmental assessments are stored.

Furthermore, the database offers central data management of the overall model (Modules 1 and 2 and user interface) and enables the connection between the single model layers (user input, analysis and output). A building shell model of the building levels and building shell components is created on the entered building scenario. Furthermore, impact-influencing effects are modelled based on the entered surrounding scenario. Subsequently, alternative building level-wise deconstruction phase plans of the process on site with a predefined deconstruction sequence and building component- and time-related activities, which are performed in different modes, are generated. Each alternative deconstruction phase plan is technically, economically and environmentally assessed. Firstly, technical suitability is examined related to the physical characteristics of the single building shell components by relational operators. Secondly, the economic and environmental plan values are calculated via costs of activity-and building-level-related resources and EIA.

Module 2, resource-, space and impact-constrained deconstruction project planning and decision support due to multi-objectives, aims to find the preference-related deconstruction plan due to minimise the environmental impacts and alternative plans due to different objectives. The module contains phase-related deconstruction alternatives with economic and environmental plan values, project constraints and an iterative solution processes. The phase-related deconstruction alternatives represent the alternative building-level-wise deconstruction plans, which are the input of Module 1. An iterative solution process is applied to find the deconstruction project plan due to minimise environmental impacts. Within this context user input in terms of project restrictions and environmental preferences are included as project constraints and preference-dependent environmental objective/s. The deconstruction project plan, including a discrete adequate mode for each activity, and alternative plans are provided via the user interface.

(3) Deconstruction project plan

The knowledge, the new findings gained by TEE-D-Plan, is primarily addressed to principals, engineering consultants, deconstruction companies and public authorities. The model results are summarised in tables and are visualised in the form of Gantt-charts and histograms. Predominately, planning and decision support is provided in terms of the adequate activity-related technique modes of the deconstruction project plan to mitigate the resulting distinct impacts of noise, dust and vibrations on the local environment. Additionally, other players, such as neighbours, can be addressed and other knowledge due to economic and environmental objectives of the decision maker can be provided by the results of TEE-D-Plan.

4.3 Model framework of Module 1: database-based deconstruction planning for environmental assessment

The model framework of Module 1 for operational planning and decision making based on single deconstruction project activities of the on-site deconstruction process is described. It has to include the following elements:

- A building shell model of the physical characteristics of the single building shell components.
- Impact-influencing characteristics of settlement structures.
- Alternative deconstruction plans of the process on site with building component- and time-related activities, activity-related modes and a predefined deconstruction sequence.

4.3.1 Building shell model

The model of the building shell, based on single building shell components and their physical characteristics, defines the deconstruction object.

4.3.1.1 Delimitation of considered building components

In this research the deconstruction project encompasses the deconstruction of the building shell.[50] Especially here emissions of noise, dust and vibrations can occur (DIN 18007:2000-05). Hence, the following generic process steps of deconstruction projects are not examined in this study:

- Removal of the building core,
- Dismounting of reusable building components,
- Elimination of interior fittings and the building (thermal) envelop and
- Removal of technical building services.

All these processes are preliminary work for the deconstruction of the building shell in this research. These processes are fixed for each deconstruction project and are outside the system boundaries.

Furthermore, processes related to the disposal of deconstruction waste are not examined in this study, such as:

- Loading and unloading of deconstruction materials,
- Transportation of deconstruction material to recycling and landfill sites and
- Handling of deconstruction material off-site.

[50] In the following the building shell to be deconstructed is also named ‘deconstruction object’.

Like processes of preliminary work, these processes of material disposal are fixed for each deconstruction project and are outside the system boundaries of this research. To guarantee the comparability of alternative single deconstruction techniques, modes, the deconstruction materials, which are the products of the deconstruction process on site and which are taken to recycling and landfill sites, have to be of the same quality. In this study good recyclability of deconstruction materials is taken for granted. This covers firstly, sorted material of 95-98% purity[51], which implies material pre-separation on site. Secondly, the material pieces are assumed to have a maximum size of 80x80x80cm, which implies material pre-crushing on site. Based on this material quality no extra costs due to material contamination and oversize are expected.

Thus, as outlined in section 2.2.1.1, in this research processes of deconstruction material handling on-site and their distinct impacts on the local environment are examined, besides the actual deconstruction of building shell components. Therefore, besides actual deconstruction activities, activities to remove the building component, additional activities of pre-separation and pre-crushing of materials are included in the model. The durations of these additional activities depend on the preceding actual deconstruction activity. Related modelling is described in detail in section 4.3.2.

4.3.1.2 Relevant building component characteristics

Besides the influence of building component characteristics on the emission level (see section 3.1.2), the suitability of single deconstruction methods, highly depends on the type, material, thickness and height above ground of building shell components to be deconstructed (DA (2015, pp. 175 et seq.), DIN 18007:2000-05, Toppel (2003, pp. 81 et seq.)). Hence, the deconstruction object is

[51] Mineral deconstruction material with only 2-5% foreign matters, such as wood, plastic and insulation materials.

modelled in a level-[52] and component-specific way, based on relevant single vertical and horizontal components of the building shell. Table 4-1 (Kühlen et al. (2016a, Table 1, p. 9) shows a typology of building structures based on existing typologies (Klauß et al. (2009); Grünthal (1998) und HAZUS (2003)). The typology encompasses the relevant generic eight building component types (ty) and ten material types (b), which are stored as basic data in the database (Table 4-2, Table 4-3).

Table 4-1: Selected building shell components of the deconstruction object[53]

Building components/ Building structures		Vertical				Horizontal			
		Outside		Inside		General floors		Top floor	
		Building component type (ty)	Material (b)	Building component type (ty)	Material (b)	Building component type (ty)	Material (b)	Building component type (ty)	Material (b)
A	Steel frame construction	Exterior pillar	Steel	Column	Steel	Girder	Steel	Roof	Steel
B	Masonry - reinforced concrete construction	Exterior wall	Masonry: ● natural stone ● brick ● sand-lime brick ● aerated concrete ● precast concrete block	Interior wall/ column	Masonry: ● natural stone ● brick ● sand-lime brick ● aerated concrete ● precast concrete block	Slab/ girder	Reinforced concrete	Roof	Reinforced concrete
C	Masonry - wood construction	Exterior wall	Masonry: ● natural stone ● brick ● sand-lime brick ● aerated concrete ● precast concrete block	Interior wall/ column	Masonry: ● natural stone ● brick ● sand-lime brick ● aerated concrete ● precast concrete block	Slab/girder	Wood	Roof	Wood
D	Timber framing	Exterior pillar	Wood	Column	Wood	Girder	Wood	Roof	Wood
E	Reinforced concrete - industrialised building	Exterior wall	Precast reinforced concrete unit	Interior wall/ column	precast reinforced concrete unit	Slab/girder	Precast reinforced concrete unit	Roof	Precast reinforced concrete unit
F	Reinforced concrete - frame construction	Exterior pillar	Reinforced concrete	Column	Reinforced concrete	Slab/girder	Reinforced concrete	Roof	Reinforced concrete
G	Concrete basement	Exterior wall	Concrete	Interior wall/ column	Concrete	Bottom plate	Reinforced concrete	Slab/roof	Reinforced concrete

[52] The building level indicates the height above ground (hg).
[53] Own illustration on the basis of Kühlen et al. (2016a, Table 1, p. 9).

Table 4-2: Generic building component types (ty)

ID_ty	Name
1	Roof
2	Slab
3	Girder
4	Exterior wall
5	Exterior pillar
6	Interior wall
7	Column
8	Bottom plate

Table 4-3: Generic building material types (b)

ID_b	Name
1	Natural stone
2	Brick
3	Sand lime brick
4	Aerated concrete
5	Precast concrete block
6	Reinforced concrete
7	Concrete
8	Precast reinforced concrete unit
9	Wood
10	Steel

Each component (k) is indicated in the database by the attributes building level g_k[54], component type ty_k, material type b_k[55], length lg_k, height/width ht_k[56], thickness th_k, height above ground hg_k[57] and volume u_k. Related notions, value ranges, units and sources of these attributes are outlined in Table 4-4.

[54] The level, where the component is located.
[55] The material type of the main material of the component.
[56] The height of the vertical component, the width of the horizontal component.
[57] The height of the building component above ground.

Table 4-4: Attributes, notions, value ranges and sources of building shell components k

Attribute	Notion	Value range		Unit	Source
ID	k		Integer		
Building the component is part of (foreign key building: ID_bd)	bd				
Building level the component is part of (foreign key building level: ID_bl)	bl		Integer	-	Input mask: building plans, on site information
Material of the component (foreign key material type: ID_b)	b_k	{1;2;...;10}; {Concrete;...}	Integer/String	-	Table 4-3
Type of the component (foreign key component type: ID_ty)	ty_k	{1;2;...;8}; {Exterior wall; slab;... }	Integer/String	-	Table 4-2
Thickness of the component	th_k		Double	m	Input mask: building plans, on site information
Length of the component	lg_k		Double	m	Input mask: building plans, on site information
Height/width of the component	ht_k		Double	m	Input mask: building plans, on site information
Height above ground of the component	hg_k		Double	m	Input mask: building plans, on site information
Volume of the component	u_k		Double	m^3	Calculated and can be adoped via input mask

4.3.1.3 Database-based deconstruction object specification

The translation from basic data to variable data of the actual building to be deconstructed is carried out within Module 1. In this module component attributes and their relations to each other are calculated and determined on the basis of basic data and of data of the existing building. Data of the existing building is drawn from building plans and/or gathered on site. Data can either be entered via input masks (Figure 4-3, Figure 4-4) or imported as a specific formatted text file (Figure 4-5) by the user into the planning module.

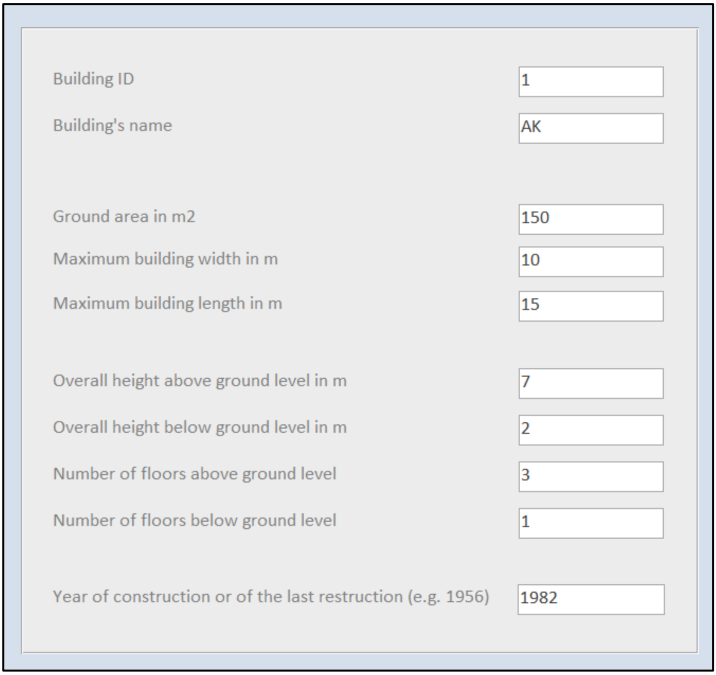


Figure 4-3: Input mask for general data of the existing building: identification number and name (1^{st} two boxes), building area in m^2 and greatest building length and width in m (3^{rd} to 5^{th} upper boxes), overall heights and number of levels above and under ground level (5^{th} to 2^{nd} lower boxes), year of construction/of the last retrofit (last box).

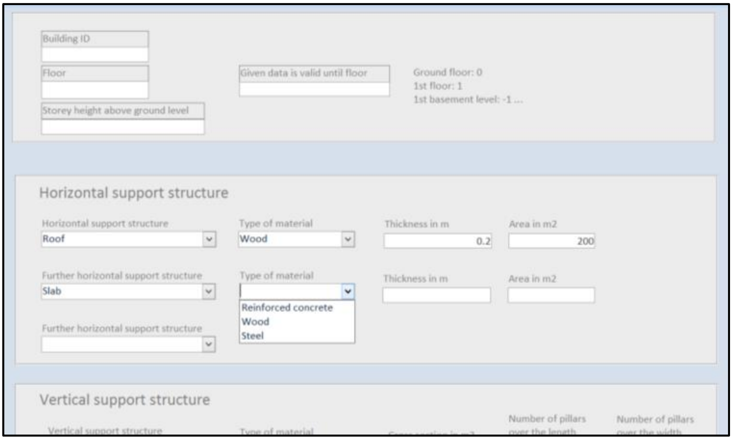
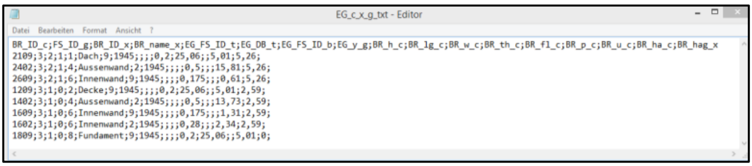


Figure 4-4: Screen-shot of the input mask for level and component specific data of the existing building: identification number, level and height above ground (upper grey area), specifications of types, materials and dimensions of components of the horizontal building structure of the level (middle grey area) and of the vertical building structure of the level (lower grey area).



EG_c_x_g_txt - Editor

Datei Bearbeiten Format Ansicht ?

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BR_ID_c;FS_ID_g;BR_ID_x;BR_name_x;EG_FS_ID_t;EG_DB_t;EG_FS_ID_b;EG_y_g;BR_h_c;BR_lg_c;BR_w_c;BR_th_c;BR_fl_c;BR_p_c;BR_u_c;BR_ha_c;BR_hag_x
2109;3;2;1;1;Dach;9;1945;;;;0,2;25,06;;5,01;5,26;
2402;3;2;1;4;Aussenwand;2;1945;;;;0,5;;;15,81;5,26;
2609;3;2;1;6;Innenwand;9;1945;;;;0,175;;;0,61;5,26;
1209;3;1;0;2;Decke;9;1945;;;;0,2;25,06;;5,01;2,59;
1402;3;1;0;4;Aussenwand;2;1945;;;;0,5;;;13,73;2,59;
1609;3;1;0;6;Innenwand;9;1945;;;;0,175;;;1,31;2,59;
1602;3;1;0;6;Innenwand;2;1945;;;;0,28;;;2,34;2,59;
1809;3;1;0;8;Fundament;9;1945;;;;0,2;25,06;;5,01;0;
```

Figure 4-5: Exemplified specific formatted text file with data of the existing building to be deconstructed

Calculated and determined variable data of the actual building is stored as a list of the single building components and their attributes within the module[58]. This list can be controlled via an input mask.

The impact-influencing characteristics of different deconstruction site surroundings, such as properties of neighbouring building structures and the environment in between buildings are described in the context of environmental assessment in section 4.5.

4.3.2 Building-component-related deconstruction plans

4.3.2.1 Deconstruction project activities

To answer the research question, a time-related mapping of the operational planning and decision making process of single deconstruction project activities is required (see sections 3.1 and 4.1). By applying the work-break-down-structure method of general project planning approaches (PMBOK (2013), DIN 69901-2:2009-01) the overall deconstruction process is broken down into units, namely deconstruction project activities j (j={1;2;...;J}). Due to the identified dependences of deconstruction method suitability and of emission level on specific building-component-related characteristics, the single deconstruction activities are assigned to the defined components (k) of the building shell (Table 4-1).

Each activity is composed of the three activity segments:

1. The deconstruction activity segment (d_j), which describes the deconstruction of the building component (k) itself.
2. The material pre-separation activity segment (o_j). This is the pre-separation of the deconstruction material (b_k) on site to

[58] See for instance Table 7-1 in section 7.1.2.

an above defined quality (see 4.3.1.1) of 95-98% purity before transportation to the recycling plant.

3. The material pre-crushing activity segment (q_j). This is the pre-crushing of the deconstruction material (b_k) on site up to the maximum size of material pieces of 80x80x80cm defined above before transportation to the recycling plant.

4.3.2.2 Activity sequences

The sequence of deconstruction activities is defined according to an actual popular deconstruction approach (DA (2015, p. 26), Kamrath (2013), Greer (2004)) in reversed order of construction, top-down, building level-wise and based on the single building components on each building level. The sequence is modelled with the help of a network plan (activity-on-node (AoN) network (Kolisch (2015, p. 4)) of the component-based deconstruction activities, exemplified in Figure 4-6. Here precedencies between the single activities are defined with respect to a top-down, building-level-wise deconstruction process. Concerning one activity, the single activity segments are performed successively (1. d_j, 2. o_j, 3. q_j) within the deconstruction sequence.

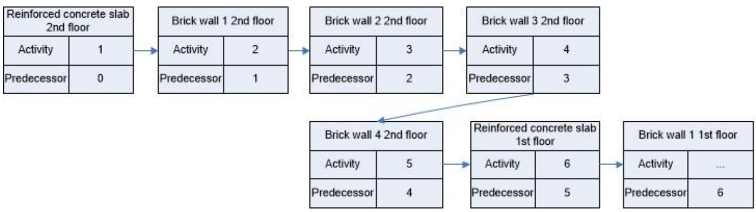

Figure 4-6: Example of a network plan of the deconstruction activity sequence

The model allows alternatives of the deconstruction activity sequence. Besides the performance of one activity at a time, parallelisation of activities in the deconstruction sequence is possible, depending on resource constraints in the form of the number of available basic units[59]. Parallelisation of activities is modelled as activity modes (see section 4.3.2.4). It is limited to building components of the same component type, material and deconstruction technique. Furthermore, operation of at most two equipment at the same time is allowed (exemplified in Figure 4-7) to keep the model calculation solvable.

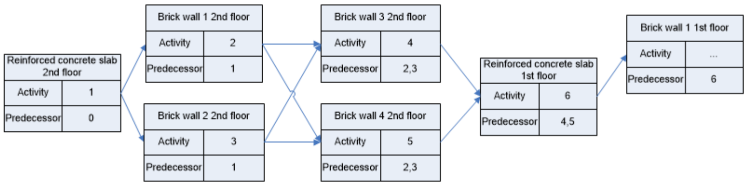

Figure 4-7: Example of the network plan of the deconstruction activity sequence with parallelisation

Whereas the attributes of the single building shell component are fixed characteristics of the existing building and the deconstruction project respectively, activity parallelisation as well as deconstruction technique options are variable parameters of a project activity. These variable parameters are modelled as activity modes in this research and imply variant deconstruction plans. In the following the deconstruction activity modes of this research are specified.

4.3.2.3 Deconstruction activity modes

The modes of a deconstruction activity j are also known as 'time-resource-tradeoffs' in project planning literature (Alcaraz et al. (2003), Hartmann (2001), see section 6.2). In this research a mode m ($m=\{1;2;\ldots;M_j\}$) is generally defined as a combination of a deconstruction method (md_m) (see Table 2 2), for instance gripping

[59] For details of resource constraints see chapter 6.

and wrapping and related efforts of material pre-separation and – crushing on site, as well as equipment, including required numbers (r^{hy}_{m}, $r^{lt}_{m,}$ $r^{cw}_{m,}$ r^{ha}_{m}) of different basic unit types (Table 4-5) and required type-number-related attachment/s (Table 4-6) to deconstruct the component (ad_m) and to sort and crush material (ab_m).

Table 4-5: Generic basic unit types

hy	Hydraulic crawler excavator
lt	Longfront hydraulic crawler excavator
cw	Cable-operated excavator
ha	Hand tool with compressor

Table 4-6: Generic type-number-related attachments (a)

ID_a	
1	1 deconstruction grab for hy
2	1 steel mass for cw
3	1 Long stick/ backhoe for hy
4	1 hydraulic hammer for hy
5	1 demolition tongs for hy
6	1 steel-/scrap shear for hy
7	1 deconstruction grab for lt
8	1 long stick/ backhoe for lt
9	1 hydraulic hammer for lt
10	1 demolition tongs for lt
11	1 steel-/scrap shear for lt
12	2 deconstruction grabs for hy
13	2 steel masses for cw
14	2 long stick/ backhoes for hy
15	2 hydraulic hammers for hy
16	2 demolition tongs for hy
17	2 steel-/scrap shears for hy
18	2 deconstruction grabs for lt
19	2 long sticks/ backhoes for lt
20	2 hydraulic hammers for lt
21	2 demolition tongs for lt
22	2 steel-/scrap shears for lt
23	No attachment for ha

The definition of modes is based on current usual combinations in deconstruction projects (DA (2015, p. 179), Toppel (2003, pp. 79 et seq.)). Consequently, 34 (M_j = 34) different modes are analysed in this research (see appendix A1). These mode are composed of 9 different methods (see Table 2 2) and 24 different equipment[60] (see Table 4-5, Table 4-6). Besides equipment, the numbers of employees required (r^{po}_m) are resources to perform activities in the mode. Hence, r^{po}_m is an additional attribute of each mode. Furthermore, minimal required space on site (sp_m) and maximal height above ground (hg_m) are attributes of a mode, which are related to the equipment. The suitability due to the eight building component types (ty) (Table 4-2) (sty^1_m, sty^2_m,..., sty^8_m), due to the ten component materials (b) (Table 4-3) (sb^1_m, sb^2_m, ..., sb^{10}_m) as well as the maximal component thickness due to the ten materials (thb^1_m, thb^2_m, … thb^{10}_m) are attributes of a mode related to the deconstruction method. The attributes and related notions, value ranges, units and sources of deconstruction technique modes m are outlined in Table 4-7.

[60] Equipment are combinations of 1 or 2 basic unit/s and attachment/s.

Table 4-7: Attributes, notions, value ranges and sources of deconstruction activity modes m

Attribute	Notion	Value range		Variable	Unit	Source
ID	m			Integer		
Type and amount of attachment/s to deconstruct the component required by mode m (foreign key attachment: ID_a)	ad_m	{1;2;…;23}		Integer	-	Table 4-6
Type and amount of attachment/s to sort and crush material required by mode m (foreign key attachment: ID_a)	ab_m	{1;7;12;18;23}		Integer	-	Table 4-6
Deconstruction method of mode (foreign key methodt: ID_md)	md_m	{1;2;…;9}	{Gripping,...}	Integer	-	Table 2-2
Number of hydraulic excavator units hy required by mode m	r^{hy}_m	{0;1;2}		Integer	amount	DA (2015)
Number of longfront excavator units lt required by mode m	r^{lt}_m	{0;1;2}		Integer	amount	DA (2015)
Number of crawler excavator units cw required by mode m	r^{cw}_m	{0;1;2}		Integer	amount	DA (2015)
Number of hand tool units ha required by mode m	r^{ha}_m	{0;2;4}		Integer	amount	DA (2015)
Number of employee units po required by mode m	r^{po}_m	{0;1;…;4}		Integer	amount	DA (2015)
Minimal space reqired by mode m	sp_m	{0;1;2}	{very limited; limited; open}	Integer	-	DA (2015)
Maximal height above ground of mode m	hg_m	{15;…;1000}		Integer	m	DA (2015), ABW (2012), Toppel (2003)
Suitability due to component type 1 (see Table 4-2) of mode m	sty^1_m	{0;1}	{suitable; not suitable}	Integer	-	DA (2015), DIN 18007:2000-05
Suitability due to component type 2 (see Table 4-2) of mode m	sty^2_m	{0;1}	{suitable; not suitable}	Integer	-	DA (2015), DIN 18007:2000-06
….						
Suitability due to component type 8 (see Table 4-2) of mode m	sty^8_m	{0;1}	{suitable; not suitable}	Integer	-	DA (2015), DIN 18007:2000-08
Suitability due to component material 1 (see Table 4-3) of mode m	sb^1_m	{0;1}	{suitable; not suitable}	Integer	-	DA (2015), Toppel (2003), DIN 18007:2000-09
Suitability due to component material 2 (see Table 4-3) of mode m	sb^2_m	{0;1}	{suitable; not suitable}	Integer	-	DA (2015), Toppel (2003), DIN 18007:2000-10
…						
Suitability due to component material 10 (see Table 4-3) of mode m	sb^{10}_m	{0;1}	{suitable; not suitable}	Integer	-	DA (2015), Toppel (2003), DIN 18007:2000-12
Maximal component thickness due to material 1 (see Table 4-3) of mode m	thb^1_m	{0.2; ….;1000}		Double	m	DA (2015), Toppel (2003)
Maximal component thickness due to material 2 (see Table 4-3) of mode m	thb^2_m	{0.2; ….;1000}		Double	m	DA (2015), Toppel (2003)
…						
Maximal component thickness due to material 10 (see Table 4-3) of mode m	thb^{10}_m	{0.2; ….;1000}		Double	m	DA (2015), Toppel (2003)

Besides the influence on the technical suitability, the mode has a large impact on the economic and environmental project-specific plan values, such as costs, durations, average emission and impact level values. These plan values are the basis for the economic and environmental assessment of the overall deconstruction plan.

For the calculation of plan values, each activity segment (*plan layer 1*) and each project activity j (*plan layer 2*) are mapped with technical, economic and environmental attributes in the database. All attributes, notions, value ranges, units and sources of the deconstruction activity segments (d_j) (*plan layer 1*) are outlined in Table 4-8. The attributes of the material separation activity segment (o_j) and material crushing activity segment (q_j) are respectively.

Table 4-8: Attributes, notions, value ranges and sources of each deconstruction activity segment d_j

Attribute	Notion	Value range	Variable	Unit	Section
ID	d_j		Integer		
Building component-related project activity the segment is part of (foreign key project activity: ID_j)	j		Integer		
Execution mode of activity j (foreign key mode: ID_m)	m	{1;2;…;34}	Integer	-	A1
Type and amount of attachment/s of deconstruction activity segment d_j of the activity j in mode m (foreign key attachments: ID_a)	$ad_{dj,m}$	{1;2;…;23}	Integer	-	A1
Number of units of hydraulic excavator resource hy of deconstruction activity segment d_j of the activity j in mode m	$r^{hy}_{dj,m}$	{0;1;2}	Integer	amount	A1
…					
Number of employee resource po of deconstruction activity segment $d_{j,m}$ of activity j in mode m	$r^{po}_{dj,m}$	{0;1;…;4}	Integer	amount	A1
Specific duration value of deconstruction activity segment d_j of activity j influenced by the mode m, material type b_j and basic unit size sz	$\delta_{dj}(m,b_j,sz)$		Double	h/m3	4.4.2.1
Duration of deconstruction activity segment d_j of activity j in mode m influenced by the basic unit size	$p_{dj,m}(sz)$		Double	h	4.4.2.1
Specific hourly labour costs of deconstruction activity segment d_j of activity j influenced by the mode m	$\kappa^{po}_{d}(m)$		Double	€/h	4.4.2.2.
Specific hourly contingency costs per hydraulic excavator units hy of deconstruction activity segment d_j of activity j influenced by the basic unit size sz and investment report-year yr	$\kappa^{ex(hy)}_{dj}(sz^{hy},yr)$		Double	€/h	4.4.2.3
…					
Specific hourly contingency costs per of deconstruction activity segment d_j of activity j influenced by the mode m, basic unit size sz and investment report-year yr	$\kappa^{ex(ad)}(m,sz,yr)$		Double	€/h	4.4.2.3
Specific hourly operation costs of deconstruction activity segment d_j of activity j influenced by the mode m and basic unit size sz	$\kappa^{op}_{d}(m, sz)$		Double	€/h	4.4.2.4
Costs of deconstruction activity segment dj of activity j in mode m influenced by the basic unit size sz and investment year yr	$c_{dj,m}(sz, yr)$		Double	€	4.4.3.1
Specific hourly average noise emission level value of deconstruction activity segment d_j of activity j influenced by the mode m, material type b_j, basic unit size sz and height above ground hg_j	$\lambda^{e}_{d}(m,b_j,sz,hg_j)$	{40-130}	Double	average dB(A)/h	4.5.2.3
Specific hourly average dust emission level value of deconstruction activity segment dj of activity j influenced by the mode m, material type b_j, basic unit size sz and height above ground hg_j	$\sigma^{e}_{d}(m,b_j,sz,hg_j)$	{0-300}	Double	average $(mg/m^3)/h$	4.5.2.3
Specific hourly average vibration emission level value of deconstruction activity segment d_j of activity j influenced by the mode m, material type b, basic unit size sz and height above ground hg	$\psi^{e}_{dj}(m,b,sz,hg)$	{0-25}	Double	average (mm/s)/h	4.5.2.3
Specific hourly average noise impact level value of deconstruction activity segment d_j of activity j influenced by the distance from the emission source dc, number of equipollent, coherent noise levels r^l, mode m, material type b_j, basic unit size sz and height above ground hg_j	$\lambda^{im}_{dj}(dc,r^l,m,b_j,sz,hg_j)$	{40-130}	Double	average dB(A)/h	4.5.3.3.
Specific hourly average vibration impact level value of deconstruction activity segment dj of activity j influenced by the distance from the emission source dc, mode m, material type b_j, basic unit size sz and height above ground hg_j	$\psi^{im}_{dj}(dc,m,b_j,sz,hg_j)$	{0-25}	Double	average (mm/s)/h	4.5.3.3.

The plan values of each project activity j (p*lan layer 2)* are calculated based on the plan values of the single segments. Furthermore, depending on the building level[61] g (g={1;2;…;G}) and the building component type (ty) the activity is related to, the position of an activity within the overall deconstruction sequence $pos_j(g,ty)$ is defined. Respective activity-related attributes, notions, value ranges, units and sources of each project activity (j) are outlined in Table 4-9.

[61] The building level is in the following called 'project phase'.

Table 4-9: Attributes, notions, value ranges and sources of deconstruction project activities j

Attribute	Notion	Value range	Variable	Unit	Section
ID	j		Integer		
Execution mode (foreign key mode: ID_m)	m	{1;2;…;34}	Integer	-	A1
Set of all possible alternative execution modes of activity j	Mj	34	Integer	-	
Building level-related project phase the activity is part of (foreign key project phase: ID_g)	g		Integer	-	
Position of activity j related to phase g and type of the component ty the activitiy is applied to	$pos_j(g, ty)$		Integer	-	
Volume of the building component the activity is related to	u_j		Double	m3	
Height above ground of the building component the activity is related to	hg_j		Double	m	
Material of the building component the activity is related to	b_j	{1;2;…;10}; {Concrete;…}	Integer/ String	-	
Deconstruction activity segment of activity j (foreign key deconstruction activity segment: ID_d)	d_j		Integer	-	
Material separation activity segment of activity j (foreign key deconstruction activity segment: ID_o)	o_j		Integer	-	
Material crushing activity segment of activity j (foreign key deconstruction activity segment: ID_q)	q_j		Integer	-	
Type and amount of attachment/s to deconstruct the component of activity j in mode m (foreign key attachments: ID_a)	$ad_{j,m}$	{1;2;…;23}	Integer	-	A1
Type and amount of attachment/s o sort and crush material of activity j in mode m (foreign key attachments: ID_a)	$ab_{j,m}$	{1;7;12;18;23}	Integer	-	A1
Number of units of hydraulic excavator resource hy of the activity j in mode m	$r^{hy}_{j,m}$	{0;1;2}	Integer	amount	A1
…					
Number of employee resource po of activity j in mode m	$r^{po}_{j,m}$	{0;1;…;4}	Integer	amount	A1
Duration of activity j in mode m influenced by the basic unit size	$p_{j,m}(sz)$		Double	h	4.4.2.1
Specific hourly contingency costs per hydraulic excavator units hy of activity j influenced by the basic unit size sz and investment report-year yr	$\kappa^{ex(hy)}_j(sz^{hy},yr)$		Double	€/h	4.4.2.3
…					
Costs of activity j in mode m influenced by the basic unit size sz and investment year yr	$c_{j,m}(sz, yr)$		Double	€	4.4.3.1
Average noise impact level of activity j in mode m influenced by the distance from the emission source dc, number of equipollent, coherent noise levels r^l and basic unit size sz	$lim_{j,m}(dc,n^l,sz)$	{40-130}	Double	dB(A)	4.5.3.3
Average dust emission level of activity j in mode m influenced by the basic unit size sz	$sim_{j,m}(sz)$	{0-300}	Double	mg/m3	4.5.3.3
Average vibration impact level of activity j in mode m influenced by the distance from the emission source dc and basic unit size sz	$vim_{j,m}(dc,sz)$	{0-25}	Double	mm/s	4.5.3.3

To select the most appropriate overall deconstruction plan, alternatives with different modes of each activity have to be compared. Certain economic and environmental project plan values have to be calculated across single activities on the basis of project phases (g) (*plan layer 3*). Hence, a respective design of phase alternatives with technical, economic and environmental attributes of project phases is required, as addressed in the following section 4.3.2.4.

4.3.2.4 Alternatives of deconstruction project phases

According to existing building structures and to keep the model calculations solvable, a project phase g (g={1;2;…;G}) can encompass up to six deconstruction project activities j_g (j_g={1;2;…;J_g}, with J_g= {1;2;…;6}). The alternatives of the project-phase-related mode-series (one alternative is denoted ms_g, with ms_g={1;2;…;MS_g}) are built by complete enumeration of all, up to six, activities (J_g) of the phase (g) and performed in different modes (m) (with M_j<=34). Hence, there are up to 34^6 alternatives of one building level-related project phase possible (MS_g<=34^6). Based on the defined top-down, building level-wise deconstruction sequence (see section 4.3.2.2) the position of a project phase within the overall deconstruction sequence pos_g is defined. All attributes, notions, value ranges, units and sources of each building level-related deconstruction project phase (g) are outlined in Table 4-10.

Table 4-10: Attributes, notions, value ranges and sources of deconstruction project phases g

Attribute	Notion	Value range	Variable	Unit	Section
ID	g		Integer		
Number of activities of deconstruction project phase g	J_g	{1;2;…;6}	Integer	-	4.3.2.4
Activity 1 of project phase g (foreign key activity: ID_j)	1_g	{0;1}	Integer	-	
Activity 2 of project phase g (foreign key activity: ID_j)	2_g	{0;1}	Integer	-	
…					
Activity 6 of project phase g (foreign key activity: ID_j)	6_g	{0;1}	Integer	-	
Position of phase g	pos_g		Integer	-	
Alternative phase-related mode-series of project phase g	ms_g		Integer	-	
Set of alternative phase-related mode-series of project phase g	MS_g	$\{1;2;\ldots;34^6\}$	Integer	-	
Number of units of hydraulic excavator resource hy of project phase g in mode-series alternative ms_g	$r^{hy}_{g,msg}$	{0;1;2}	Integer	amount	4.4.3.2
…					
Number of employee resource po of project phase g in mode-series alternative ms_g	$r^{po}_{g,msg}$	{0;1;…;4}	Integer	amount	4.4.3.2
Duration of project phase g in mode-series alternative ms_g influenced by the basic unit size	$p_{g,\,msg}(sz)$		Double	h	4.4.2.1
Costs of project phase g in mode-series alternative ms_g influenced by the basic unit size sz and investment year yr	$c_{g,msg}(sz,\,yr)$		Double	€	4.4.3.2
Average noise impact level of project phase g in mode-series alternative ms_g influenced by the distance from the emission source dc, number of equipollent, coherent noise levels r^l and basic unit size sz	$lim_{g,msg}(dc,n^l,sz)$	{40-130}	Double	dB(A)	4.5.3.3
Average dust emission level of project phase g in mode-series alternative ms_g influenced by the basic unit size sz	$sim_{g,msg}(sz)$	{0-300}	Double	mg/m3	4.5.3.3
Average vibration impact level of project phase g in mode-series alternative ms_g influenced by the distance from the emission source dc and basic unit size sz	$vim_{g,msg}(dc,sz)$	{0-25}	Double	mm/s	4.5.3.3
Percentage of average noise impact level of project phase g in mode-series alternative ms_g influenced by the distance from the emission source dc, number of equipollent, coherent noise levels r^l and basic unit size sz	$pc^{lim}_{g,msg}(dc,n^l,sz)$	{0;0.125;0.25;…;1}	Double	%	4.5.3.3
Percentage of average dust emission level of project phase g in mode-series alternative ms_g influenced by the basic unit size sz	$pc^{sim}_{g,msg}(sz)$	{0;0.125;0.25;…;1}	Double	%	4.5.3.3
Percentage of average vibration impact level of project phase g in mode-series alternative ms_g influenced by the distance from the emission source dc and basic unit size sz	$pc^{vim}_{g,msg}(dc,sz)$	{0;0.125;0.25;…;1}	Double	%	4.5.3.3

The technical, economic and environmental assessment of deconstruction plans, including the calculation of activity- and project phase-related plan values and the preparation of required data, are described in detail in sections 4.4 and 4.5.

4.4 Modelling for technical and economic assessment

The modelling of technical and economic assessment within Module 1 for operational planning and decision making and the preparation of required data has to include the following elements:

- Sequential application of relational operators due to the technical suitability related to physical characteristics of the single building shell components.
- Costs of activity-and phase-related resources due to the activity modes.
- Activity-related specific values and classification numbers for the technical and economic assessments.

4.4.1 Relational operators and activity-mode-depending feasibility parameters for technical assessment

From all possible activity modes (m) (see appendix A1), the feasible technique modes are identified for each activity by relational operators due to comparative values of physical characteristics of the single building shell components. The attributes of deconstruction activity modes (m) (see Table 4-7), which are linked to the building-component-related suitability, form the building component-related technical feasibility parameters. These parameters and respective implemented relational operators are outlined in Table 4-11.

Table 4-11: Building-component-related technical feasibility parameters and implemented rational operators

Building component-related technical feasibility parameter	Notion	Value range	Rational operator	Solution
Suitability due to component type ty (ty=1-8)	$sty^{ty}{}_{m}$	{1}	=	Boolean: true/false
Suitability due to component material b (b=1-10)	$sb^{b}{}_{m}$	{1}	=	Boolean: true/false
Maximal component thickness due to material b (b=1-10)	$thb^{b}{}_{m}$	{0.2; ….;1000}	<=	Boolean: true/false
Maximal height above ground	hg_m	{15;…;1000}	<=	Boolean: true/false

The feasible technique modes of each activity form the set of deconstruction activity modes (M_j). To create M_j, in general a distinct decision for or against a certain deconstruction technique mode (m) is made according to all four building component-related technical feasibility parameters/mode attributes (Table 4-11). In this regard, decision making is modelled for each technique mode by sequential application of the relational operators resulting in a Boolean value (true/false) as solution. The model contains feasibility matrices in form of adjacency matrices of each feasibility parameter. The single feasibility parameters and their implementation in the model are explained in detail in the following.

4.4.1.1 Component type suitability ($sty^{ty}{}_{m}$)

For the deconstruction of the different building shell component types (ty), specified in section 4.3.1.2, Table 4-2, distinct deconstruction methods are suitable and not suitable (DA (2015, p. 175), DIN 18007:2000-05). In this research, each technique mode (m) includes a district deconstruction method (md_m). Hence, via the assigned deconstruction method the component type suitability is defined for each mode. This suitability (1: suitable; 0: not suitable) related to the eight building component types (ty) is shown for all deconstruction technique modes in columns $sty^{1}{}_{m}$ – $sty^{8}{}_{m}$ in appendix A1. Decision making related to this first parameter of the technical feasibility is modelled with a feasibility matrix, the rational operator '=' (=1) and with the help of the Boolean logic (true (suitable); false (not suitable)).

4.4.1.2 Component material suitability (sb^{b}_{m})

Like the component type, also for the component material (b), specified in section 4.3.1.2, Table 4-3, certain deconstruction methods are suitable or not (DA (2015, pp. 176, 178), DIN 18007:2000-05, Toppel (2003, p. 81 et seq.)). Hence, via the assigned deconstruction method the component material suitability is defined for each mode as well. This suitability (1: suitable; 0: not suitable) related to the ten building component materials (b) is shown for all deconstruction technique modes in columns sb^{1}_{m} – sb^{10}_{m} in appendix A1. Decision making related to this second parameter of the technical feasibility is modelled with a feasibility matrix, the rational operator '=' (=1) and with the help of the Boolean logic (true (suitable); false (not suitable)).

4.4.1.3 Maximal material-related component thickness (thb^{b}_{m})

Furthermore, the suitability of deconstruction methods depends on the material thickness, respectively the thickness of a building component made of a certain material (DA (2015, pp. 175 et seq.), Toppel (2003, p. 81 et seq.)). The maximal material-related component thicknesses, which are manageable by specific deconstruction methods, are summarized for the ten materials and all technique modes in columns thb^{1}_{m} - thb^{10}_{m} in appendix A1. Decision making related to this third parameter of the technical feasibility is implemented with a feasibility matrix, the rational operator '<=' (<= max. thickness) and with the help of the Boolean logic (true (suitable); false (not suitable)).

4.4.1.4 Maximal height above ground (hg_{m})

The deconstruction height above ground describes the height above ground, where the building component to be deconstructed is placed (ha). For instance, the height above ground (ha) of a building wall is the height above ground of the building level the building wall is part of plus the actual height of the wall itself. The height above ground (ha) of a slab correlates with the height above ground of the building walls of this level plus the width/thickness of the slab. Particular deconstruction technique modes can only be applied up to a certain height above ground with respect to the reach of the basic unit and the deconstruction method (DA (2015, p. 262), Toppel (2003, p. 81 et seq.)). The maximal heights above ground, which are manageable by specific deconstruction technique modes, are summarized in column hg_m in appendix A1. Decision making related to this fourth parameter of the technical feasibility is implemented with a feasibility matrix, the rational operator '<=' (<= max. height) and with the help of the Boolean logic (true (suitable); false (not suitable)).

4.4.2 Activity-related specific economic values in the database

In section 3.2 the approach of costs of activity-and phase-related resources of the on-site deconstruction process[62] was selected for the economic assessment in this thesis. Within this context labour costs as well as equipment contingency and operation-related equipment costs are calculated for each deconstruction activity mode and project phase scenario respectively. Both activity-related and phase-related costs of resources are time-dependent. Hence, the costs are calculated based on the following activity segment-related specific economic values:

- Specific duration values and
- Hourly costs of the single resources, including labour, basic unit and attachment.

[62] As specified in section 3.2.3 the on-site deconstruction process includes the actual deconstruction of the building and pre-crushing and –sorting of material on site.

The basic data and formalisation of these activity-segment-related specific economic values is described in the following.

4.4.2.1 Specific duration values and durations

The durations of the project activity in different modes ($p_{j,m}(sz)$) and of the project phase in alternative project-phase-related mode-series ($p_{g,msg}(sz)$) are partly influenced by the basic unit size indicator[63] (sz). The durations are calculated based on the durations of the single activity segments in different modes ($p_{dj,m}(sz)$, $p_{oj,m}$, $p_{qj,m}$)[64], whereby the activity duration ($p_{j,m}(sz)$) is the sum of the durations of the single activity segments (Equation 4-1).

Equation 4-1: Activity duration

$$p_{j,m}(\mathrm{sz}) = \sum_{i(d_j,o_j,q_j)} p_{i,m}\,(sz)[\mathrm{h}]$$

The phase duration ($p_{g,msg}(sz)$) is the sum of the durations of all activities J_g performed in modes m of this phase g. The duration of a phase varies with the alternative phase-related mode-series ms_g. The alternative includes all the activities of this phase performed in certain modes (Equation 4-2).

Equation 4-2: Phase duration

$$p_{g,ms_g}(\mathrm{sz}) = \sum_{j_g=1}^{J_g} \sum_{m=1}^{M_{jg}} p_{j_g,m}(sz) * z_{j_g,m}\ [\mathrm{h}]$$

With

$z_{jg,m}$: binary variable (1, if activity j_g is performed in mode m; 0, else)

[63] In the following, the size indicator of a basic unit is called ‘size’ of the basic unit due to simplification.

[64] The durations of the material-sorting and -crushing segments are not influenced by the basic unit size.

$\sum_{m=1}^{M_{jg}} z_{jg,m} = 1$ (to ensure that one activity is performed exactly once in a phase/phase alternative).

The segment durations are the product of the specific duration value of the single activity segments (δ_d(m,b,sz)/δ_d(m,b), δ_o(m,b), δ_q(m,b)) and the *volume* u_j (m^3) of the building component the activity is related to. The specific duration values are influenced by the mode (m) and the material type (b)[65] and partly by the basic unit size (sz). Equation 4-3 shows the calculation of the duration of the deconstruction activity segment (d_j). The durations of the material pre-separation activity segment (o_j) and the material pre-crushing activity segment (q_j) are calculated similarly.

Equation 4-3: Duration of the deconstruction activity segment d_j

$$p_{d_j,m}(\mathrm{sz}) = \delta_{d_j}(\mathrm{m}, \mathrm{b}_j, \mathrm{sz}) \cdot u_j \text{ [h]}$$

The specific duration values of the single activity segments [h/m^3] are a function of the mode (m) and the material (b_j) of the building component the activity is related to. Furthermore, specific duration values of the deconstruction activity segment (δ_d(m,b,sz)) depend on the available sizes of the mode-related basic unit types (sz^{hy}, sz^{lt}, sz^{cw}, sz^{ha})[66], entered by the user for the overall project. In the following, the notation 'sz' is regularly used instead of sz^{hy} and sz^{lt}, when the basic unit size of both, of hydraulic or longfront crawler excavators, is applicable. Equation 4-4 and Equation 4-5 show the functions of the specific duration value (δ_d(m,b,sz)/δ_d(m,b)) of the deconstruction

[65] The material type of the specific building component (b_j).
[66] The available sizes of basic units are defined in kilowatts (kW) for hydraulic (hy) and longfront (lt) crawler excavators and in ton meters (tm) for cable-operated excavators (cw). The size of hand tools (with compressor) (ha) is defined in kilograms (kg) and is assumed fixed with 20kg in this research.

activity segment of activity j (d_j) depending on the required basic unit type[67]. This specific value represents the duration required to actual deconstruct 1m^3 of the component of material (b_j). The functions of the specific duration values of the other two activity segments correspond to Equation 4-5, as they are independent of the basic unit size. These specific values represent the durations required to separate (δ_o(m,b), and respectively crush (δ_q(m,b)) 1m^3 of the material (b_j) to reach a high material quality for recycling (see sections, 4.3.1.1. and 4.3.2.1).

Equation 4-4: Function of the specific duration value of the activity segment d_j of modes performed with hydraulic (hy) or longfront (lt) crawler excavators

$$\delta_{d_j}(\mathrm{m}, \mathrm{b}_j, \mathrm{sz}) = \mathrm{f}(m, b_j, sz) \text{ [h/m}^3\text{]}$$

Equation 4-5: Function of the specific duration value of the activity segment d_j of modes performed with cable-operated excavators (cw) or hand tools (ha)

$$\delta_{d_j}(\mathrm{m}, \mathrm{b}_j) = \mathrm{f}(m, b_j) \text{ [h/m}^3\text{]}$$

Learning effects of employees over time as well as productivity regressions related to the amount of labour (see Schultmann (1998, p. 84)) are not considered in the activity durations in this research.

Specific duration values of the deconstruction activity segment (δ_d(m,b,sz)/δ_d(m,b)) are obtained from expert evaluation via a body of experts and literature (Weimann et al. (2013, pp. 62, 204 et seq.), DA (2015, pp. 293 et seq.), Seemann (2003, p. 49), Rentz et al. (2002); Schultmann (1998, p. 39); Rentz (1993)). Specific duration values of the material pre-separation (δ_o(m,b)) and pre-crushing activity segment (δ_q(m,b)) are generated via primary data by an expert survey and consultations within this research. The collection of primary data

[67] The available sizes of cable-operated excavators (sz^{cw}) and hand tools (sz^{ha}) have no influence on the specific duration values in this research.

by an expert survey and consultations is described in detail in chapter 5, in section 5.2.[68] All possible combinations of relevant deconstruction methods (see Table 2 2, white highlighted methods) and of building material types (b) (see Table 4-3) are evaluated with regard to average time required for deconstruction material pre-separation and pre-crushing to reach the high material quality for recycling defined in section 4.3.1.1.

All functions of specific duration values of the deconstruction segment (δ_d(m,b,sz)/δ_d(m,b)) related to the basic unit size (sz) depending on different modes (m) and component materials (b), which are implemented in the model, are documented in appendix A2. The specific duration values of the material pre-separation and pre-crushing activity segment (δ_o(m,b), δ_q(m,b)) depending on different modes (m) and component materials (b) are included in appendix A2 as well.

The relationship between the specific duration value the deconstruction segment (δ_d(m,b,sz), in h/m^3) and the size of the hydraulic crawler excavator (sz^{hy}, in kW) is shown in Figure 4-8 (according to expert evaluation) for the example of δ_d(m,b,sz) in mode gripping applied to the component materials brick and concrete. The relationships are based on the expert evaluation of deconstruction site managers.

[68] Primary data collection was performed within the research project, this study is related to.

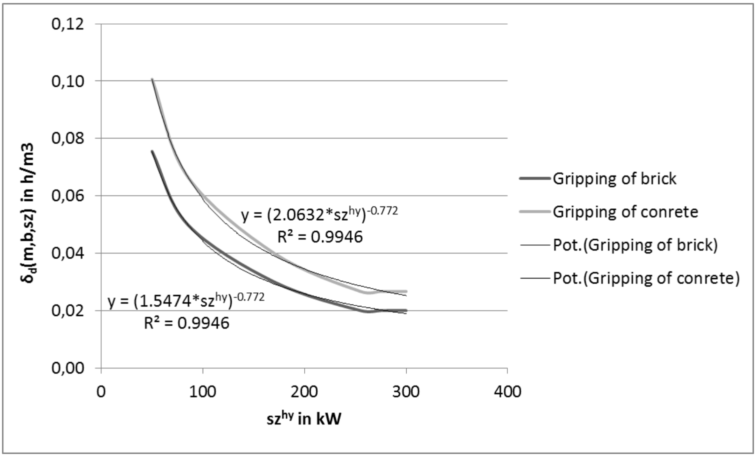

Figure 4-8: Relationship between the specific deconstruction duration value of the activity segment (δ_d(m,b,sz), in h/m3) in the mode gripping applied to the component materials brick and concrete and the hydraulic excavator size (sz^{hy} in kW)[69]

Figure 4-9 (BGL(2015, p. D 15)) illustrates the relationship of kilowatts (kW) and tons (t) of a hydraulic excavator/longfront crawler excavator according to BGL (2015, p. D 15) and implemented in the model.

[69] According to expert evaluation.

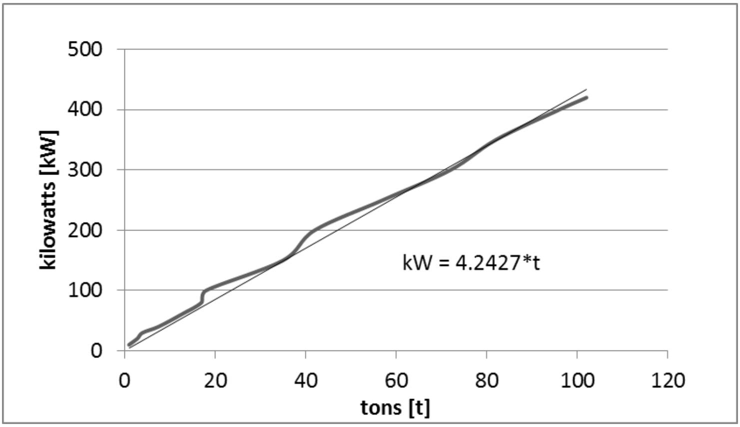

Figure 4-9: Relationship of kilowatts (kW) and tons (t) of a hydraulic/longfront crawler excavator[70]

Besides specific duration values, cost calculation requires hourly costs of single resources. Hourly costs for labour, basic units and attachments based on the assumptions made in section 3.2 are specified in the following.

4.4.2.2 Labour costs

For the generation of the specific hourly labour costs of the segments of each activity influenced by the mode ($\kappa^{po}{}_{d}(m)$, $\kappa^{po}{}_{o}(m)$,$\kappa^{po}{}_{q}(m)$), first an average salary ASL (Figure 3 3 in section 3.2.4.2) (Kattenbusch et al. (2012, p. 40), Girmsheid and Motzko (2013, p. 182)) per employee is calculated and pre-set in the model. This average salary ASL can be adapted by the user (see section 7.1.2). According to the regular skills of employees on deconstruction sites (DA (2015, p. 181)) the average salary ASL is based on the wages of one operator and one skilled worker. Further assumptions are stated in section 3.2.2.2. Calculation of ASL and respective steps is shown in Figure 4-10.

[70] BGL (2015, p. D 15).

		Workers	Basic standard wages (including a construction markup of 5.9%)	Total wage
Wage group	Name	Amount	€/h	€/h
4	Operator	1	18.64	18.64
3	Skilled worker	1	17.07	17.07
	Total	2	*Total*	35.71
Average basic (standard) labour wage			35.71 / 2=	**17.86**
Additional labour costs	Long hours (10% of the hourly basic operator wage for			1.86
	Difficult work conditions			1.65
Average salary A				**21.37**
Social (90% of A)				19.23
Average salary AS				**40.59**
		€/WD	Hours per WD	
Non-wage labour costs	Travel expenses	4	8	0.5
Average salary ASL				**41.09**
			WD: working day	

Figure 4-10: Calculation of average salary ASL

Secondly, the average salary ASL 41.10 €/h[71] is multiplied by the mode-dependent number of required labour ($r^{po}{}_m$) (Table 4-8). The result is specific labour costs $\kappa^{po}{}_d(m)$, $\kappa^{po}{}_o(m)$,$\kappa^{po}{}_q(m)$ per activity mode.

4.4.2.3 Equipment contingency costs

According to section 3.2.2.2, equipment contingency costs encompass investment-based equipment costs and contingency reserves for probable equipment repairs. Investment-based equipment costs include amortization and the interest rate.

For each equipment basic unit (Table 4-5) and type-number-related attachment/s (Table 4-6) functions[72] of specific hourly equipment

[71] The pre-set average salary ASL of 41.10 €/h is a first assumption and can be adapted by the user in the model (see section 7.1.2).
[72] In general, the functions of specific hourly equipment contingency costs are size-related. They depend on the size of the basic unit of the mode, sz^{hy}, sz^{lt}, sz^{cw}, sz^{ha}.

contingency costs are deducted from specific costs of single equipment components of BGL (2015). These single contingency cost functions (with the price basis 2014) of each basic unit of equipment and attachment with respective BGL equipment components are included in appendix A3. The contingency cost functions are translated to other investment years by adding the producer price index of construction equipment related to the base year 2014 (i_{yr})[73] as a multiplication factor into each function. With the investment year (yr) and the size of each basic unit (sz^{hy}, sz^{lt}, sz^{cw}, sz^{ha})[74], entered by the user[75], specific hourly contingency costs per basic unit ($\kappa^{ex(hy)}(sz^{hy},yr)$, $\kappa^{ex(lt)}(sz^{lt},yr)$, $\kappa^{ex(cw)}(sz^{cw},yr)$, $\kappa^{ex(ha)}(sz^{ha},yr)$[76]) are calculated. Figure 4-11 shows the size-related function of specific hourly contingency costs of a hydraulic crawler excavator. The costs include relevant positions of a hydraulic crawler excavator of BGL (2015)[77].

Whereas, the size of hand tools (with compressor) (sz^{ha}) is assumed fixed with 20kg in this research, as mentioned above.

[73] According to the producer price index for construction equipment (Destatis (2016, p. 189)) and the base year change by the Association of the German Construction Industry (BGL (2015, p. 18).

[74] In the following, the notation 'sz' is regularly used instead of sz^{hy}, sz^{lt}, sz^{cw}, sz^{ha}, when the size of any basic units is meant.

[75] Whereas, the size of hand tools (with compressor) (sz^{ha}) is fixed 20kg and cannot be entered/adapted by the user.

[76] The size of hand tools (with compressor) (sz^{ha}) is fixed and 20kg.

[77] Detailed information about relevant positions of BGL (2015) of each basic unit is included in in appendix A3.

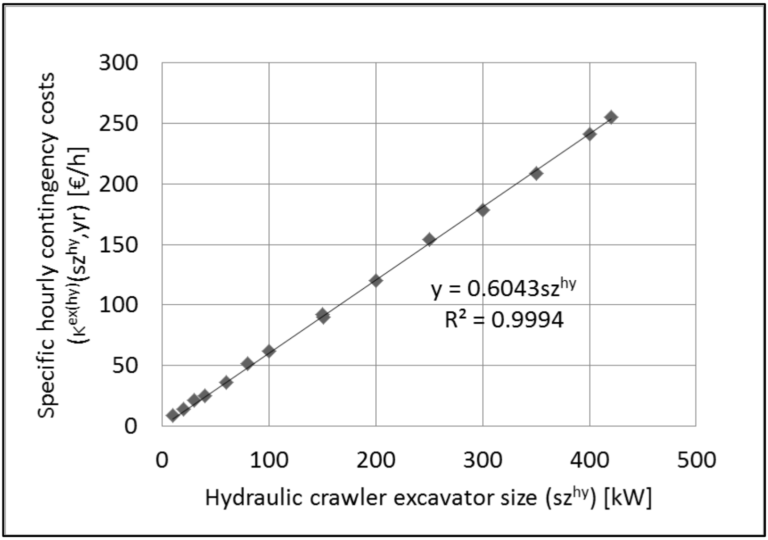

Figure 4-11: Function of the specific hourly contingency costs of a hydraulic crawler excavator ($\kappa^{ex(hy)}(sz^{hy},yr)$) related to the excavator size (sz^{hy}) of investment year (yr) 2014

Moreover, specific hourly type-number-related attachment contingency costs of the deconstruction project activity segments of each activity depending on the mode, the basic unit size and the investment year ($\kappa^{ex(ad)}(m,sz,yr)$, $\kappa^{ex(ab)}(m,sz,yr)$) are calculated. Figure 5-2 illustrates the size-related function of specific hourly contingency costs of one deconstruction grab (ID_a = 1, see Table 4-6). For instance, is one grab the attachment for the activity mode 'gripping with one hydraulic excavator’. One grab is here applied to perform all three activity segments[78].

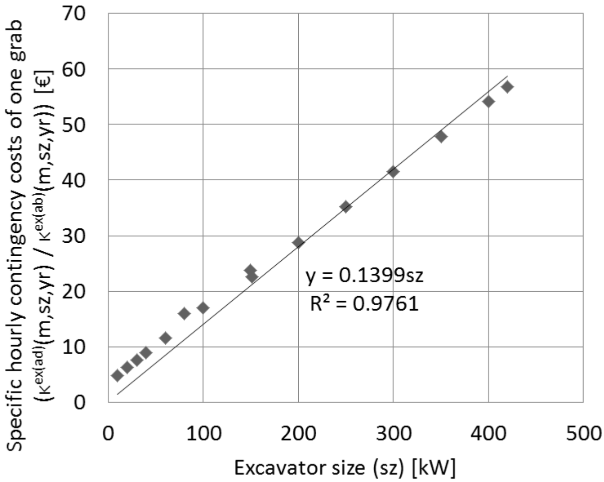

Figure 4-12: Function of the specific hourly contingency costs of one deconstruction grab ($\kappa^{ex(ad)}(m,sz,yr)/\kappa^{ex(ab)}(m,sz,yr)$) related to the excavator size (sz) of investment year (yr) 2014

Both, the specific hourly contingency costs per basic unit and specific hourly type-number-related attachment contingency costs are pre-set in the model and can be adapted by the user.

[78] The grab is the attachment for deconstruction (ad_m) and for material sorting and crushing (ab_m) for the activity mode ‘gripping’ with one hydraulic excavator’ (see Appendix A1).

4.4.2.4 Operation-related equipment costs

According to section 3.2.2.2, operation-related equipment costs include costs of fuel and lubricants. The general size-related functions of hourly fuel and lubricants costs (κ^{ful}) is shown by Equation 4-6 (BGL (2015, p. 13)) and Equation 4-7.

Equation 4-6: Hourly fuel and lubricants costs of activities performed in modes with hydraulic crawler excavator/s of size/s sz^{hy} in kW [79]

$$\kappa^{ful} = sz^{hy} \cdot \frac{125}{1000 \cdot 0.84} \cdot \kappa^{diesel} \cdot 1.11 \text{ [€/h]}$$

Equation 4-7: Hourly fuel and lubricants costs of activities performed in modes with hand tools with compressor (ha)[80]

$$\kappa^{ful} = \kappa^{diesel} \cdot 5 \cdot 1.11 \text{ [€/h]}$$

With

Pre-set and user-specific adaptable specific diesel costs per litre (κ^{diesel}) of 1.17 €/l[81] and

lubricants costs per hour, calculated as 11% of the diesel costs per hour, according BGL (2015, p. 15).

[79] Equation applies to longfront crawler excavator/s (lt) and cable-operated excavators (cw) of size/s sz^{lt} and sz^{cw} respectively in kW. For cw the size is converted from ton meters (tm) to kW by sz^{cw} (in tm)*(-0.0004) + 0.6288 = sz^{cw} (in kW), according to BGL (2015) C.2.2, Raupenkrane (p. C 32).

[80] In the research it assumed that two hand tools of 20kg with one compressor (HA) require 10 litres fuel per hour. This results in 5 litres fuel per hour per hand tool.

[81] Average costs based on monthly gross consumer prices of one litre diesel in Germany within the year 2015 (Mineralölwirtschaftsverband (2016)). The pre-set specific diesel costs per litre of 1.17 €/l are a first assumption and can be adapted by the user in the model (see section 7.1.2).

Specific hourly operation costs of the deconstruction project activity segments of each activity influenced by the mode and the basic unit size ($\kappa^{op}{}_{d}(m, sz)$, $\kappa^{op}{}_{o}(m, sz)$, $\kappa^{op}{}_{q}(m, sz)$) are generated based on Equation 4-6[82] and Equation 4-7 of the mode-related basic unit type multiplied by the respective number of basic units[83]

4.4.3 Costs of activity-and phase-related resources for economic assessment

For the economic assessment of deconstruction projects it is relevant that some resource costs cannot be assigned to the single deconstruction activity. In this regard, the contingency costs of basic units have to be calculated across single activities in the form of contingency costs for project phases g (see section 3.2.4.2). However, labour costs, contingency costs of attachments and operation-related equipment costs can be assigned to the single deconstruction project activities (see section 3.2.4.2).

4.4.3.1 Modelling of activity-related costs

The costs of an activity j in mode m influenced by the basic unit sizes and investment year ($c_{j,m}(sz,yr)$) are the sum of the costs of the resources of all activity segments ($c_{dj,m}(sz,yr)$, $c_{oj,m}(sz,yr)$, $c_{qj,m}(sz,yr)$) (Equation 4-8).

Equation 4-8: Activitiy costs

$$c_{j,m}(\mathrm{sz},\mathrm{yr}) = \sum\nolimits_{i(d_j,\, o_j,\, q_j)} c_{i,m}(sz, yr) \quad [€]$$

The costs of each activity segment are the sum of labour costs, contingency costs of attachments and operation-related equipment

[82] The size of each basic unit (sz^{hy}, sz^{lt}, sz^{cw} (in kW)) is entered by the user.
[83] Number of basic units related to the activity segments: $r^{hy}{}_{dj,m}$, $r^{lt}{}_{dj,m}$, $r^{cw}{}_{dj,m}$, $r^{ha}{}_{dj,m}$, $r^{hy}{}_{oj,m}$, $r^{lt}{}_{oj,m}$, $r^{cw}{}_{oj,m}$, $r^{ha}{}_{oj,m}$ $r^{hy}{}_{qj,m}$, $r^{lt}{}_{qj,m}$, $r^{cw}{}_{qj,m}$, $r^{ha}{}_{qj,m}$.

costs. The activity segment costs are calculated based on the mode- and partly size-depending activity-segment-related durations ($p_{dj,m}$(sz), $p_{oj,m}$, $p_{qj,m}$) and specific values of labour costs ($\kappa^{po}{}_{d}$(m), $\kappa^{po}{}_{o}$(m),$\kappa^{po}{}_{q}$(m)), type-number-related attachment contingency costs ($\kappa^{ex(ad)}$(m,sz,yr), $\kappa^{ex(ab)}$(m,sz,yr)) and of operation-related equipment costs ($\kappa^{op}{}_{d}$(m,sz), $\kappa^{op}{}_{o}$(m, sz), $\kappa^{op}{}_{q}$(m, sz)), defined in section 4.4.2. Equation 4-9 shows the calculation of the deconstruction activity segment costs ($c_{dj,m}$(sz,yr). The costs of the material pre-separation activity segment $o_{j,m}$ and the material pre-crushing activity segment $q_{j,m}$ are calculated respectively.

Equation 4-9: Deconstruction activity segment costs

$$c_{d_{j},m}(\mathrm{sz},\mathrm{yr}) = p_{d_{j},m}(sz) * \left(\kappa_{d}^{po}(m) + \kappa_{d}^{ex(ad)}(m,sz,yr) + \kappa_{d}^{op}(m,sz)\right) \quad [€]$$

4.4.3.2 Modelling of phase-related costs

A building-level-related project phase g can contain up to six deconstruction activities j_g (j_g=1-J_g, with J_g= {1-6}), which are performed in different modes. The combination of activities in different modes defines the alternative phase-related mode-series of project phase g (ms_g) (see section 4.3.2.4). Hence, the costs of a project phase g depend on the phase-related mode-series alternative ms_g and is influenced by the basic unit sizes and investment year ($c_{g,msg}$(sz,yr)). $c_{g,msg}$(sz,yr) is the sum of the costs of all activities j_g of the phase ($c_{jg,m}$(sz,yr)) and of the phase-related contingency costs of all required basic units in this phase. The phase-related contingency costs of the basic units are calculated based on the phase duration ($p_{g,msg}$(sz)) (see section 4.4.2.1) and specific values of contingency costs ($\kappa^{ex(hy)}$(sz^{hy},yr), $\kappa^{ex(lt)}$(sz^{lt},yr), $\kappa^{ex(cw)}$(sz^{cw},yr), $\kappa^{ex(ha)}$(sz^{ha},yr)[84]),

[84] The size of hand tools (with compressor) (s^{ha}) is fixed and 20kg.

influenced by the basic unit sizes and investment year (see section 4.4.2.3), multiplied by the number of required basic units in the phase g depending on the mode-series alternative ($r^{hy}_{g,msg}$, $r^{lt}_{g,msg}$, $r^{cw}_{g,msg}$, $r^{ha}_{g,msg}$) (Equation 4-10).

Equation 4-10: Deconstruction project phase costs

$$c_{g,ms_g}(\mathrm{sz},\mathrm{yr}) = \sum_{j_g=1}^{J_g}\sum_{m=1}^{M_{j_g}} c_{j_g,m}(sz,yr) * z_{j_g,m} + p_{g,ms_g}(sz) * \Big(r^{hy}_{g,ms_g} * \kappa^{ex(hy)}(sz^{hy},yr) + r^{lt}_{g,ms_g} * \kappa^{ex(lt)}(sz^{lt},yr) + r^{cw}_{g,ms_g} * \kappa^{ex(cw)}(sz^{cw},yr) + r^{ha}_{g,ms_g} * \kappa^{ex(ha)}(sz^{ha},yr)\Big)\ [€]$$

With

$z_{jg,m}$: binary variable (1, if activity j_g is performed in mode m; 0, else)

$\sum_{m=1}^{M_{j_g}} z_{j_g,m} = 1$ (to ensure that one activity is performed exactly once in a phase/phase-related mode-series alternative).

$r^{hy}_{g,ms_g} = \sum_{j_g=1}^{J_g}\sum_{m=1}^{M_{j_g}} max\left\{r^{hy}_{j_g,m} * z_{j_g,m}\right\}$; $r^{hy}_{g,ms_g} \in \{0,1,2\}$[85]

$r^{hy}_{j_g,m} = \sum_{i(d_{j,m},o_{j,m},q_{j,m})} max\{r^{hy}_i\}$; $r^{hy}_{j_g,m} \in \{0,1,2\}$[86]

$r^{ha}_{g,ms_g} = \sum_{j_g=1}^{J_g}\sum_{m=1}^{M_{j_g}} max\left\{r^{ha}_{j_g,m} * z_{j_g,m}\right\}$; $r^{ha}_{g,ms_g} \in \{0,2,4\}$

$r^{ha}_{j_g,m} = \sum_{i(d_{j,m},o_{j,m},q_{j,m})} max\{r^{ha}_i\}$; $r^{ha}_{j_g,m} \in \{0,2,4\}$

[85] Equation applies to $r^{lt}_{g,msg}$ with $r^{lt}_{jg,m}$ and $r^{cw}_{g,msg}$ with $r^{cw}_{jg,m}$ respectively.
[86] Equation applies to $r^{lt}_{jg,m}$ with r^{lt}_{i} and $r^{cw}_{jg,m}$ with r^{cw}_{i} respectively.

To answer the research question/s, environmental assessment of deconstruction plans has to be performed, including the calculation of project activity- and phase-related plan values and the preparation of required data, besides technical and economic assessment. Related environmental assessment is addressed in the following section 4.5.

4.5 Modelling for environmental assessment

The modelling of environmental assessment within Module 1 for operational planning and decision making and the preparation of respectively required data has to include the following elements:

- Activity-related emission level classification numbers for environmental assessments.
- Activity-and phase-related environmental impact assessments (EIA)[87] of the activity modes.

Based on the stages illustrated in Figure 5-5, scope definition, estimation of emissions and assessment of effects on the local environment, the following sections 4.5.1 to 4.5.3 describe the environmental assessment of deconstruction projects applied in this research.

[87] In this reseach the term EIA includes the assessment of impacts and emissions. Hence, technically speaking EIA stands for 'environmental effect assessment' in this thesis.

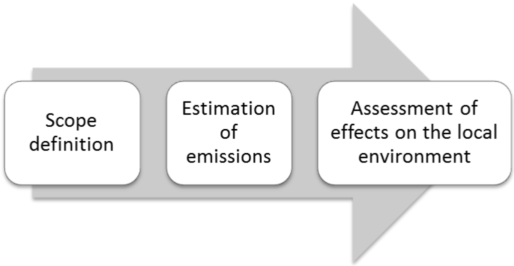

Figure 4-13: Stages of environmental assessment

4.5.1 Scope of environmental assessment

To answer the research question, environmental assessment covers the quantitative estimation of potential emissions and related temporary impacts on the local environment of deconstruction projects based on activity segments and single activities, performed in different modes. Within this context, EIA is applied for the environmental assessment. The results of EIA are output of Module 1 and input for Module 2 (see chapter 6), for deconstruction project planning and decision support due to multi-objectives.

The scope of EIA in this research refers to the on-site execution process of a deconstruction project (see section 2.1.2). Therefore, all activity segments to actual deconstruct single components of the building shell and to separate and crush material on site[88] are examined in terms of their outputs in the form of emissions of noise, dust and vibrations (see section 2.2.1.1). As outlined in section 4.3.1.1, process activities to clear the building and to remove interior installations, such as fittings before deconstruction of the building shell, as well as processes related to the disposal and recycling of deconstruction materials are excluded. Also on-site activities, which

[88] Pre-separation and pre-crushing.

remain unchanged within one deconstruction project, are neglected in the analysis (see section 2.2.1.1), as they are not influenced by different applied deconstruction techniques[89]. As deconstruction activities in general take place during daytime, no distinctions relating the time of day are made in evaluating emissions and environmental impacts. Furthermore, the focus of this research is especially on emission and impact levels caused by deconstruction projects themselves and within this context on a generalisable approach for deconstruction projects. Local initial impact levels of noise, dust and vibrations at the subjects of protection are specific for and change with the surroundings. These levels depend on the ambient conditions and can vary over time. Hence, local initial impact levels are not considered in environmental assessment in this study.

4.5.2 Estimation of emissions and required basic data

Distinct average emissions of noise, dust and vibrations are estimated based on the reference units of TEE-D-Plan. The reference units are the activity segments (d_j, o_j, q_j) related to the time unit of one hour. The emissions do not include further activities and activity segments, for instance preliminary activities on site. Therefore, characteristic factors in the form of classification numbers and specific values of the average level of each emission for the single activity segments are required. These specific emission values and emission classification numbers have to be related to configurations of the identified mainly emission-influencing parameters (see section 3.3.1.1): different deconstruction techniques and activity parallelisation, both modelled as technique modes (m), basic unit sizes (sz^{hy}, sz^{lt}), building shell (component) materials (b_j) and height above ground (hg_j). As

[89] E.g. activities including equipment at rest and operation of power units, cleaning and preparation of equipment and surfaces, loading and unloading of deconstruction material. These activities only influence the material volume and quality, which is equalised by method-dependent pre-separation and pre-crushing activities.

applicable data is currently not available (see section 3.3.1.2), a database of specific values and classification numbers of levels of the distinct emissions related to the emission-influencing parameters (mode-, material-, equipment size- and height above ground-related) is developed in this research[90]. The following steps are carried out to develop the database:

1. Definition of generic five-stage emission level categories of noise dust and vibrations with generic emission level intervals according to the human sense and legal critical limits based on literature.
2. Generation of semi-quantitative, nine-stage emission level classification numbers of noise, dust and vibrations related to possible configurations of emission-influencing activity parameters[91]. These classification numbers are based on the generic five-stage emission categories and on mainly primary data collected by experimental noise, dust and vibration measurements and an expert survey and consultations.
3. Deduction of specific emission level values of noise, dust and vibrations related to the possible configurations of emission-influencing parameters by assigning generic emission level mean values to the nine-stage classification numbers. Therefore the generic literature-based, category-related emission level intervals of step 1 are interpolated according to the nine-stage classification of step 2 and interval mean values are calculated.

[90] The database is developed in conjunction with the research, this study is related to. Parts of the following descriptions are documented in Kühlen et al. (2015) and Kühlen et al. (2016).
[91] Possible combinations of different modes, building materials, equipment support frame sizes and deconstruction heights above ground.

4.5.2.1 Generic emission level categories and emission level intervals

Generic five-stage categories of levels of noise, dust and vibration emissions are defined based on the following general emission level categories:

- Category 0: not annoying emissions
- Category 1: little annoying emissions
- Category 2: medium emissions/partly annoying
- Category 3: high emissions/annoying
- Category 4: very high emissions/very annoying

According to the human sense and legal critical limits, they represent generic emission level intervals of the distinct emissions.

Noise: The categorisation of noise emission levels on the basis of intervals is related to the human sense of noise (A-weighted decibels (dB(A)), see section 2.2.2.1) and respective noise sources, defined for instance in BGBAU-Noise (2016), Sinambari and Sentpali (2014, p. 214), LfU (2013, p. 7) and SCENIHR (2008, pp. 16, 17). Furthermore, legal guidance values of noise impact levels according to TA Lärm (1998), DIN 18005-1 supplement 1:1987-05and AVV Baulärm (1970) (Table 4-12) are considered for the categorisation. As the noise emission level of a conservation on normal sound level is assigned to 40 to 50 dB(A) and the daytime impact guidance value of residential-only areas is 50 dB(A), an interval of 40 to 50 dB(A) is assigned to category 0. Category 1 represents noise emission levels over 50 dB(A) and up to 70 dB(A). These levels, for instance, correspond to the noise emission level of a car. Noise emission levels between 70 and 90 dB(A), which match noise emission levels of a main street and are often partly annoying humans (BMUB UBA (2015), pp. 42, 43), are assigned to category 2. Category 3 represents noise emission levels over 90 and up to 110 dB(A). This interval corresponds to noise emission levels of a circular saw, jack-hammer or the loudness inside a discotheque and can cause hearing damage, when this level longer impacts on the human. A noise emission level over 110 dB(A) matches for instance the loudness of a jet plane at low altitude. The interval of 110 to 130 dB(A) is assigned to category 4. Noise of these emission levels can cause hearing damages, when even briefly occurring.

Table 4-12: Generic categories and intervalls of noise emission levels

Noise emission level category		Interval [dB(A)]	
#	meaning	from (>)	to (<=)
0	not annoying	40	50
1	little annoying	50	70
2	partly annoying	70	90
3	annoying and hearing damages when longer exposed	90	110
4	painful and hearing damages even when shortly exposed	110	130

Dust: The categorisation of dust emission levels on the basis of intervals is linked to the human sense due to the concentration of total dust in the air (see section 2.2.2.2) and to legal critical limits related to the concentration of inhalable dust (so called E-dust) in the air (TRGS 900 (2015, p. 5)) and connected work-safety-related breathing protection usage recommendations (VBG (2011, p. 24)) (Table 4-13)[92]. The critical limit of air pollution due to the concentration of inhalable dust is 10 mg/m^3. This concentration is assigned to little dust exposure. Hence, the interval of 1 to 10mg/m^3

[92] As outlined in section 2.2.2.2, in this research it is assumed that the total dust concentration correlates with the concentration of inhalable dust.

E-dust concentration is assigned to category 1 (little annoying) and category 0 represents 0 to 1mg/m^3. The other category intervals are defined based on work-safety-related breathing protection usage recommendations according to E-dust concentrations in the air, E-dust exposures. Dust levels in terms of E-dust concentrations between 10 and 40mg/m3 are assigned to category 2. Category 3 represents dust emission levels over 40 and up to 100mg/m^3. The interval of 100 to 300mg/m^3 is assigned to category 4.

Table 4-13: Generic categories and intervals of dust emission levels

Dust emission level category		Interval [mg/m^3 inhalable dust (E-dust) concentration in the air]	
#	meaning	from (>)	to (<=)
0	no dust exposure noticable	0	1
1	little dust exposure	1	10
2	medium dust exposure and breathing protection recommended	10	40
3	high dust exposure and breathing protection required	40	100
4	hardly breathing due to very high dust exposure and high quality breathing protection and dust reduction measures required	100	300

Vibration: The categorisation of vibration emissions on the basis of intervals is related to the human sense of vibrations and to legal guidance values of the effective vibration speed according to DIN 4150-2:1999-06 and PFA 1.3 (2013, p. 11), referring to the withdrawn VDI 2057-3:1987-05[93]) (Table 4-14). As effective vibration speeds of less than 0.1mm/s are classified as not noticeable by the human

[93] According to PFA 1.3 (2013, p. 11), the relationship between the human sense of vibrations and the effective vibration speed in Table 1 of the VDI 2057-3:1987-02 is still valid, even VDI 2057-3:1987-02 was withdrawn in 2002.

sense, the interval of 0 to 0.1mm/s is assigned to category 0. Category 1 represents just noticeable effective vibration speeds of 0.1 to 0.4mm/s. Good noticeable vibration emission levels in terms of effective vibration speeds between 0.4 and 1.6mm/s are assigned to category 2. Category 3 represents vibration emission levels over 1.6 and up to 6.3mm/s. Vibration speeds over 6.3mm/s are very strong noticeable by humans. Hence, an interval of 6.3 to 25mm/s is assigned to category 4.

Table 4-14: Generic categories and intervals of vibration emission levels

Vibration emission level category		Interval [mm/s effective vibration speed]	
#	meaning	from (>)	to (<=)
0	no vibration noticeable	0	0,1
1	little vibration noticeable	0,1	0,4
2	noticeable vibration with little impulse	0,4	1,6
3	strongly noticeable vibration with strong impulse	1,6	6,3
4	very strong noticeable vibration with very strong impulse	6,3	25

4.5.2.2 Emission level classification numbers of activity parameter configurations

Based on the generic five-stage categories, defined above in section 4.5.2.1, and on mainly primary data, semi-quantitative, nine-stage emission level classification numbers (0; 0.5; 1; 1.5;...; 4) of noise, dust and vibrations related to possible configurations of emission-influencing activity parameters are generated. Via an expert survey and consultations, all possible combinations[94] of relevant deconstruction methods (see Table 2 2, white highlighted methods) and of building material types (b) (see Table 4-3) are classified with regard to average emission levels of noise, dust and vibrations based to the generic five-stage emission level categories (see Table 4-12, Table 4-13, Table 4-14). Additionally, influencing factors of different basic unit sizes and deconstruction heights above ground on the average emission level are defined via an expert survey and consultations. Within this context, it is distinguished between two specifications of basic unit sizes (sz) (<= 160 kW/40 t; <160 kW/40 t) and two specifications of deconstruction heights above ground (hg) (<= 15 m; >15 m). Via experiments of experimental noise, dust and vibration measurements different combinations of the relevant deconstruction methods (see Table 2 2, white highlighted methods) and of building material types (b) (see Table 4-3) are relatively compared with each other in regard to their average emission levels of noise, dust and vibrations. The collection of primary data by an expert survey and consultations and experiments is described in detail in chapter 5, sections 5.2 and 5.3[95].

4.5.2.3 Activity-related specific hourly average emission level values

From the emission level classification numbers related to possible configurations of emission-influencing activity parameters (section 4.5.2.2), specific hourly average emission level values of noise, dust and vibrations related to these configurations are deducted. Therefore firstly, the generic literature-based, category-related

[94] The basis of the combinations of methods and materials is the feasibility of deconstruction methods related to the building component material (see section 4.4.1.2 and, table columns sb^{1}_{m} to sb^{10}_{m} in appendix A1). The classified combinations represent deconstruction activities performed with one basic unit of the size up to 160 kW/40 t and in heights above ground up to 15 m.

[95] Primary data collection (see chapter 5) was performed within the research project, this study is related to.

emission level intervals (section 4.5.2.1) are interpolated according to the nine-stage classification (0; 0.5; 1; 1.5;…; 4, see section 4.5.2.2). Generic emission level mean values for each of the nine classes are calculated (Table 4-15).

Table 4-15: Generic emission level mean values related to the emission level classes

Emission level classes	Emission level category	Emission level class mean values		
		db(A)	mg/m^3 inhalable dust (E-dust) concentration in the air	mm/s effective vibration speed
0	0	45	0.5	0.1
0.5	0-1	50	1	0.2
1	1	60	5.5	0.3
1.5	1-2	70	10	0.4
2	2	80	25	1
2.5	2-3	90	40	1.6
3	3	100	70	4
3.5	3-4	110	100	6.3
4	4	120	200	15.7

Secondly, these generic emission level mean values are assigning to the generated emission level classification numbers of activity parameter configurations (see section 4.5.2.2 and chapter 5, sections 5.2 and 5.3). This results in specific hourly average noise (λ^e(m,b,sz,hg)), dust (σ^e(m,b,sz,hg)) and vibration (ψ^e(m,b,sz,hg)) emission level values of the activity segments, the reference units, influenced by the method, material, basic unit size and height above ground.

Additionally, specific hourly emission level values of noise, dust and vibrations of those combinations with deconstruction modes with two parallel operating basic units are calculated. Within this context, firstly, the specific hourly emission level values of the combinations of different methods, building materials, equipment basic unit sizes and deconstruction heights above ground are doubled.[96] Secondly, each doubled specific hourly emission level value is converted into a nine-stage emission level classification number by rounding the value up/down to the next generic emission level mean value according to Table 4-15. Finally, specific noise, dust and vibration emission level values of those modes with two parallel operating basic units are gained by assigning again the generic emission level mean values to the converted emission level classification numbers. Tables with all activity-related specific hourly average emission level values of noise, dust and vibrations[97] related to all combinations of different modes, building materials, equipment basic unit sizes and deconstruction heights above ground are included in appendix A4.

4.5.3 Assessment of effects on the local environment

Based on the estimated emissions (see section 4.5.2), the temporary effects of on-site deconstruction processes on the local environment are assessed in terms of noise, dust and vibrations. Within this context, the environmental effects[98] are defined with the help of the 'EEA typology of indicators' and the 'DPSIR[99] framework', standardly used for environmental reports by the European Environmental Agency (EEA (1999). These environmental indicators are included into TEE-D-Plan to estimate and assess potential effects of noise, dust and vibrations on the local environment. The analysis of current approaches in section 3.3.2.1 shows that the few existing studies of

[96] The specific hourly dust and vibration emission level values are multiplied by two. The specific hourly noise emission level values are increased by 6 dB(A), which is the noise level increase due to two equipollent, coherent noise levels, according to Sengpiel (2016) (http://www.sengpielaudio.com/Rechner-kohquellen.htm).

[97] Specific hourly average noise emission level values: $\lambda^e_d(m,b,sz,hg)$, $\lambda^e_o(m,b,sz,hg)$, $\lambda^e_q(m,b,sz,hg)$; specific hourly average dust emission level values: ($\sigma^e_d(m,b,sz,hg)$, $\sigma^e_o(m,b,sz,hg)$, $\sigma^e_q(m,b,sz,hg)$; specific hourly average vibration emission level values: $\psi^e_d(m,b,sz,hg)$, $\psi^e_o(m,b,sz,hg)$, $\psi^e_q(m,b,sz,hg)$.

[98] Relationships between origins and consequences of environmental problems.

[99] DPSIR: Driving forces, Pressure, State, Impact, Response.

environmental assessment related to the three effects noise, dust and vibrations do not provide appropriate methods. Hence, to answer the research question, in the following new assessment methods are established for EIA in sections 4.5.3.1 and 4.5.3.2 and environmental indicators for noise, dust and vibration are defined in section 4.5.3.3.

4.5.3.1 Properties of environmental assessment methods

For environmental assessment, distinct temporary effects on the local environment caused by deconstruction projects have to be estimated. This is done with the help of quantitative environmental assessment methods, newly developed for the application in EIA. Within these methods, the impact distribution characteristics of the local environment between the emission source and the subject of protection have to be described. Moreover, the relevant subject of protection has to be identified. According to the definitions of EEA (1999), emissions in terms of substances released at the emission source are named ‘pressure’. ‘Pressure indicators’ are used to describe these pressures. Furthermore, changes of the state of the environment due to the ‘pressures’ on the environment are called ‘impacts’. ‘Impact indicators’ are used to describe these impacts[100].

Impact distribution characteristics

Deconstruction projects, which release pressures and cause impacts of noise, dust and vibrations on the local environment, especially take place in cities (see section 1.1). On the basis of VDI 3782-1:2016-01, VDI 3783-13:2010-01, DIN 18005-1:2002-07, DIN ISO 9613-2:1999-10[101], DIN 4150-1:2001-06, the following characteristics of the local

[100] In the context of this research, the impact indicator singly describes the change in the state of the environment and does not include the initial state of the environment before the pressure was released (see section 4.5.1).

[101] In Germany the 16th BImSchV (2014) refers to DIN ISO 9613-2:1999-10 related to the calculation of the distribution of nose impacts on the local environment caused by construction (respectively deconstruction) projects.

environment in cities mainly influence the impact distribution, which describes the relationship between the pressure indicator and the impact indicator:

- Characteristics of building structures of the neighbourhood.
- Characteristics of the environment in-between buildings.
- Meteorological conditions.

Meteorological conditions, such as the direction and speed of wind, air humidity, air pressure, precipitation and temperature, highly fluctuate within days and even hours. Hence, they are difficult to predict and they cannot be considered for future planning and decision making of deconstruction projects (IAQM (2014, p. 10)). Consequently, in this research only preliminary predictable impact distribution characteristics are considered. These neighbourhood-dependent impact distribution characteristics are (VDI 3783-13:2010-01, DIN 18005-1:2002-07, DIN ISO 9613-2:1999-10, DIN 4150-1:2001-06):

- Distance to the emission source, where the pressure is released: the distance between the building to be deconstructed, the deconstruction site, and other occupied buildings.
- Average building heights: average height of the building to be deconstructed and the buildings close to the site.
- Arrangement of buildings: the arrangement of buildings with respect to each other, including the building density.
- Soil and surface properties: soil and surface properties and vegetation in-between buildings.

The major preliminary predictable influence on impact mitigation states the distance to the emission source (VDI 3783-13:2010-01, DIN 18005-1:2002-07, DIN 4150-1:2001-06).

Subject of protection

According to §1BImSchG and Article (1) 2014/52/EU the relevant subjects of protection/the receptors of the local environment, are the people living/staying in buildings of the neighbourhood around the deconstruction site. Due to the distance to the emission source as the main impact mitigation influence, in this research the distinct impacts on these subjects of protection are assessed by calculating the impacts at the building/s with the least distance to the building to be deconstructed (see as well IAQM (2014, pp. 9, 10))[102]. To estimate the distinct impacts on the people of the neighbourhood, the subjects of protection, the identified, above listed mainly neighbourhood-dependent impact distribution characteristics are analysed in the following due to their shares in emission level reduction effects.

Distance to the emission source

The following shares in the emission level reduction effect related to the distinct impacts are assigned to the distance between the building to be deconstructed (where the pressure is released) and the closest occupied building/s (where the impact is the consequence of the pressure).

Noise: The share in the hourly average noise emission level reduction effect due to the distance ($\Delta\lambda^{er}$(dc)) in average dB(A)/h) is calculated based on Equation 2-1, according to DIN ISO 9613-2:1999-10, as part of attenuation of sound during propagation outdoors.

Equation 4-11: Distance-related share in the noise emission reduction effect

$$\Delta\lambda^{er}(\mathrm{dc}) = A_{div} - D_c = 20 \cdot log_{10}(\mathrm{dc}) + 11 - D_c \text{ [average dB(A)/h]}$$

[102] In contrast to IAQM (2014, p. 16), in this research it is not differentiated between different numbers of receptors for the definition of an area sensitivity, as deconstruction projects regularly take place in cities, where numerous people are living.

With

dc, distance between the building to be deconstructed and the closest occupied building/s [m]

A_{div}, absorption of noise due to geometry [average dB(A)/h]

D_c, parameter of the correction of sound radiation distribution dependent on the position of the emission source (Table 4-16) [103] [average dB(A)/h]

Table 4-16: Parameter D_c

Typical position of the noise emission (number of adjacent surfaces)	Noise distribution area	Sound radiation distribution correction parameter D_c [dB(A)] [average dB(A)/h]	Estimated level of noise reduction in dB(A) at the source (in 1 m distance of the source): 11dB(A) - D_c [dB(A)] [average dB(A)/h]
Totally free without an adjacent surface	Sphere	0	11
On the ground or at a wall (1 surface)	Hemisphere	3	8
On the ground and at a wall or at 2 walls (2 surfaces)	Quarter of a sphere	6	5
At an edge (3 surfaces)	Eighth of a sphere	9	2

In this research, pressure in terms of noise emissions by deconstruction projects is directly released at the building component to be deconstructed, where falling component pieces strike and at the engine of equipment (see section 2.2.2.1). Hence, the typical emission position is on the ground and at a wall, which represent two surfaces. This implies a noise distribution area of a quarter sphere and a noise

[103] D_C is calculated by conservatively assuming D_I (rate of the directional effect of a point source) to be 0. The value 11 of A_{div} implies totally free sound radiation distribution without an adjacent surface in form of a sphere.

reduction level at the source of 5 dB(A) (see Table 4-16). If the noise emission source is mainly at the building component and its position is high above the ground, a hemispheric noise distribution would infer a greater noise reduction level of 8 dB(A) (see Table 4-16). In this research, generally a noise reduction level of 5 dB(A) is conservatively assumed.

As stated in section 2.2.1.1, noise emission sources caused by deconstruction projects are defined as point sources. Additionally, further assumptions are made to apply Equation 2-1. Freely noise distribution is assumed between the emission source and the subject of protection. This is realistic, as the subject of protection is assigned to the building with the least distance. Hence, there is no building in between. Furthermore, as this research focuses on deconstruction projects in cities, the distance between the emission source and the subject of protection is usually less than 20 meters (see as well section 4.5.3.2, Table 4-17). Hence, this implies to neglect additional reduction effects, such as absorption of noise through the surface (A_{gr}), the air (A_{atm})[104] (Krämer (1998, p. 7), Krämer et al. (2004, p. 8), DIN ISO 9613-2:1999-10) and vegetation (A_{fol}) (DIN ISO 9613-2:1999-10; Prinz (1999, p. 166)). Consequently, the distance-related share in the hourly average noise emission level reduction effect ($\Delta\lambda^{er}(dc)$) is solely defined by the absorption of noise due to geometry (A_{div}) in this research.

Dust: The share in the hourly average dust emission level reduction effect due to the distance (dc) is nearly solely dependent on the direction and speed of wind. These are meteorological conditions, which are not considered in this study, as they cannot be included in future planning and decision making of deconstruction projects (see

[104] As well as absorption through meteorological conditions, which are in general not considered in this research.

above). Consequently, there is no distance-related share in the hourly average dust emission level reduction effect.

Vibration: The share in the hourly average vibration emission level reduction effect ($\Delta\psi^{er}$(dc,m,b,sz,hg) in average (mm/s)/h) due to the distance (dc) is calculated based on Equation 4-12 deducted from the transfer function T1 (the distribution of vibrations) according to DIN 4150-1: 2001-06.

Equation 4-12: Distance-related share in the vibration emission reduction effect

$$\Delta\psi^{er}(\mathrm{dc,m,b,sz,hg}) = \psi^{e}(\mathrm{m,b,sz,hg}) - \psi^{im}(\mathrm{dc,m,b,sz,hg}) = \psi^{e}(\mathrm{m,b,sz,hg}) \cdot \left(1 - \left(\frac{dc_1}{dc}\right)^{n^{ex}}\right) [\text{average (mm/s)/h}]$$

With

Ψ^{im}(dc,m,b,sz,hg), specific hourly average vibration impact level value of an activity segment (reference unit) [105] (the amplitude of the vibration speed at point of measurement) [average (mm/s)/h];

dc, distance between the subject of protection and the emission source [m];

dc_1, reference distance (assumed to be 0.5 m, at/close to the emission source) [m];

ψ^{e}(m,b,sz,hg), specific hourly average vibration emission level value of an activity segment (reference unit) (see section 4.5.2.3)[106] (amplitude

[105] The specific hourly average vibration impact level value of the deconstruction (ψ^{im}_{d}(dc,m,b,sz,hg)), material separation (ψ^{im}_{o}(dc,m,b,sz,hg)) or crushing (ψ^{im}_{q}(dc,m,b,sz,hg)) activity segment respectively.
[106] The specific hourly average vibration emission level values of the deconstruction (ψ^{e}_{d}(m,b,sz,hg)), material separation (ψ^{e}_{o}(m,b,sz,hg)) or crushing (ψ^{e}_{q}(m,b,sz,hg)) activity segment respectively.

of the vibration speed at the reference distance dc_1 (hence at the emission source) [average (mm/s)/h]

nv^{exp}, exponent according to DIN 4150-1: 2001-06, figure 1, which depends on the geometric and temporal emission source type and the oscillating wave type (nv^{exp}=1.0)[107].

Equation 4-12 is based on the reduction of the vibration speed due to geometry. The transfer function T1 of DIN 4150-1:2001-06 usually includes reductions of the vibration speed due to damping by the ground material as well. But additional reductions of the vibration speed due to damping by the ground material are neglected, as the distance between the emission source and the subjects of protection is relatively small[108] for deconstruction projects in cities. Furthermore, this is the the conservative assumtion. Hence, the distance-related share in the hourly average vibration emission level reduction effect ($\Delta\psi^e$(dc,m,b,sz,hg)) is solely defined by the geometric reduction of the vibration speed in this research.

Average building heights

The following shares in the hourly average emission level reduction effect related to the distinct impacts are assigned to the average heights of the building to be deconstructed and of the buildings close to the site.

The height of the building to be deconstructed describes the maximal drop height of a building component. In general, depending on the applied deconstruction technique, this drop height has an influence

[107] As stated in section 2.2.1.1, vibration emission sources caused by deconstruction projects are defined as point sources (geometric emission source type) and occur impulsively (temporal emission source type). The oscillating wave type can be specified as surface wave (Fritz and Schneider (2010, p. 19)). According to DIN 4150-1:2001-06, figure 1 these specifications result in nv^{exp}=1.0.

[108] Compare DIN 4150-1:2001-06 regarding distances.

on the pressures/the emission level of noise, dust and vibrations. This aspect is covered in section 4.5.2.2. Here the emission level classification numbers of activity parameter configurations are generated by considering the influence of different deconstruction heights above ground (hg) on the average emission levels.

Noise and dust: Besides the influence on the actual emission level, the height of the building to be deconstructed and the height of surrounding buildings have an influence on the distribution of noise and dust in terms of noise reflection and absorption and dust turbulences.

Noise reflection of the building to be deconstructed is already considered in the distance-related share in the noise emission reduction effect. It is considered by the noise distribution area of a quarter sphere and a noise distribution correction parameter (D_c) of 6 dB(A) (Table 4-16).

In general, the dispersion of dust is highly influences by the height of the emission above ground. But less than 20 meters above ground, which corresponds to usual deconstruction heights, particularly in cities, no dilution of dust in the ambient air is assumed in current research models (Notter (2015)). If the emission source is located high[109], noise and dust emissions can have cause an impact on the surrounding neighbourhood in further distances from the source. Nevertheless, the released substances in terms of sound pressure and dust concentration can disperse over a greater area. Therefore, the level of impact at a distinct distance is less than the impact levels at the closest building and related to impact distribution in-between buildings. Hence, conservatively assumed, in-between building impact distribution, including reflection, absorption and turbulences, is considered to define the impact level at the building with the least

[109] For instance, the emission source of the deconstruction of upper building components of a high building is located high.

distance. The handling of these influences within this study is described below related to building arrangement characteristic and the effect is assigned to the arrangement-related share in the emission reduction effect. Consequently, there are no height-related shares in hourly average noise and dust emission level reduction effects.

Vibration: Besides the influence on the actual emission level, the height of the building to be deconstructed and the height of surrounding buildings have no relevant influence on the distribution of vibration impacts. Hence, there is no height-related share in the hourly average vibration emission level reduction effect.

Arrangement of buildings

The following shares in the hourly average emission level reduction effect related to the distinct impacts are assigned to the arrangement of buildings to each other, including the building density.

Noise: The influences of the building arrangement with respect to each other on noise distribution are noise reflection and absorption. To quantify the share in the emission level reduction effect[110] by these influences, especially the surface material, size, orientation, number and distance of reflecting/absorbing objects around the emission source and facing the subject of protection are relevant (DIN ISO 9613-2:1999-10; DIN 18005-1:2002-07; due to surface material: Sälzer (1982, S. 45); due to orientation: Schreiber (1971, S. 40)). In cities reflecting/absorbing objects are synonymous with exterior walls. Therefore in this research, reflecting/absorbing objects are exterior building walls next to the deconstruction site and facing to the building[111] with the least distance to the building to be deconstructed.

[110] The share can be negative or positive.
[111] The people living and staying in this building are the subject of protection.

The surface material of building exterior walls specifies the degree of sound reflection/absorption, expressed by a reflection/absorption coefficient (Deng et al. (2015), DIN ISO 9613-2:1999-10). The absorption coefficient is the difference of unity minus the reflection coefficient and vice versa. In this study the reflection coefficient (rc) of the surface material of all exterior walls is conservatively assumed to be unity according to the reflection coefficient of hard and plain walls in DIN ISO 9613-2:1999-10. Hence, the noise level is totally reflected by the wall and increases the level of noise at the subject of protection. The reflected noise level ($\lambda^{e,ref}$(rc,m,b,sz,hg)) for the specific hourly average noise emission level values of the activity segments, the reference units (see section 4.5.2.3), is calculated according to DIN ISO 9613-2:1999-10 based on Equation 4-13, representing the noise emission level of one/each reflecting exterior wall.

Equation 4-13: Noise level of one reflecting exterior wall for the specific hourly average noise emission level value of an activity segment[112]

$$\lambda^{e,ref}(rc,m,b,sz,hg) = \lambda^{e}(m,b,sz,hg) + 10 \cdot \log(\mathrm{rc}) + D_{I,rc}$$

[average dB(A)/h]

With

rc, reflection coefficient (rc=1, as stated above)

$D_{I,rc}$, rate of the directional effect of the noise reflecting object ($D_{I,rc}$ = 0, conservatively assumed, following DI = 0 (the rate of the directional effect of a point source), defined above)

[112] Equation applies to the calculation of the noise level of one reflecting exterior wall for the specific hourly average noise emission level values of the deconstruction (λ^{e}_{d}(m,b,sz,hg)), material separation (λ^{e}_{o}(m,b,sz,hg) or crushing (λ^{e}_{q}(m,b,sz,hg)) activity segments respectively.

$\lambda^{e}(m,b,sz,hg)$, specific noise emission level value of the activity segment, the reference unit (see section 4.5.2.3)

Consequently, the noise emission level of each reflecting exterior wall ($\lambda^{e,ref}(rc,m,b,sz,hg)$)[113] is equal to the specific hourly average noise emission level value ($\lambda^{e}(m,b,sz,hg)$)[114] caused by the activity segment of the deconstruction project.

The size of building exterior walls influences the possibility that noise is reflected by a wall. The bigger the wall, the higher is the probability that the incident ray directly meets the surface and is reflected. Furthermore, the specific wall orientation defines the direction of reflection. Within this context the angle of incidence is equal to the angle of radiation (DIN ISO 9613-2:1999-10). Hence, the wall orientation determines, if the reflected ray directly (versus indirectly) increases the noise level at the subject of protection. As indirect reflection is possible as well, in this research the size and specific orientation of walls are neglected to identify the number and related distances of relevant exterior building walls according to the subject of protection.

Thus, the number of reflecting objects is equal to all walls adjacent to the emission source at the building to be deconstructed and facing to the subject of protection. Furthermore, the distance of each relevant exterior wall to the subject of protection influences the increase of the noise level at the subject of protection. In this research the distance of all relevant exterior walls conservatively equates with the distance of the closest building to the building to be deconstructed.

As a result, the arrangement-related share in the noise emission level reduction effect is negative and increases the noise impact level at the

[113] $\lambda^{e,ref}{}_{d}(rc,m,b,sz,hg)$, $\lambda^{e,ref}{}_{o}(rc,m,b,sz,hg)$ or $\lambda^{e,ref}{}_{q}(rc,m,b,sz,hg)$ respectively.
[114] $\lambda^{e}{}_{d}(m,b,sz,hg)$, $\lambda^{e}{}_{o}(m,b,sz,hg)$ or $\lambda^{e}{}_{q}(m,b,sz,hg)$ respectively.

subject of protection. It is calculated by the noise level increase ($\Delta\lambda^{er}(n^l)$) due to the number of equipollent, coherent[115] noise levels (n^l) (Equation 4-14) (Sengpiel (2016)) caused by the emission source and the reflection from (n^l-1) exterior building walls, which are identified to be relevant.

Equation 4-14: Arrangement-related share of noise level reduction

$$\Delta\lambda^{er}(n^l) = -20 \cdot log_{10}(\mathrm{n}^l) \text{ [dB(A)]}$$

Dust: The influence of buildings and building arrangements on dust distribution is described by ‘surface roughness’ (VDI 3782-1:2016-01) or ‘complex terrains’ (VDI 3783-13:2010-01) (besides the influence of the height above ground of the dust emission source, described above). These influences result in highly fluctuating wind and turbulence fields. These are meteorological conditions, which cannot be considered in ahead planning and decision making of deconstruction projects (see above). Consequently, there is no building-arrangement-related share in the dust emission reduction effect.

Vibration: Predictions on the influence of the arrangement of buildings on the distribution of vibration impacts (e.g. due to basement floors) would imply experimental on-site studies in the individual case. Nevertheless, due to the general short distance between the emission source and the subject of protection in cities, freely vibration

[115] The noise emission level of the deconstruction-related source and the reflected noise emission levels are assumed to be coherent noise levels, as they are equal in terms of their sound wave shapes due to the same source. Differences in the noise level (amplitude) and the phase have no influence on the coherence of noise levels. Furthermore, respective calculation of the arrangement-related noise level reduction share is the conservative assumption, as the noise level increase based on coherent noise levels is higher than the increase based on incoherent noise levels (Sengpiel (2016)).

distribution is assumed in this research and there is no building-arrangement-related share in the hourly average vibration emission level reduction effect.

Soil and surface properties

As stated above, in general the distance between the emission source and the subject of protection is small. Therefore, additional reduction effects, such as absorption of noise through ground surface properties (Krämer (1998, p. 7), Krämer et al. (2004, p. 8), Sälzer (1982, p. 42)) and vegetation (Prinz (1999, p. 166), DIN ISO 9613-2:1999-10) and vibration damping depending on the ground material (DIN 4150-1:2001-06) are neglected. Furthermore, similar to the characteristic of building arrangements, surface and vegetation properties, described by 'surface roughness' (VDI 3782-1:2016-01, VDI 3783-13:2010-01), have an effect on dust distribution in the form of highly fluctuating turbulences via meteorological conditions. For instance, according to VDI 3782-1:2016-01 and VDI 3783-13:2010-01 the surface roughness has an impact on the wind profile, especially the wind speed. Summing up, there are no surface-related shares in noise, dust and vibration emission reduction effects included in this research.

Overall, the noise emission level reduction effect includes the distance-related ($\Delta\lambda^{er}(dc)$) and arrangement-related ($\Delta\lambda^{er}(n^{l})$) share. All shares in the dust emission reduction effect are zero due to the high dependence on fluctuating meteorological conditions. Consequently, the level of impact at the subject of protection is equal to the emission level. The vibration emission level reduction effect consists of the distance-related share ($\Delta\psi^{er}(dc,m,b,sz,hg)$).

For noise and vibrations, the result of the specific hourly average emission level values caused by the activity segment in different modes, minus the defined respective shares in the emission reduction effects are specific hourly average impact level values at the subject of protection related to the single activity segments (reference units). For dust, no dust emission reduction effects are included. The specific hourly average dust emission level values caused by the activity segment in different modes are the basis for environmental assessment. Consequently, in this research environmental assessment is performed on the basis of noise and vibration impact levels and dust emission levels. According the ‘typology of indicators’ of EEA (1999), noise and vibration impact levels are defined as ‘impact indicators’ and dust emission levels are defined as ‘pressure indicators’ for EIA. The calculation of these impact indicators and the pressure indicator is described in section 4.5.3.3.

4.5.3.2 Alternatives of impact estimation

To estimate the noise and vibration impacts on the subject of protection within EIA, two alternative approaches are proposed in this study. The choice of one of these two alternatives depends on related available information for the decision maker to define the single shares in the emission level reduction effects outlined above. Namely information on:

1. The distance between the subject of protection and the deconstruction-related emission source. Hence the distance (dc) of the deconstructed building and the closest occupied building/s to this building, to calculate
   - the distance-related share in the noise emission level reduction effect ($\Delta\lambda^{er}(dc)$) and
   - the distance-related share in the vibration emission level reduction effect ($\Delta\psi^{er}(dc,m,b,sz,hg)$).
2. The number of reflecting objects (n^{l}-1)/the number of relevant exterior building walls adjacent to the building to be deconstructed and facing the subject of protection, to estimate the arrangement-related share in the noise emission level reduction effect ($\Delta\lambda^{er}(n^{l})$).

If this specific information is available, emission level reduction effects and resulting noise and vibration impacts on the subject of protection are individually calculated based on Equation 2-1, Equation 4-12 and Equation 4-14. If not so, a so called 'neighbourhood typology' including diverse types of building structures and settlement patterns with defined impact distribution characteristics is applied to calculate the emission level reduction effects and resulting distinct impacts on the local environment. Depending on major building structures and settlement patterns of the site surrounding neighbourhood, the actual deconstruction project is assigned to a neighbourhood type in the planning and decision phase. The neighbourhood typology is developed in the following.

In general, urban areas with similar building structures and settlement patterns are defined as housing schemes[116]. Forms of housing schemes can be combined to types of housing scheme forms. According to Koch and Jenssen (2010, p. 7) types of housing scheme forms are used to describe similar building structures and recurring settlement patterns and to classify urban areas respectively. In the following, types of housing scheme forms are named 'neighbourhood types'. A neighbourhood typology including diverse neighbourhood types is developed as an alternative to estimate the distinct impacts on the local environment in this study. For each type, the relevant subject of protection and the relevant neighbourhood-dependent impact distribution characteristics, the distance to the emission source (dc) and the number of reflecting objects (n^l-1), are identified. In the research project this thesis is based on a neighbourhood typology for impact estimation in German cities is developed based on a literature review of existing neighbourhood typologies[117], structural

[116] Duden (2016): http://www.duden.de/rechtschreibung/Siedlung. Bibliographisches Institut GmbH, accessed 07.05.2016.
[117] The first German neighbourhood typology, including nine different neighbourhood types, was developed by Roth (1980) by analysing diverse maps of settlement patterns of different German municipalities. This basic typology was further developed by

definitions of construction-related legislations and standards and the analysis of single maps of settlement patterns.

Subject of protection

The relevant subjects of protection in the typology are the people living/staying in buildings of the neighbourhood around the deconstruction site, according to the definition in section 4.5.3.1. The distinct impacts on these subjects of protection are assessed by calculating the impacts at the building/s with the least distance to the building to be deconstructed.

Distance to the emission source

The minimal distance between the building to be deconstructed, the deconstruction site, and other occupied buildings in the neighbourhood is defined as the distance to the emission source of each neighbourhood type according to the settlement patterns. In the neighbourhood typologies of Blesl (2002) and Neuffer et al. (2001) an average distance between the building and the street is stated. But the distance between buildings is not outlined in the examined existing typologies. Hence, the minimal distance between buildings is determined according to legally defined minimal spacing between buildings and property boundaries according to the state building

refining the level of detail and adopting types related to temporal developments, for instance by Hegger and Dettmar (2014), Erhorn-Kluttig et al. (2011), Neuffer et al. (2001), Blesl (2002) and Winkens (1994). The level of detail of all these typologies is above the level of a single building. But they use the structure of single buildings as well as the arrangement of buildings with respect to each other to classify neighbourhood types and afterwards to assign existing neighbourhoods to the types (Erhorn-Kluttig et al. (2011, p. 32)). As these existing neighbourhood typologies are especially developed for building-energy-related analysis and they are not directly transferable for impact assessment in the context of this study, a new typology has to be developed for the purpose of this research.

code of Baden-Württemberg[118] (§5para.7 LBO BW (2014)). In this context, the minimal spacing between buildings and property boundaries is calculated by multiplying the average height of the building exterior walls[119] with the factor 0.4. For the neighbourhood types city centre, village area and special residential area the factor is 0.2. And for trade and industrial areas it is 0.125. In general, the minimal distance between buildings and property boundaries has to be at least 2.5 meters. In the case of deconstruction of twin and terraced houses, it is assumed that directly adjacent buildings are vacant. Thus, the subject of protection is still assigned to the building with the least distance to the building to be deconstructed.

The minimal distance between buildings and property boundaries according to §5para.7 LBO BW (2014) is defined by the average height of the building to be deconstructed and of the buildings close to the site. Therefore, an average height of exterior walls of all buildings within a neighbourhood is defined for each neighbourhood type. The average number of building story proper and the typical building types within a neighbourhood type, which are stated in existing neighbourhood typologies (Hegger and Dettmar (2014), Erhorn-Kluttig et al. (2011), Blesl (2002) and Neuffer et al. (2001)), are used to determine an average height of exterior walls based on average building-type-dependent building level heights defined by (Mannek (2011, pp. 133 et seq.)).

[118] There are different state building codes for each state, which can also little differ in their definitions of minimal spacing between buildings. For this study the state building code of the state Baden-Württemberg is taken.

[119] The height of the building exterior walls is calculated according to §5para.4 LBO BW (2014). Here the height is the distance between the intersection of the wall and the topographic surface and the intersection of the wall and the roof (related to flat roofs) or the upper end of the wall. For the typology the height of building exterior walls within each neighbourhood type is determined based on average building level heights of isolated or middle houses related to building types according to Mannek (2011, p. 133et seq.).

Number of reflecting objects

The number of relevant exterior walls, which especially have an influence on the noise level at the subject of protection, is partly influenced by the building density. The density is defined in some existing neighbourhood typologies through the site occupancy ratio (GRZ) per neighbourhood type (Hegger and Dettmar (2014), Roth (1980)). To identify the number of relevant exterior walls for each neighbourhood type, the arrangement of buildings within a neighbourhood type are analysed with the help of 3D-maps of the single neighbourhood types (3D building block models) within the research, this study is related to. These maps are created based on minimal building-type-dependent land areas (Prinz (1999, p. 194)), legally defined minimal spacing between buildings and property boundaries according to §5para.7 LBO BW (2014) and on neighbourhood type-specific average buildings areas (Neuffer et al. (2001), Blesl (2002)), site occupancy ratios (GRZ) per neighbourhood type (Hegger and Dettmar (2014), Roth (1980)), average distances between buildings and streets (Blesl (2002), Neuffer et al. (2001)) and illustrations of neighbourhood types of Erhorn-Kluttig et al. (2011)).

In Table 4-17 the developed neighbourhood typology with the relevant neighbourhood-dependent impact distribution characteristics (Kühlen et al. (2016a)) is summarised as they are stored in the database of TEE-D-Plan (within Module 1).

Table 4-17: Neighbourhood typology[120]

Type of neighbourhood structure			Neighbourhood-dependent impact distribution characteristics	
Denotation	**Name**	**Characteristics**	**Distance to the emission source [m]**	**Amount of reflecting objects [amount]**
ST 1	Open low-density areas (scattered settlement)	Scattered low- density areas, mainly on the outskirts and in drawn- out street villages	5	3
ST 2	Settlement of single family houses and duplex houses	Suburbs, usual with a dense geometric route network	5	5
ST 3a	Urban village centre	Village structure without a centre, remaining in medium-sized cities or in subcities	5	5
ST 3b	Rural village centre	Village centre in rural areas or in small incorporations	5	5
ST 4	Terraced houses	Dense geometric developped estate of terraced houses	5	6
ST 5a	Settlement of small apartment blocks	Small apartment blocks, usual with a dense geometric route network (since the middle of the 1980's)	7	4
ST 5b	Ribbon development wih small and bigger apartment blocks	mainly medium-sized residential areas, relatively short distance between buildings, relatively wide meshed route network	7	4
ST 6	Ribbon development with big aparment blocks and high-rise buildings	Big apartment blocks/ high- rise buildings with large distances in between	14.5	3
ST 7a	Block development with low density	mainly in large cities, development on the outskirts, regular road network	5	5
ST 7b	Block development with high density	mainly in large cities, development on the outskirts, regular road network with overbuilt courtyards	5	6
ST 8	City development	City development with overbuilt courtyards (at the turn of the century)	5	7
ST 9	Historic old town	Medieval city centre, high density, closed development, winding streets	5	7
ST 10a	Public special constructions (big)	Big individual buildings, unusual floor plans, mainly free-standing, often in large cities (e.g. hospitals, university)	9.5	3
ST 11b	Commercial special construcions/ service buildings	Industrial buildings with unusual floor plans without process heat demand	5	3

For each deconstruction project the decision maker can select one of the neighbourhood structure types of Table 4-17 via the user interface of TEE-D-Plan. Then, the emission level reduction effects and resulting distinct noise and vibration impacts on the subject of protection are calculated based on the neighbourhood-dependent impact

[120] Kühlen et al. (2016a).

distribution characteristics connected to the selected neighbourhood structure type.

4.5.3.3 Impact and pressure indicators for EIA

By applying the newly established environmental assessment methods, dust pressures and noise and vibration impacts on the local environment are modelled. In this context, the activity (segment)-related specific hourly emission level values of noise, dust and vibrations are converted to the indicator results. The indicators reflect the potential impacts of noise and vibrations and the potential dust pressures on the local environment[121] caused by deconstruction projects themselves. Hence, as stated in section 4.5.1, initial impact levels of noise, dust and vibrations, which depend on the ambient conditions and can vary over time, are not considered in the environmental assessment of this research.

To quantify the potential distinct pressures on and impacts at the subject of protection for environmental assessment, firstly, the specific hourly emission and impact level values related to the single activity segments in different modes (reference units) have to be estimated. Secondly, the duration of these pressures and impacts has to be considered. Thereby, the pressure/impact duration is directly connected to the duration of the durations of the single deconstruction activity segments ($p_{dj,m}(sz)$, $p_{oj,m}$, $p_{zj,m}$) and of the project activities ($p_{j,m}(sz)$) in different modes and durations of the phases of different alternatives ($p_{g,msg}(sz)$) (see section 4.4.2.1). This result in duration-based average emission and impact level values related to single activities in different modes and to building phases of different alternatives. In the following, these values are also called activity- and phase-related average emission/impact level values. Thirdly, the

[121] The local environment, the subject/s of protection, is/are the people of the neighbourhood in the building/s with the least distance to the building to be deconstructed.

phase-related average emission/impact level values are converted into phase-related nine-stage percentage emission levels of dust and impact levels of noise and vibrations according to the nine emission level classes (Table 4-15).

Specific hourly emission and impact level values

The specific hourly average noise and vibration impact level values related to the single activity segments state the difference of the specific hourly average emission level values caused by the activity segment[122] minus respective shares in the emission level reduction effects[123] (Equation 4-15, Equation 4-16). The equations show that the specific hourly average noise ($\lambda^{im}(dc,n^l,m,b,sz,hg)$) and vibration ($\psi^{im}(dc,m,b,sz,hg)$) impact level values of an activity segment (d_j, o_j, q_j) depend on the mode, material, basic unit size and height above ground[124] and on the distance to the emission source, the number of reflecting objects[125].

Equation 4-15: Specific hourly average noise impact level value[126]

$$\lambda^{im}(dc,n^l,m,b,sz,hg) = \lambda^e(m,b,sz,hg) - \Delta\lambda^{er}(\mathrm{dc}) - \Delta\lambda^{er}(n^l)$$

[average dB(A)/h]

---

[122] Specific hourly average noise emission level values: $\lambda^e_d(m,b,sz,hg)$, $\lambda^e_o(m,b,sz,hg)$, $\lambda^e_q(m,b,sz,hg)$; specific hourly average vibration emission level values: $\psi^e_d(m,b,sz,hg)$, $\psi^e_o(m,b,sz,hg)$, $\psi^e_q(m,b,sz,hg)$.

[123] Shares of the noise emission level reduction effect: $\Delta\lambda^{er}(dc)$, $\Delta\lambda^{er}(n^l)$; shares of the vibration emission level reduction effect: $\Delta\psi^{er}(dc,m,b,sz,hg)$.

[124] As shown by the equation, the dependence of impact levels on the mode m, material b, basic unit size sz and height above ground hg is related to the specific hourly emission level values.

[125] The dependence of impact levels on the number of reflecting objects is related to the emission reduction effects.

[126] Equation applies to $\lambda^{im}_d(dc,n^l,m,b,sz,hg)$, $\lambda^{im}_o(dc,n^l,m,b,sz,hg)$ and $\lambda^{im}_q(dc,n^l,m,b,sz,hg)$ with $\lambda^e_d(m,b,sz,hg)$, $\lambda^e_o(m,b,sz,hg)$ and $\lambda^e_q(m,b,sz,hg)$ respectively.

Equation 4-16: Specific hourly average vibration impact level value[127]

$$\psi^{im}(dc,m,b,sz,hg) = \psi^{e}(m,b,sz,hg) - \Delta\psi^{er}(\mathrm{dc,m,b,sz,hg})$$
[average (mm/s)/h]

As described in section 4.5.3.1, no dust emission reduction effects are included in this reseach. Hence, the specific hourly average dust emission level values caused by the activity segment[128] are the basis for the environmental assessment. These specific hourly average dust emission level values (σ^{e}(m,b,sz,hg), in average (mg/m^3)/h) of an activity segment (d_j, o_j, q_j) depend on the mode, material, basic unit size and height above ground.

Activity-related and phase-related average emission/impact level values

Phase-related average emission/impact level values of each phase alternative enable the consideration of emission/impact durations. To calculate the phase-related average emission/impact level values, firstly, activity-related average emission/impact level values of noise, dust and vibrations of each activity mode are calculated over all activity segments (d_j, o_j, q_j) via the specific hourly average emission/impact level values[129] and the durations of the single activity segments ($p_{dj,m}$(sz), $p_{Oj,m}$, $p_{zj,m}$) and of the activities ($p_{j,m}$(sz)). Within this context, the activity-related average noise impact level value ($lim_{j,m}$(dc,n^l,sz)) is calculated according to equation (7) of the time-average sound pressure level (L_{eq}) of DIN 45641:1990-06 (Equation

[127] Equation applies to ψ^{im}_{d}(dc,m,b,sz,hg), ψ^{im}_{o}(dc,m,b,sz,hg) and ψ^{im}_{q}(dc,m,b,sz,hg) with ψ^{e}_{d}(m,b,sz,hg), ψ^{e}_{o}(m,b,sz,hg) and ψ^{e}_{q}(m,b,sz,hg) respectively.
[128] Specific hourly average dust emission level values: σ^{e}_{d}(m,b,sz,hg), σ^{e}_{o}(m,b,sz,hg), σ^{e}_{q}(m,b,sz,hg).
[129] Specific hourly average noise impact level values: λ^{im}_{d}(dc,n^l,m,b,sz,hg), λ^{im}_{o}(dc,n^l,m,b,sz,hg), λ^{im}_{q}(dc,n^l,m,b,sz,hg); specific hourly average dust emission level values: σ^{e}_{d}(m,b,sz,hg), σ^{e}_{o}(m,b,sz,hg), σ^{e}_{q}(m,b,sz,hg); specific hourly average vibration impact level values: ψ^{im}_{d}(dc,m,b,sz,hg), ψ^{im}_{o}(dc,m,b,sz,hg), ψ^{im}_{q}(dc,m,b,sz,hg).

4-17). This is also the basis of legal noise impact guideline values related to the evaluation of environmental impacts due to different neighbourhood usage types according to BauNVO (2013). L_{eq} is a representative value for noise levels over a period of time (Deng et al. (2015)). The activity-related average dust emission level value ($sim_{j,m}(sz)$) is the arithmetic mean of the duration-related dust emission level values of the single activity segments (Equation 4-18). And the activity-related average vibration impact level value ($vim_{j,m}(dc,sz)$) is the arithmetic mean of the duration-related vibation impact level values of the single activity segments (Equation 4-19).

Equation 4-17: Activity-related average noise impact level value[130]

$$lim_{j,m}(dc, n^l, sz) = 10 * log_{10}\left(\frac{1}{p_{j,m}(sz)} * \sum\nolimits_{i(d_j,o_j,q_j)}\left(10^{\frac{\lambda_i^{im}(dc,n^l,m,b_j,sz,hg_j)}{10}} * p_{i,m}(sz)\right)\right)$$

[dB(A)]

Equation 4-18: Activity-related average dust emission level value

$$\text{sim}_{j,m}(sz) = \frac{1}{p_{j,m}(sz)} * \sum\nolimits_{i(d_j,o_j,q_j)}\left(\sigma_i^e\left(m, b_j, sz, hg_j\right) * p_{i,m}(sz)\right)$$

[g/m³]

Equation 4-19: Activity-related average vibration impact level value

$$\text{vim}_{j,m}(\text{dc}, \text{sz}) = \frac{1}{p_{j,m}(sz)} * \sum\nolimits_{i(d_j,o_j,q_j)}\left(\psi_i^{im}\left(dc, m, b_j, sz, hg_j\right) * p_{i,m}(sz)\right)$$

[mm/s]

130 According to equation (7) of the time-average sound pressure level (L_{eq}) of DIN 45641:1990-06.

Secondly, phase-related average emission/impact level values of noise, dust and vibrations of each alternative of the project-phase-related mode-series ms_g (see section 4.3.2.4) are calculated. They are calculated over all activities j_g (j_g=1-J_g, with J_g= {1-6}) of the phase g via the activity-related average emission/impact level values of noise, dust and vibrations[131], the project activity durations ($p_{jg,m}(sz)$) and the phase duration ($p_{g,msg}(sz)$). In the style of the calculation of the activity-related average impact level values, the phase-related average noise impact level value of each alternative ($lim_{g,msg}(dc,n^l,sz)$) is calculated according to equation (7) of the time-average sound pressure level (L_{eq}) of DIN 45641:1990-06 (Equation 4-20). The phase-related average dust emission level value ($sim_{g,msg}(sz)$) is the arithmetic mean of the duration-related dust emission level values of the phase activities (Equation 4-21). And the phase-related average vibration impact level value ($vim_{g,msg}(dc,sz)$) is the arithmetic mean of the duration-related vibration impact level values of the phase activities (Equation 4-22).

Equation 4-20: Phase-related average noise impact level value[132]

$$lim_{g,ms_g}(dc,n^l,sz) = 10 * log_{10}\left(\frac{1}{p_{g,ms_g}(sz)} * \sum_{j_g=1}^{J_g} \sum_{m=1}^{M_{j_g}} \left(10^{\frac{lim_{g,ms_g}(dc,n^l,sz)}{10}} * p_{g,ms_g}(sz)\right) * z_{j_g,m}\right) \text{[dB(A)]}$$

[131] $lim_{j,m}(dc,n^l,sz)$, $sim_{j,m}(sz)$, $vim_{j,m}(dc,sz)$.

[132] According to equation (7) of the time-average sound pressure level (L_{eq}) of DIN 45641:1990-06.

Equation 4-21: Phase-related average dust emission level value

$$\mathrm{sim}_{g,ms_g}(sz) = \frac{1}{p_{g,ms_g}(sz)} * \sum_{j_g=1}^{J_g} \sum_{m=1}^{M_{j_g}} \left(sim_{g,ms_g}(sz) * p_{g,ms_g}(sz) \right) * z_{j_g,m} \text{ [g/m}^3\text{]}$$

Equation 4-22: Phase-related average vibration impact level value

$$\mathrm{vim}_{g,ms_g}(\mathrm{dc},\mathrm{sz}) = \frac{1}{p_{g,ms_g}(sz)} * \sum_{j_g=1}^{J_g} \sum_{m=1}^{M_{j_g}} \left(vim_{g,ms_g}(dc,sz) * p_{g,ms_g}(sz) \right) * z_{j_g,m} \text{ [mm/s]}$$

With

$z_{jg,m}$: binary variable (1, if activity j_g is performed in mode m; 0, else)

$\sum_{m=1}^{M_{j_g}} z_{j_g,m} = 1$ (to ensure that one activity is performed exactly once in a phase/phase-related mode-series alternative).

Phase-related nine-stage percentage emission/impact levels

Phase-related nine-stage percentage emission/impact levels state the pressure respectively impact indicators, the potential impacts of noise and vibrations and the potential dust pressures on the local environment caused by deconstruction projects, for the environmental assessment of deconstruction projects. To gain these indicators, the phase-related average emission/impact level values[133] are converted into phase-related average nine-stage percentage emission/impact levels of noise, dust and vibrations ($pc^{lim}_{g,msg}(dc,n^l,sz)$,

[133] $lim_{g,msg}(dc,n^l,sz)$, $sim_{g,msg}(sz)$, $vim_{g,msg}(dc,sz)$.

$pc^{sim}_{g,msg}(sz)$, $pc^{vim}_{g,msg}(dc,sz)$). The conversion is based on the nine emission level classes, specified in section 4.5.2.3 (Table 4-15). Within this context, nine percentage emission/impact levels and related emission/impact level value intervals are defined (Table 4-18) in dependence of the nine emission level classes and the related generic emission level mean values.

Table 4-18: Percentage emission/impact levels and related emission/impact level value intervals

Emission / impact level classes	Percentage emission / impact levels ($pc^{lim}/pc^{sim}/pc^{vim}$)	Intervals of emission / impact level values					
		lim [db(A)]		sim [mg/m³, inhalable dust (E-dust) concentration in the air]		vim [mm/s, effective vibration speed]	
		lower bound (>=)	upper bound (<)	lower bound (>=)	upper bound (<)	lower bound (>=)	upper bound (<)
0	0	0	47,5	0	0,75	0	0,15
0.5	0.125	47,5	55	0,75	3,25	0,15	0,25
1	0.25	55	65	3,25	7,75	0,25	0,35
1.5	0.375	65	75	7,75	17,5	0,35	0,7
2	0.5	75	85	17,5	32,5	0,7	1,3
2.5	0.625	85	95	32,5	55	1,3	2,8
3	0.75	95	105	55	85	2,8	5,15
3.5	0.875	105	115	85	150	5,15	11
4	1	115	∞	150	∞	11	∞

Based on the intervals the phase-related average emission/impact level values are assigned to the percentage emission/impact levels, resulting in phase-related nine-stage percentage emission/impact levels.

In summary, for EIA first potential emissions of deconstruction projects are quantitatively estimated based on single deconstruction activities/activity segments and their alternatives (see section 4.5.2). Then the effects on the local environment are assessed by using pressure and impact indicators. Within this context, average noise and vibration impact levels and dust emission levels are quantitatively estimated (see section 4.5.3). The results of EIA are included in the newly developed model TEE-D-Plan. Within this context, the EIA results are the output of Module 1 and the input for Module 2 of the model.

From the environmental perspective, the overall effects on the local environment caused by the deconstruction project, examined across all project phases, should be limited. Additionally, defined legal limits depending on the usage of the neighbourhood should be met, so that the health and safety of the subjects of protection in the local environment can be guaranteed. As stated above, in this study the relevant subjects of protection according to §1BImSchG are the people living/staying in the building/s, assigned to the buildings with the least distance to the building to be deconstructed. Respective applied deconstruction project planning and decision support within Module 2 due to multi-objectives is described in chapter 6.

5 Database-structure and primary data collection

The database-based storage and provision of data and information within the model for technical, economic and environmental deconstruction project planning and decision support (TEE-D-Plan) and the collection of required primary data is described in this chapter.

Firstly, in section 5.1 the database structure is depicted. Then the two approaches of primary data collection and data preparation are outlined. Within this context, in section 5.2 an expert survey and consultations and in section 5.3 the experiments in the form of experimental noise, dust and vibration measurements are described.

5.1 Database elements and structure

The central data management of the overall model, TEE-D-Plan, encompassing Module 1 and Module 2, is provided by a relational database developed in the software Microsoft Access (MS Access). All data and information used and calculated in database-based deconstruction planning for environmental assessment (Module 1) are stored in and are provided by this database for resource-, space and impact-constrained deconstruction project planning and decision support due to multi-objectives (Module 2).

Within this context, in Module 1 the basic data of the database is accessed for the creation of the model framework of Module 1 (section 4.3) and the technical, economic and environmental assessment of the phase-related deconstruction alternatives (sections 4.4 and 4.5). Then the results of Module 1 are stored in the database for use in Module 2, which is further described in chapter 6. Furthermore, the database enables the connection between the single model layers illustrated in Figure 4-2, namely user input, analysis in Module 1 and 2 and model output.

By MS Access and programming in the scripting language Visual Basic for Applications (VBA) data of the database are physically described. Relations between data are formalised via an entity-relationship model (ER model) (Chen (1976)). In ER models, similar items are combined in one entity type defined by attribute combinations. Thereby, entities of one type have the same attributes and the value of these attributes can differ. Entities of different types differ in their attributes, show different attribute combinations. The attributes and related notions, value ranges, units and sources of most entity types of the database are already specified in sections 4.3 to 4.5.

For instance, building shell component is an entity type. Attributes/combination of attributes of this entity type are/is specified in Table 4-4. For example, a specific building outer wall (c) is one entity of this entity type. Single entities are related to each other. Entities and their relationships are both modelled as entities in the relational database. These entities are specified a relation over the value ranges of the attributes of the respective entity type. Hence, relations are illustrated as two-dimensional tables. The table columns capture the attribute names and the table rows contain the attribute values (the order of attributes and of rows has no meaning). Hence, each table row is an element of the relation, defined by the table. The structure of the relational database of this study is shown in Figure 5-1 based on selected significant tables and links. For clarity, a more detailed graphic, including all 99 tables of the database and related links, is omitted.

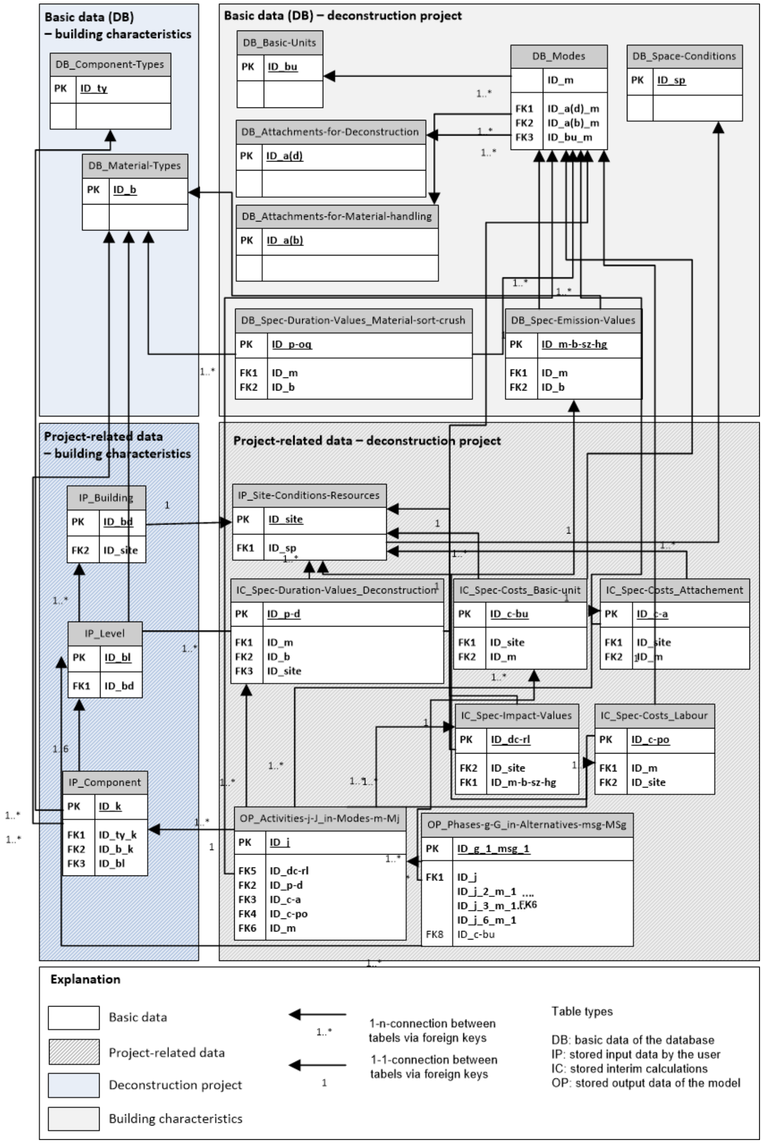

Figure 5-1: Overview of the database structure based on selected significant tables, attributes and links

The comprehensive basic data of the database is developed based on primary data and literature, as presented in the previous sections 4.3 to 4.5. Especially emission level classification numbers of noise, dust and vibrations related to possible configurations of emission-influencing activity parameters (see section 4.5.2.2) are developed based on primary data for the environmental assessments within Module 1. The collection of primary data, including the two approaches an expert survey and consultations (section 5.2) and experiments in the form of experimental noise, dust and vibration measurements (section 5.3) and the preparation of this data are described in the following.

5.2 Expert survey and consultations

Via an expert survey and consultations[134], all possible combinations[135] of relevant deconstruction methods (see Table 2 2, white highlighted methods), resulting in respective modes, and of building material types (b) (see Table 4-3), resulting in building component materials, are analysed due to different characteristics. Firstly, all combinations are evaluated with regard to average expenditures of time of deconstruction material pre-separation and pre-crushing to reach the high material quality for recycling defined in section 4.3.1.1. Secondly, the combinations are classified with regard to average emission levels of noise, dust and vibrations based to the general five-stage emission level categories (see section 4.5.2.1. and Table 4-12, Table 4-13, Table 4-14). Thirdly, influencing factors of different basic unit sizes and

[134] The expert survey and consultations were performed within the research project, this study is related to. Parts of the following descriptions are documented in Kühlen et al. (2016a).
[135] The basis for the combinations of methods and materials is the feasibility of deconstruction methods related to the building component material (see section 4.4.1.2 and sb^{1}_{m} to sb^{10}_{m} in Appendix A1).

deconstruction heights above ground on the average emission level of each combination are defined.

5.2.1 Approach

Experts of the deconstruction industry are consulted. The expert consultations are performed in three steps:

- Firstly, an online survey of those members of the German Deconstruction Association (DA), who are deconstruction/demolition and recycling companies, is performed.
- Secondly, survey-based model parameters are generated from the single written responses of the experts of the online survey by averaging.
- Thirdly, the generated survey-based model parameters are reviewed by a body of experts resulting in expert valuation-based model parameters.

Firstly, the online survey of the members of the DA was carried out over a period of seven weeks, between 12.January and 3.March 2015.The method of the online survey enables the written and independent survey of experts of German deconstruction/demolition and recycling companies. Out of the 84 (100%) contacted companies, 57 experts started and 17 (20%) finished the survey. The main reason that 40 experts did not finish the survey was the time needed for the survey. On average the 17 experts finishing the survey required 40 minutes. Only those single written responses of the 17 experts who finished the survey are included in the next steps.

Secondly, the method of averaging enables the accumulation of the responses in one average value in terms of an arithmetic mean or median of each question. Based on these average values and their evaluation denotations, survey-based model parameters, including specific duration values of material pre-separation and pre-crushing and emission level classification numbers of noise, dust and vibrations related to different configurations of emission-influencing activity parameters, are generated. These survey-based model parameters are the basis for the next step.

Thirdly, the method of the body of experts enables an interactive discussion and exchange of former experiences between experts based on the survey-based model parameters. Finally, expert valuation-based model parameters are set.

Details of the online survey, obtained responses and the approach to gain the survey-based model parameters based on the finalised written responses of the 17 experts are described in the following. More details on the survey responses and their analysis are outlined in appendix A5.

5.2.2 General deconstruction-related information on the survey respondent

As shown in the histogram in Figure 5-2 all experts (N=17)[136], who finished the survey, have practical, on site experience in deconstruction of more than 10 years. With the arithmetic mean of 24.7 years, 50% of the respondents have experience of more than 20 years.

[136] In the following, the total number of experts/respondents is specified by N.

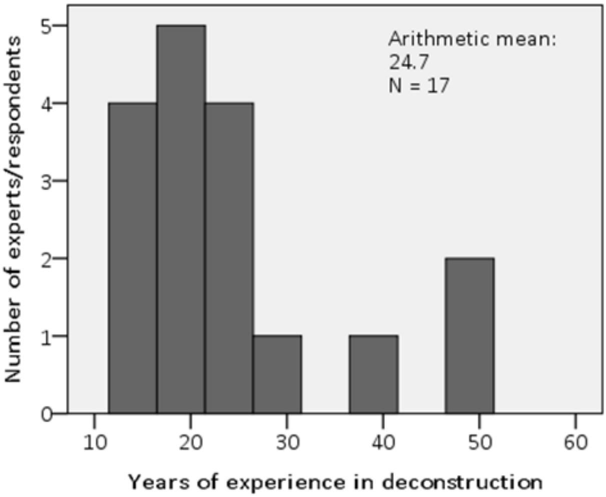

Figure 5-2: Histogram of number of experts with their years of experience in deconstruction

Most respondents (more than 55%, Figure 5-3) work in small and medium-sized enterprises (SMEs) with less than 200 employees. Overall, the deconstruction sector is characterised by small enterprises. For instance, according to the industry branch classification scheme NACE (EC-NACE (2010)) the deconstruction sector with the code 'F43.1 demolition and site preparation' is assigned to the construction sector with the code 'F construction' in Europe. And 98% of the enterprises of the construction sector in general have less than 20 employees based on the status in 2013 (EC–Eurostat (2016)).

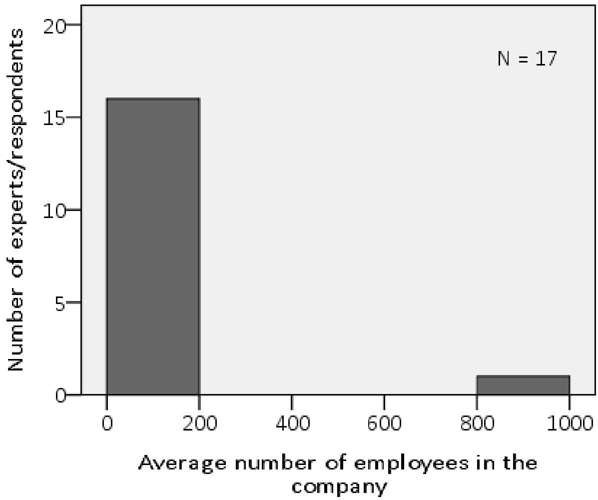

Figure 5-3: Histogram of number of experts and the average number of employees in their company

With 31 nominations[137], as the sum of the upper three numbers of nominations in Figure 5-4 (on the basis of Kühlen et al. (2016a, p. 85)), the hydraulic excavator is the regularly mainly used basic unit of the experts/respondents in deconstruction compared to other common basic units, such as cranes, wheel loaders and cable-operated excavators.

[137] Multiple nominations are allowed.

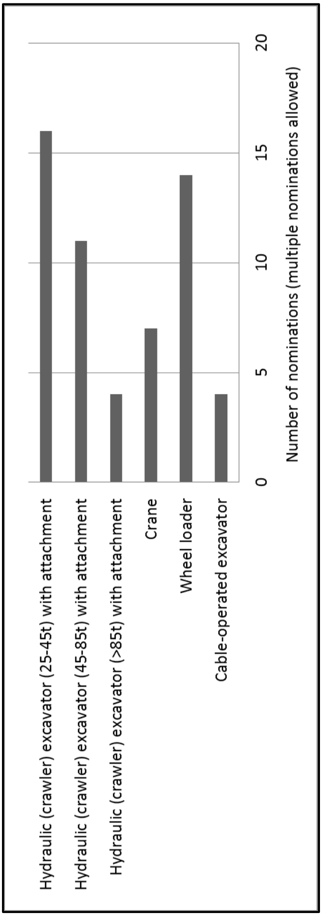

Figure 5-4: Regularly used basic unit in deconstruction

With more than 50%, hydraulic excavators with sizes between 25 and 45 tons are mostly utilised. With 16 nominations, an excavator of this size is applied by nearly 95%[138] of the respondents as basic unit in deconstruction.

[138] 16 out of 17 respondents/experts.

The most used attachments by the respondents are demolition tongs, the hydraulic hammer and the deconstruction grab, each with 16 nominations[139] (Figure 5-5 (on the basis of Kühlen et al. (2016a, p. 85))).

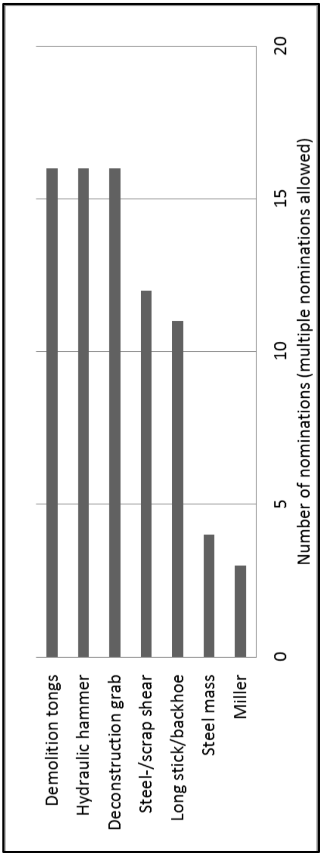

Figure 5-5: Regularly used attachments in deconstruction

The number of regularly used attachments and related modes due to Table 4-8 is also reflected in the mainly applied deconstruction

[139] Multiple nominations are allowed.

methods (Figure 5-6 (on the basis of (Kühlen et al. (2016a, Figure 4, p. 23)).

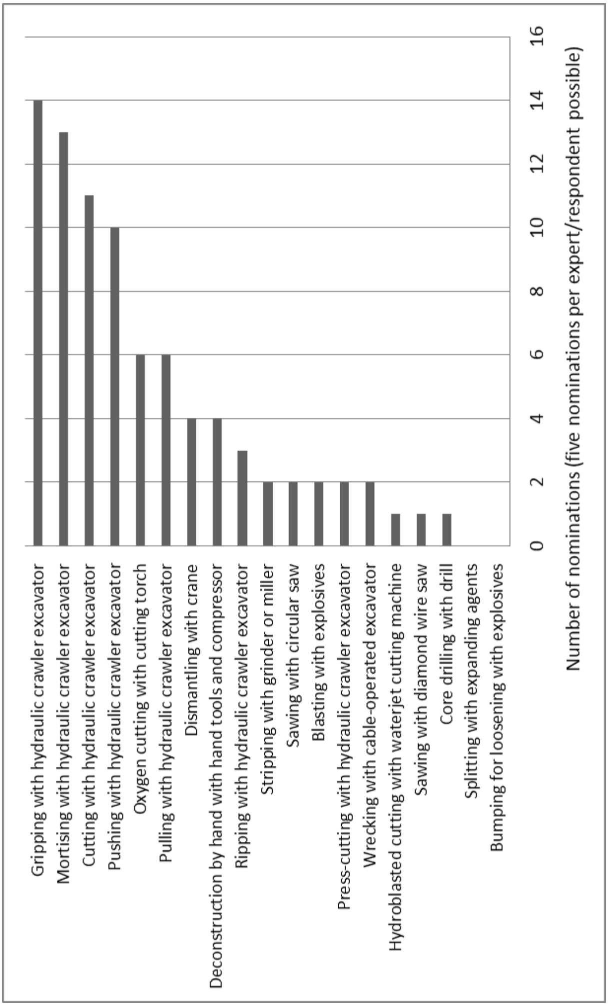

Figure 5-6: Five mainly applied deconstruction methods

Out of the standardized deconstruction methods according to DIN 18007:2000-05 (compare Table 2-2), gripping (82%[140]), mortising (76%) and cutting (65%) are mostly nominated within the five mainly applied methods by the experts/respondents. As shown in Table 4-8, all three methods are performed with hydraulic excavators. In terms of attachments, gripping is executed with a deconstruction grab, mortising requires a hydraulic hammer and tongs are used for cutting. The respondents do not often apply bumping, splitting, drilling, sawing, hydroblasted cutting and stripping. These are all attachments of those methods, which are not in the focus of this study, as stated in section 2.1.3.

In the course of the survey, the questions addressed to each expert are limited to the five mainly applied deconstruction methods selected by this expert. Each expert has to distinctly evaluate the designated five deconstruction methods applied to all building material types (b) of this study (see Table 4-3) with regard to the following three criteria:

1. Average expenditures of time of deconstruction material pre-separation and pre-crushing to reach the high material quality for recycling defined in section 4.3.1.1 (section 4.6.2.3).
2. Average emission levels of noise, dust and vibrations based on the generic five-stage emission level categories (see Table 4-12, Table 4-13, Table 4-14) (section 4.6.2.4).
3. Influencing factors of different discrete basic unit sizes and deconstruction heights above ground on the average emission level (section 4.6.2.5).

[140] By 14 of the 17 respondents.

Example responses and the approach to generate the survey-based model parameters due to the three criteria are described in the following sections.

5.2.3 Specific duration values of material pre-separation and pre-crushing

As stated in section 4.3.1.1 good recyclability of deconstruction materials is taken for granted to compare different deconstruction techniques/deconstruction activity modes. Within this context, on the one hand, pre-separation on site is required to reach sorted material of 95-98 % purity. On the other hand, pre-crushing on site is necessary to have material pieces with a maximum size of 80x80x80 cm. Hence, each expert has to distinctly evaluate the designated five deconstruction methods applied to all building material types (b) with regard to average expenditures of time of deconstruction material pre-separation and pre-crushing to reach the high material quality for recycling. As options[141] the following four discrete, interval-scaled[142] evaluation categories are available to the experts:

1. No expenditure of time: 0 min/m^3
2. Average expenditure of time of 2 min/m^3
3. Average expenditure of time of 4 min/m^3
4. Average expenditure of time of 6 min/m^3

The categories represent average expenditures of time of pre-separation and pre-crushing of 1 m^3 deconstruction material.

[141] Furthermore, the experts have the possibility to choose no evaluation, if they are not able to answer the question.

[142] Interval-scaled means that the intervals between the numerical values of the scale are the same. For instance, the intervals between values 1 and 2 and between values 3 and 4 are average 2 min/m^3.

The responses result in a frequency distribution of discrete, interval-scaled numerical values (1, 2, 3, 4) for each combination of deconstruction method and building material type for pre-separation and pre-crushing. Figure 5-7 and Figure 5-8 (on the basis of Kühlen et al. (2016a, Figures 7 and 8, p. 26) illustrate the frequency distributions (histograms) of the discrete evaluation categories of average expenditures of time of pre-separation and pre-crushing of 1 m^3 brick for the method 'gripping'.

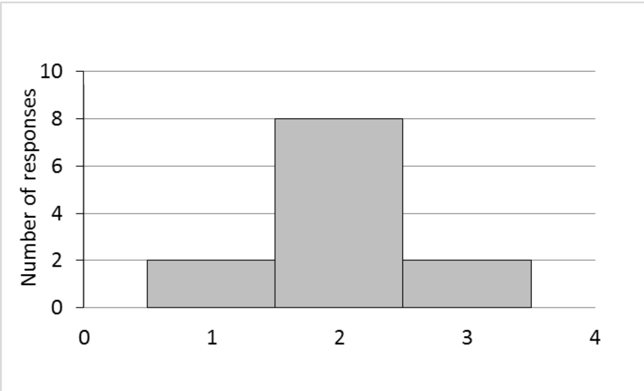

Figure 5-7: Histogram of the evaluation categories (1, 2, 3, 4) of average pre-separation expenditure of time of 1m^3 brick for the method 'gripping'

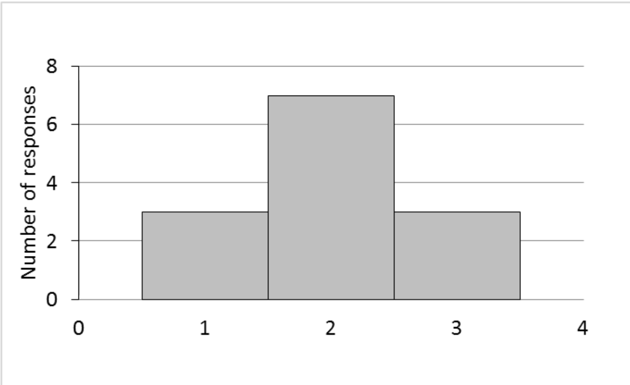

Figure 5-8: Histogram of the evaluation categories (1, 2, 3, 4) of average pre-crushing expenditure of time of 1m^3 brick for the method 'gripping'

An average value of response to each question is gained by the calculation of the arithmetical mean of the response values. The response analysis with arithmetic means and the standard deviations of the evaluation categories of average pre-separation and pre-crushing time expenditures for 1 m^3 material (1, 2, 3, 4) of all questions/of each combination of deconstruction method and building material type are summarised in appendix A5-1.

Based on the arithmetical means and the denotations of the four discrete evaluation categories in terms of min/m^3 (see above), average expenditures of time (min/m^3 and h/m^3 respectively) are generated. For instance, the arithmetic mean of the evaluation categories of average pre-separation expenditure of time of 2.0 is equal to an average expenditure of time of pre-separation of 2 min/m^3 (0.03 h/m^3). These average expenditures of time of each combination of deconstruction method and building material type represent the survey-based specific duration values of material pre-separation and pre-crushing. The survey-based specific duration values are reviewed by a body of experts and are included in the model as specific duration values of the material pre-separation ($p_{oj,m}$) and pre-crushing activity segment ($p_{qj,m}$) (appendix A2).

5.2.4 Emission level classification numbers of deconstruction-method-material-combinations

Next, each expert has to distinctly evaluate the designated five deconstruction methods, which result in respective modes, applied to all building material types (b) with regard to average emission levels of noise, dust and vibrations. Within this context, deconstruction method and building material type represent deconstruction activities performed with one basic unit of the size up to 170 kW/40 t and in heights above ground up to 15 m.

Based on the generic five-stage emission level categories (see section 4.5.2.1. and Table 4-12, Table 4-13, Table 4-14), the following five discrete, ordinal-scaled evaluation categories are available to the experts as options[143]:

0. Not annoying emissions
1. Little annoying emissions
2. Medium emissions/partly annoying
3. High emissions/annoying
4. Very high emissions/very annoying

To verify the evaluation responses of the experts, comparative questions of each distinct emission are posed. The responses, representing the sense of the distinct emission level of each expert, are compared with the generic emission level categories and related intervals of distinct emissions from literature (see Table 4-12, Table

[143] Furthermore, the experts have the possibility to choose no evaluation, if they are not able to answer the question.

4-13, Table 4-14). Overall, the categorisations of all distinct emission levels (the senses of emissions) of all experts correlate with the literature-based categorisations. Hence, the responses of all experts are included in the analysis. Figure 4-9, Figure 5-10 and Figure 5-11 show the average response values of responses in terms of noise, dust and vibration emission levels of selected emission sources and related literature values. The general slight underestimation of the experts due to very high noise, dust and vibration emission levels is considered in the third step of expert consultations (see section 5.2.1), within the review of the survey-based model parameters by a body of experts.

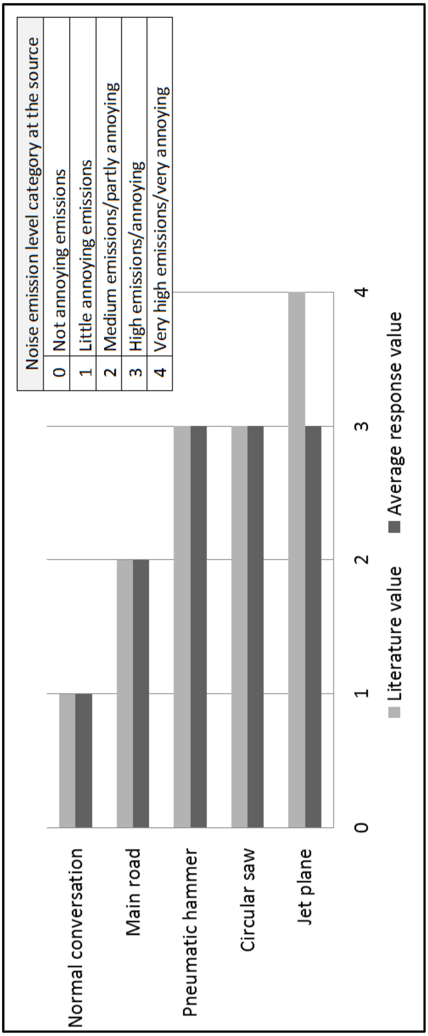

Figure 5-9: Comparison of average response values and literature values in terms of noise emission level categories (0-4) of selected emission sources

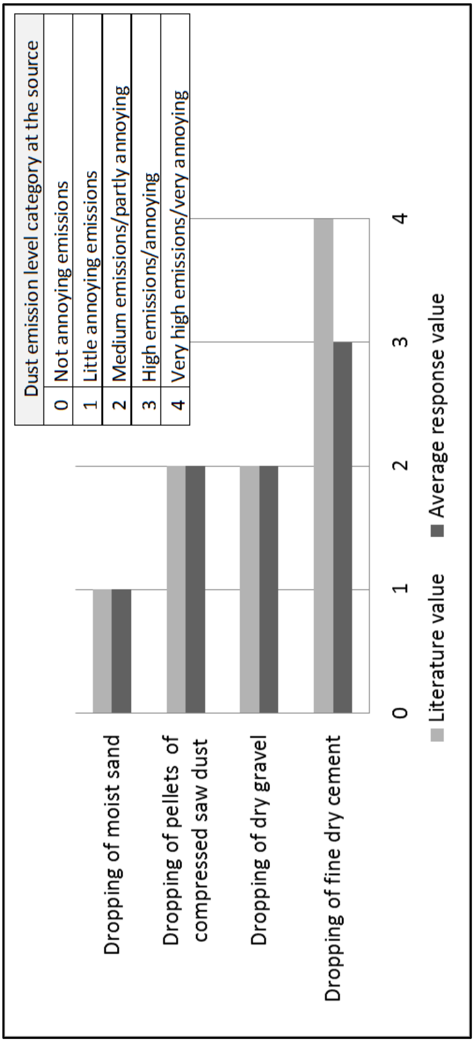

Figure 5-10: Comparison of average response values and literature values in terms of dust emission level categories (0-4) of selected emission sources

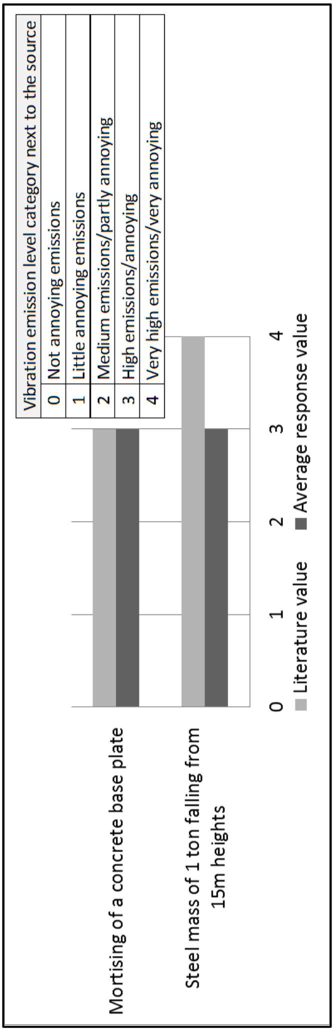

Figure 5-11: Comparison of average response values and literature values in terms of vibration emission level categories (0-4) next to selected emission sources

The responses result in a frequency distribution of discrete, ordinal-scaled numerical values (0, 1, 2, 3, 4) for each combination of deconstruction method and building material type for noise, dust and vibration emissions. Figure 5-12 illustrates the frequency distributions, the bar chart, of the discrete evaluation categories of average emission levels of dust for the method 'gripping' applied to the material brick.

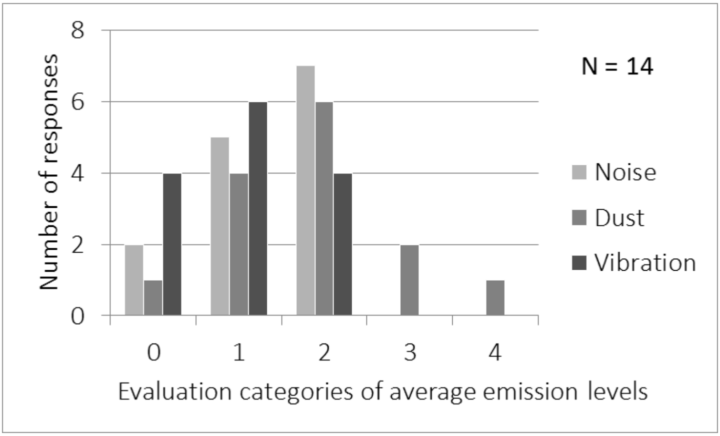

Figure 5-12: Bar chart of the evaluation categories of average emission levels (0, 1, 2, 3, 4) of noise, dust and vibrations for the method 'gripping' applied to the material brick

As the evaluation categories are ordinal-scaled, an average value of response to each question is gained by the calculation of the median of the response values. Figure 5-13, Figure 5-14 and Figure 5-15 show the boxplots with median (black thick line) and quantiles (grey boxes) of the evaluation categories of average emission levels of noise, dust and vibrations for the method 'gripping' applied to different materials.

In the figures the small circles illustrate spikes[144] and the asterisks demonstrate extreme values[145]. The response analysis with median and quantiles of the evaluation categories of average emission levels (0, 1, 2, 3, 4) of noise, dust and vibrations of all questions, hence of each combination of deconstruction method and building material type, are summarised in appendix A5-2.

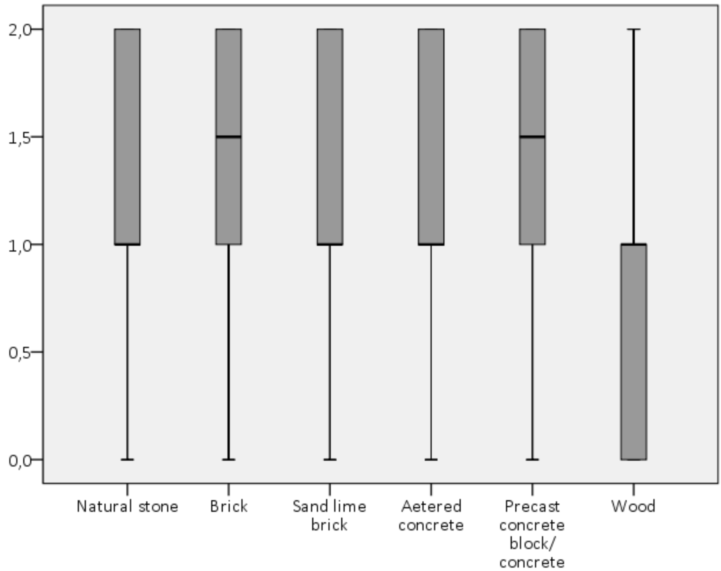

Figure 5-13: Boxplot with median (black thick line) and quantiles (grey boxes) of the evaluation categories of average emission levels (0, 1, 2, 3, 4) of noise for the method 'gripping' applied to different materials. The small circle illustrates a spike.

[144] Spikes are values with a distance, which is 1.5- to 3-times the box height either down from the 25 %-percentile down or up from the 75 %-percentile. The box height is the distance between the 25 % and the 75 %-percentile.
[145] Extreme values are values with a distance from the 25%-percentile or from the 75 %-percentile of more than 3-times the box height.

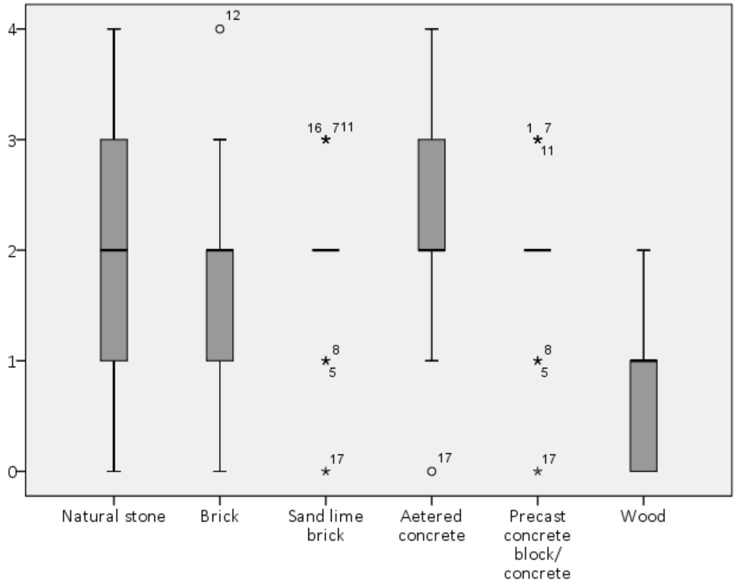

Figure 5-14: Boxplot with median (black thick line) and quantiles (grey boxes) of the evaluation categories of average emission levels of dust for the method 'gripping' applied to different materials

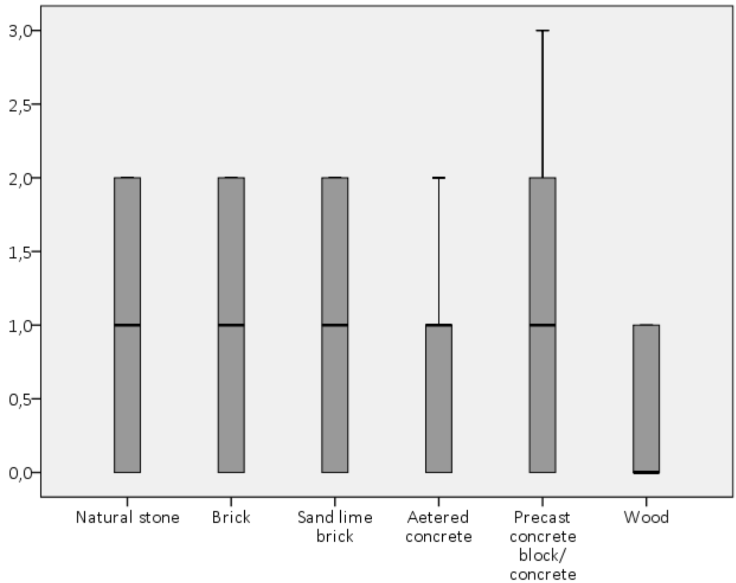

Figure 5-15: Boxplot with median (black thick line) and quantiles (grey boxes) of the evaluation categories of average emission levels of vibrations for the method 'gripping' applied to different materials

The median states one of the five discrete evaluation categories (0, 1, 2, 3, 4) or an interim category (0.5, 1.5, 2.5, 3.5). Consequently, according to the nine emission level classes (Table 4-15) in section 4.5.2.2), the medians of each combination of deconstruction method and building material type represent the survey-based nine-stage emission level classification numbers of noise, dust and vibrations. These survey-based nine-stage emission level classification numbers are reviewed by a body of experts. Furthermore, they are double-checked with the results of the experiments, the relative average emission levels of noise, dust and vibrations of different combinations of deconstruction methods and materials, described in section 5.3.

These final nine-stage emission level classification numbers of combinations of deconstruction method and building material type represent emissions of deconstruction activities performed with one basic unit of the size up to 170 kW/40 t and in heights above ground up to 15 m. Furthermore, these nine-stage emission level classification numbers are used for the generation of emission level classification numbers due to varying basic unit sizes and deconstruction heights above ground. They are calculated with the influencing factors, described in the following section 5.2.5.

5.2.5 Basic-unit-size- and deconstruction-height-related influencing factors

Finally, each expert has to distinctly evaluate the designated five deconstruction methods applied to all building material types (b) with regard to influencing factors of different discrete basic unit sizes and deconstruction heights above ground on the average emission level.

Within this context, it is distinguished between two specifications of basic unit sizes (sz <= 170 kW/40 t; >170 kW/40 t) and two specifications of deconstruction heights above ground (hg <= 15 m; >15 m). Hence, on the one hand, the experts have to estimate the influencing on the emission level due to basic unit sizes greater than 170 kW/40 t compared to the initially specified basic unit size of up to 170 kW/40 t. On the other hand, they have to assess the influencing on the emission level due to heights above ground greater than 15 m compared to the initially height above ground of up to 15 m.

As options[146] the following five discrete, interval-scaled evaluation categories are available to the experts:

[146] Furthermore, the experts have the possibility to choose no evaluation, if they are not able to answer the question.

- 1: No influence on the emission level
- 1.5: Increase of the emission level by 1.5
- 2: Doubling of the emission level
- 2.5: Increase of the emission level by 2.5
- 3: Tripling of the emission level

The responses result in a frequency distribution of discrete, interval-scaled numerical values (1, 1.5, 2, 2.5, 3) for each combination of deconstruction method and building material type for the influence of basic unit sizes and deconstruction heights above ground on the distinct emission levels. An average value of response to each question is gained by the calculation of the arithmetical mean of the response values.[147] The calculated mean directly represents the factor (fk) of the emission level increase due to the variation of the basic unit size (fk_{sz}) or deconstruction height above ground (fk_{hg}).

For the generation of respective emission level classification numbers of different combinations of deconstruction methods and materials extended by varying basic unit sizes and deconstruction heights above ground the following three calculation steps are executed:

1. The final nine-stage emission level classification numbers, the output of section 5.2.4 double-checked with the results of the experiments of section 5.3, are assigned to the generic emission level mean values according to (Table 4-15). This results in specific hourly average noise, dust and vibration emission level values of the activity segments (reference units) depending on the mode and material and related to

[147] The response analysis with arithmetic means and the standard deviations of all questions/of each combination of deconstruction method and building material type for the influence of basic unit sizes and deconstruction heights above ground on the distinct emission levels are summarised in appendix A5-3.

basic unit sizes of sz <= 170 kW/40 t and deconstruction heights above ground of hg <= 15 m.[148]

2. Each specific hourly average emission level value is increased by the factor (fk_{sz}/fk_{hg}) due to the variation of the basic unit size (sz) or deconstruction height above ground (hg). Within this context, the increase of the dust and vibration emission level value is carried out by multiplication with (fk_{sz}/fk_{hg}) (Equation 5-1). The increase of the noise emission level value is calculated with Equation 5-2 with respect to the human sense of loudness, the perceived psychoacoustics quantity, according to Sengpiel (2016b).
3. Finally, each increased specific hourly emission level value is converted into a nine-stage emission level classification number of noise, dust or vibrations by rounding the value up/down to the next generic emission level mean value according to Table 4-15.

Equation 5-1: Increased specific hourly average dust emission level value due to basic unit size variation[149]

$$\sigma^{e}{}_{(2)}(\mathrm{m,b,sz,hg}) = \sigma^{e}{}_{(1)}\left(\mathrm{m,b,sz_{(1)},hg}\right) * fk_{sz_{(2)}} \ [\mathrm{g/m^3}]$$

Equation 5-2: Increased specific hourly average noise emission level value due to basic unit size variation[150]

$$\lambda^{e}{}_{(2)}(\mathrm{m,b,sz,hg}) = \lambda^{e}{}_{(1)}\left(\mathrm{m,b,sz_{(1)},hg}\right) + \left(10 * log_2\left(fk_{sz_{(2)}}\right)\right)$$
[dB(A)]

[148] Noise: $\lambda^{e}{}_{d}$(m,b,sz,hg), $\lambda^{e}{}_{o}$(m,b,sz,hg), $\lambda^{e}{}_{q}$(m,b,sz,hg); dust: $\sigma^{e}{}_{d}$(m,b,sz,hg), $\sigma^{e}{}_{o}$(m,b,sz,hg), $\sigma^{e}{}_{q}$(m,b,sz,hg); vibration: $\psi^{e}{}_{d}$(m,b,sz,hg), $\psi^{e}{}_{o}$(m,b,sz,hg), $\psi^{e}{}_{q}$(m,b,sz,hg) (see section 4.5.2.3 and appendix A4).

[149] Equation applies to increased specific hourly average vibration emission level values (ψ^{e} (m,b,sz,hg)) and due to deconstruction height above ground variations (fk_{hg}) respectively.

[150] Equation applies due to deconstruction height above ground variations (fk_{hg}) respectively.

From all nine-stage emission level classification numbers related to possible configurations of emission-influencing activity parameters, specific hourly emission level values of noise, dust and vibrations related to these configurations are deducted, as described in section 4.5.2.3. These specific hourly emission level values of all configurations of emission-influencing activity parameters[151], are included in the model and are documented in appendix A4.

5.3 Experiments

Via experiments, in terms of experimental noise, dust and vibration measurements[152], different combinations of relevant deconstruction methods (see Table 2 2, white highlighted methods) and of building material types (b) (see Table 4-3) are compared with each other regarding their relative average emission levels of noise, dust and vibrations. To enable the relative comparison of different combinations, all impact-influencing surrounding conditions are kept constant within the experiments. Furthermore the experimental measurements of impacts of noise, dust and vibrations are performed in the immediate vicinity of the emission source.[153]

[151] The emission-influencing activity parameters are mode, material, basic unit size and deconstruction height above ground.

[152] The experiments/experimental measurements were performed within the research project, this study is related to. Parts of the following descriptions are documented in Kühlen et al. (2016a).

[153] As impacts are measured within spitting distance of the emission source and surrounding conditions are kept constant, in the following, it is referred to the measurement of ‘emissions’. Nevertheless, as the constant surrounding conditions of the experiments are different from usual conditions on site, it is referred to relative and not absolute emission values for the analysis and comparison.

5.3.1 Experimental setup

Impact-influencing parameters of the surroundings include meteorological conditions, such as wind, temperature and humidity, characteristics of close structures and soil and surface conditions, as specified in section 4.5.3.1. By conducting the experiments indoors in a hall, all these impact-influencing parameters are kept constant, except small temperature variations.

Two experimental series are performed to analyse the influence of different deconstruction methods and material types on emission levels of noise, dust and vibrations. To analyse the influence of different deconstruction methods, which result in respective technique modes, a 14-tons hydraulic crawler excavator (Hitachi KX135) is used as a basic unit and different attachments are applied. The attachments encompass demolition tongs for press-cutting, a deconstruction grab for gripping and a hydraulic hammer for mortising. Furthermore, a diamond cutter of 235 mm for sawing is tested for relative emission level comparisons with the relevant deconstruction methods. To analyse the influence of diverse building material types, on the one hand, within the first experimental series masonry stones out of brick, sand lime brick, concrete (precast concrete block) and aerated concrete are used. All stones have the dimensions 24x25x30 cm, which is a regular size of stones with key and slot in practice (DF10 according to Schneider (2016, p. 7.4). Single stones, instead of masonry walls out of several stones connected by mortar layers, are used to avoid dust due to mortar as fixed additional dust emission besides the dust emission due to the different materials. On the other hand, within the second experimental series blocks of the dimension 130x75x13 cm out of reinforced concrete are used for the experiments.

Several measurement systems are applied to continuously and simultaneously measure noise, dust and vibrations. Noise is measured continuously in real time as A-weighted sound by six class 2 sonars of the type PCE-322 A from the company PCE. The sonars have a measuring range of 30 to 130 dB and a frequency range of 31.5 Hz to 8 kHz. Dust measurement is performed with two portable aerosol spectrometers of the type IAQ-11-A from Grimm Aerosol Technik. The devices detect dust particles permanently in real time in the size range 0.25 µm to 32 µm and represent the results in particle concentration (mm/m^3, µm/m^3). Furthermore, six optical dust sensors, which were developed within the research project this study is related to (see Kühlen et al. (2014, p. 79 et seq.) and Kühlen et al (2016, pp. 60 et seq.)), are applied. These sensors measure the dust particle concentration via laser beams on the basis of the difference between sent and received light. Vibrations are measured continuously in real time in terms of vibration speed (mm/s) and the frequency spectrum (Hz) by two standard systems according to DIN 45669-1:2010-09. One system is of the type ZEB/SM-3C of the company ZEB-Maxam with 3 channels, one channel for each measurement direction. The three measurement directions are horizontal to the ground (x), horizontal to the ground and vertical to x (y), and vertical to the ground (z). The other system is of the type SM 9800 of the company Beitzer with 8 channels, including two integrated vibration sensors with 3 channels each for the three directions x, y and z and two sensors of one channel for the vertical direction z.

The setup of the experiments is shown in Figure 5-16, Figure 5-17 and Figure 5-18. The equipment, the hydraulic crawler excavator with attachment, is located in a channel in the hall (Figure 5-16 and Figure 5-17, right side; Figure 5-18, left side). The masonry stones of the first experimental series are placed at the height of about 1 meter on fixed concrete blocks in front of the equipment in the middle of all measurement devices (Figure 5-16, middle). The concrete blocks of the second experimental series are placed in front of the equipment in the middle of all measurement devices as well. For the method mortising the block is horizontally laid on a fixed concrete plate (Figure 5-17). For the other deconstruction methods the concrete block is horizontally put into a steel fitting fixed on the ground (Figure 5-18).

The measurement systems are positioned around and as close as possible (generally in 2 to 5 meters distance) to the material stones/blocks (Figure 5-16 and Figure 5-17, e.g. left side and in the back; Figure 5-18, right side, in the back in the middle and in the front).

Figure 5-16: Setup of the first experimental series: equipment (right side), masonry stones on blocks (in the middle) and measurement systems (left side, in the back, and at the front in the middle)

Figure 5-17: Setup of the second experimental series for mortising: equipment (right side), concrete block on a concrete plate (in the middle) and measurement systems (left side and at the back)

Figure 5-18: Setup of the second experimental series for other methods than mortising: equipment (left side), concrete block in a steel fitting (in the middle) and measurement systems (right side, at the back in the middle and at the front)

5.3.2 Test procedure

The first experimental series includes in total 60 experiments (Table 5-1).

Table 5-1: Number of experiments of the first experimental series

Material/ method	Aerated concrete	Brick	Sand lime brick	Concrete (precast concrete block)
Gripping	4	4	4	4
Press-cutting	4	4	4	4
Mortising	4	4	4	4
Sawing	3	3	3	3

As listed in Table 5-1, different combinations of deconstruction methods and different masonry stones are examined. Figure 5-19 shows the explored masonry stones made out of aerated concrete (top left), brick (top right), sand lime brick (bottom left) and concrete (bottom right).

Figure 5-19: Explored masonry stones made out of aerated concrete (top left), brick (top right), sand lime brick (bottom left) and concrete (bottom right)

This first experimental series targets on the relative comparison of the combinations with regard to their average emission levels of noise and dust. Tested methods include press-cutting, gripping, mortising and sawing. Each experiment of the first series includes the demolishing of the six single masonry stones (see Figure 5-16, six stones on blocks in the middle) by the respective deconstruction method related to the attachment. Within this context and to compare the emissions of the different combinations, each deconstruction method is applied to each stone until the stone is at least taken apart into two pieces. To enable the relative comparison of dust emission levels, the following experiment is not started before the just-in time measured dust level got back to the initial dust level of pollution measured before the previous experiment was conducted. Hence, there is a break in between the each experiment of the series.

The second experimental series includes in total 13 experiments (Table 5-2).

Table 5-2: Experiments of the second experimental series

Material/ method	Reinforced concrete
Press-cutting	5
Mortising	5
Sawing	3

Here out of the four probable deconstruction methods (see section 5.3.1) the three methods press-cutting, mortising and sawing are applied to blocks out of reinforced concrete. The method gripping is not suitable for the building component material type reinforced concrete (see appendix A1, sty^6_m and sty^8_m). The reinforced concrete blocks have a good link to the ground due to their high weights. Hence, the second experimental series targets on the relative comparison of the combinations of different methods applied to concrete blocks with regard to their average emission levels of vibrations, in addition to average emission levels noise and dust. Each experiment of the second series includes the demolishing of one reinforced concrete block (see Figure 5-16 and Figure 5-17, concrete block in the middle) by the respective deconstruction method, related to the attachment. Within this context and to compare the emissions of the different combinations, each deconstruction method is applied six times to the reinforced concrete block. As in the first experimental series, the following experiment is not started before the just-in time measured dust level got back to the initial dust level of pollution measured before the previous experiment was conducted. Hence, there is a break in between the each experiment of the series to enable the relative comparison of dust emission levels.

5.3.3 Experimental result

In general, for the relative comparison of distinct emission levels of the different combinations, measured data is analysed and summarised according to the same combinations of materials and methods.

The data analysis of is performed in four steps:

1. Permanently measured emission data of each measurement system/sensor is assigned to the durations of the single experiments and is corrected[154].
2. Based on the cleaned emission data, an average emission level value of noise and dust and vibration[155] is calculated for each measurement system/sensor of each experiment.
3. The average distinct emission level values of each measurement system/sensor of each experiment are summarised to one average emission level value of noise and dust (and vibration[156]) for each experiment.
4. The average distinct emission level values of each experiment are summarised to one average emission level value of noise

[154] The data is corrected due to the distance to the emission source and measuring errors. Especially, the data of dust emissions is cleaned of the initial dust level of pollution. The initial noise level is 50 dB(A) and the initial vibration level is 0 mm/sec. As already a difference between two noise levels of 10 dB(A) results in a level increase of the higher noise level of less than 0.5 dB(A) (DIN 18005-1:2002-07), the initial noise level has no influence on the measured noise levels caused by the experiments.
[155] For the second experimental series.
[156] For the second experimental series.

and dust (and vibration[157]) of each material-method-combination.

In the following the experimental results are presented in terms of these relative average distinct emission level values of each material-method-combination.

Within the **first experimental series** the experiments of gripping applied to the solid masonry stones out of sand lime brick and concrete provide no reliable results. Here the demolition tongs cannot destroy the solid masonry stones.[158] Overall, 40 significant experiments (Table 5-3 (on the basis of Kühlen et al. (2016a, Table 4, p. 30))) out of 60 are introduced into the experimental results in terms of relative comparisons of the combinations.

Table 5-3: Number of significant experiments of the first experimental series

Material/ method	Aerated concrete	Brick	Sand lime brick	Concrete (precast concrete block)
Gripping	4	3	-	-
Press-cutting	4	4	4	4
Mortising	3	2	3	4
Sawing	1	1	1	2
- experiments with no results				

For the relative comparison of the noise emission levels of the different combinations, measured data of the six class 2 sonars are

[157] For the second experimental series.
[158] Nevertheless, in general gripping is suitable for the building component material types sand lime brick (sty^4_m) and concrete (sty^5_m) (see appendix A1). Within this context, masonry building components out of sand lime brick or concrete are usually destroyed by gripping in the mortar layer. Furthermore, the efforts of pre-crushing to reach material pieces with a maximum size of 80x80X80 cm are not necessarily higher for sand lime brick or concrete than for other ‘softer’ masonry stones, as a regular size of mortared stones/blocks is 24x25x30 cm, which is smaller than 80x80X80 cm.

analysed and summarised according to the same combinations of materials and methods (Table 5-4).

Table 5-4: Summary of noise measurement results of the first experimental series (in dB(A))

Material/ method	Relative average noise emission level value (in dB(A))			
	Aerated concrete	Brick	Sand lime brick	Concrete (precast concrete block)
Gripping	83	82	-	-
Press-cutting	82	84	82	83
Mortising	87	84	84	92
Sawing	92	98	103	110

- experiments with no results

As shown in Table 5-4 the relative average noise emission level values of different masonry-method-combinations varies between 82 dB(A) and 110 dB(A). According to the noise emission level intervals of the generic noise emission level categories in Table 4-12 (see section 4.5.2.1) these measured noise emission levels could be assigned to the categories 2 ('partly annoying') to 4 ('painful and hearing damages even when shortly exposed'), if the measured results are presumed as absolute emission values. Nevertheless, in the following analysis and for double check with the results of the expert survey and consultations (see section 5.2) it is referred to relative instead of absolute emission level values, as the constant surrounding conditions of the experiments are different from common conditions on site. When relatively comparing the four different masonry materials, the experimental results underpin the general perception that concrete is the material with the highest noise emission levels related to the deconstruction methods mortising and sawing. When relatively comparing the four different deconstruction methods, a specific influence of the different methods is identifiable across all materials. Sawing shows the highest noise emission level values compared to the other three methods. The noise emission levels of mortising is 5 to

20 dB(A) lower than those of sawing depending on the masonry material. Pre-cutting and gripping cause similar noise emission levels and the levels are almost independent of the material. Furthermore, the noise level of these two methods corresponds approximately to the noise level of the excavator in action in general. Here a relative average noise emission level value between 82 dB(A) and 83 dB(A) is measured in the experiments.

For the relative comparison of the dust emission levels of the different combinations with each other, measured data of six optical dust sensors analysed and summarised to a relative dimensionless value of the dust concentration according to the same combinations of materials and methods (Table 5-5).

Table 5-5: Summary of dust measurement results of the first experimental series (dimensionless)

Material/ method	Average dust emission level value (dimensionless)			
	Aerated concrete	Brick	Sand lime brick	Concrete (precast concrete block)
Gripping	382	207	-	-
Press-cutting	243	190	337	184
Mortising	1142	993	960	693
Sawing	6659	1927	6061	3813
- experiments with no results				

Measured data of the two portable aerosol spectrometers show many errors in measurement within the first experimental series and do not allow the summary of data of same combinations of materials and methods. Hence, they are not used for/included in the comparison of combinations.

From the relative dimensionless average dust emission level values in Table 5-5 can be deducted gripping and press-cutting cause similar average dust emission levels. This is reasonable as materials are demolished by demolition tongs (for press-cutting) and deconstruction grabs (for gripping) in similar ways. The relative emission level value of press-cutting of sand lime brick and aerated concrete is greater than of brick and concrete. Mortising shows relatively higher dust emission levels compared to gripping and press-cutting across all materials. Mortising of concrete causes a lower relative emission level value compared to the other three materials. As for noise emission levels, sawing produces relatively the highest noise emission levels compared to the other three methods over all materials. In this regard, the influence of the size of the cut surface is considerable. As all material in the sawed joint is converted to dust, the relative dust emission level value of sand lime brick and aerated concrete is higher than the relative emission level value of brick and concrete. The air cells/chambers in the stones out of brick and concrete decrease the material cross sections, resulting in lower dust emission levels.

Within the **second experimental series** overall, 11 significant experiments (Table 5-6 (on the basis of Kühlen et al. (2016a, p. 31))) out of 13 are introduced into the experimental results in terms of relative comparisons of the combinations.

Table 5-6: Number of significant experiments of the second experimental series

Material/ method	Reinforced concrete
Press-cutting	5
Mortising	3
Sawing	3

For the relative comparison of the noise, dust and vibration emission levels of the different combinations of deconstruction methods applied to reinforced steel, measured data of six class 2 sonars, six optical dust sensors, the two portable aerosol spectrometers and the two standard vibration measurement systems are analysed and summarised according to the same method combinations (Table 5-7, Table 5-8 and Table 5-9).

Table 5-7: Summary of noise measurement results of the second experimental series (in dB(A))

Material/ method	Relative average noise emission level value (in dB(A))
	Reinforced concrete
Press-cutting	92
Mortising	107
Sawing	107

The results in Table 5-7 show that press-cutting is the deconstruction method with the lowest noise emission level value compared to the other two methods applied to reinforced concrete. Mortising and sawing cause similar noise emission levels (in terms of dB(A), without considering the influence of frequency).

Table 5-8: Summary of dust measurement results of the second experimental series (%)

Material/ measuring system/ method	Relative average dust emission level value (in % of press-cutting)	
	Reinforced concrete	
	Optical dust sensors	Aerosol spectrometers
Press-cutting	100%	100%
Mortising	97%	94%

As shown in Table 5-8 the comparison of dust emission levels of different methods applied to reinforced concrete includes press-cutting and mortising. Both methods cause similar average dust emission level values. No feasible measured data for the analysis of sawing is available.

Table 5-9: Summary of vibration measurement results of the second experimental series (%)

Material/ measuring system/ method	Relative average vibration emission level value (in % of mortising)	
	Reinforced concrete	
	3-channel-system	8-channel-system
Press-cutting	10%	18%
Mortising	100%	100%
Sawing	1%	0%

As expected, the relative average vibration emission level values in Table 5-9 show that mortising is the method with the highest and sawing is the method with the lowest vibration values applied to reinforced concrete.

All presented results of the experiments, the relative average emission levels of noise, dust and vibrations of different combinations of deconstruction methods and materials, are used to verify the nine-stage emission level classification numbers of the expert survey and consultations (see section 5.2). The result is final emission level classification numbers of noise, dust and vibrations related to different configurations of emission-influencing activity parameters, which are included as basic data in the database of TEE-D-Plan.

6 Resource-, space and impact-constrained deconstruction project planning and decision support due to environmental objectives

The output of Module 1, the database-based deconstruction planning for environmental assessment (see chapter 4), is the building component-related activities J of a deconstruction project, each activity performed in different modes M_j. Each project activity performed in a mode holds economic and environmental plan values, duration ($p_{j,m}(sz)$), costs ($c_{j,m}(sz,yr)$) and average impact level values ($lim_{j,m}(dc,n^l,sz)$, $sim_{j,m}(sz)$, $vim_{j,m}(dc,sz)$), drawn from the technical, economic and environmental assessments in Module 1.

These project activity alternatives with different modes and economic and environmental plan values are input for Module 2 to find the overall deconstruction project plan due to different environmental and economic objectives.

This Module 2 for deconstruction project planning and decision support due to environmental and economic objectives is described in the following, which includes the following elements:

- Set up of the basic method for deconstruction project planning in the form of a resource-constrained project scheduling problem (RCPSP) with resource-dependent project constraints modelled as ‘renewable resources’.
- Adaption of the basic method in terms of a multi-mode resource constrained project scheduling problem (MRCPSP)

by alternative deconstruction techniques modelled as 'time-resource-tradeoffs' and space- and impact-level-dependent project constraints modelled as 'renewable resources'.

- Usage of phase-related economic and environmental plan values based on a predefined deconstruction activity sequence including costs across single activity durations, distinct non-linear scaling of noise impacts and time-dependent average impact level values as a basis for the selection process, the objective function.
- Performance of an iterative solution process, an iterative objective function based on the predefined activity sequence to provide a solution due to different environmental and economic objectives.
- Application of the Multi-Attribute Value Theory (MAVT) as an approach of Multi Attribute Decision Making (MADM) to the independent conflicting economic and environmental (multi) objectives/objective preferences of the decision maker.

6.1 Basic method in the form of a resource-constrained project scheduling problem

The basic method of resource-constrained project scheduling problems (RCPSP) describes a project by a set of scheduling constraints and an objective function (Hartmann and Briskorn (2010)). In the following the parameters of this basic RCPSP method are defined related to this research and based on the most common formulations in literature.

As defined in sections 4.3 and 4.4, each deconstruction project has J activities, specified j ={1;2;...;J}. Each activity consists of three activity segments d_j, o_j, q_j. The duration of an activity (p_j) is known and decimal numbered (double variable) and discrete. Resources (resource types and numbers) required to perform the activity are known as well. In this research discrete resources are implemented in the model. These resources are the number of required employees (r^{po}_j), numbers of different basic unit types (r^{hy}_j, r^{lt}_j, r^{cw}_j, r^{ha}_j) and type-number-related attachment/s to deconstruct the component (ad_j) and to sort and crush material (ab_j). There are precedence relations between the activities, which are presented in a network plan (activity-on-node (AoN) network) (see Figure 4 6, Figure 4 7). In an AoN network each node denotes an activity. The network has a single source and a single sink ('dummy activities') with durations of 0 and no required resources. The precedence relations are represented by arcs (Kolisch (2015)). The sum of all activity durations can be defined as the maximal overall project duration ($\bar{T} = \sum_{j=1}^{J} p_j$). For instance, by serial schedule generation schemes (SGS), firstly, the earliest start (ES_j) and earliest finish (EF_j) times of activity j can be calculated. Secondly, with $LF_J = \bar{T}$, the latest start (LS_j) and finish (LF_j) times of activity j can be calculated (Schultmann (1998, p. 113)).

Resource-dependent restrictions in the project are modelled as 'renewable resources' (Kolisch (2015)). Renewable resources refer to the overall deconstruction project and are constant over the project duration in this research. Resource-dependent restrictions implemented in the model state capacities of available basic unit types (R^{hy}, R^{lt}, R^{cw}, R^{ha}). Referring to the parallelisation of activities (see section 4.3.2.2), the model allows the availability of between zero and a maximum of two basic units of one type for the overall project. The numbers of different basic unit types available for the specific deconstruction project can be entered as project constraints into the model by the user, the decision maker via the user interface. Information on the user interface and user inputs due to these project constraints is further described and illustrated in the context of the application of TEE-D-Plan in chapter 7, section 7.2.1.3.

In general, in RCPSP the objective is to find a schedule leading to the earliest possible project finish time (Hartmann and Briskorn (2010)). Based on the assumptions and for instance according to Schultmann (1998, p. 114) the following equations describe the objective function (Equation 6-1) and the scheduling constraints (Equation 6-2 and Equation 6-3) of the basic resource-constrained project scheduling method for this research:

Equation 6-1: Objective function to minimise the project duration

$$Min \sum_{t=EF_J}^{LF_J} t * z_{Jt}$$

Equation 6-2: Time-dependent activity execution constraints

$\sum_{t=EF_j}^{LF_j} z_{j,t} = 1$ j=1,…,J

$\sum_{t=EF_i}^{LF_i} t * z_{i,t} \leq \sum_{t=EF_j}^{LF_j} (t - p_j) z_{j,t}$ j=2,…,J; i ∈ Pred(j)

$z_{j,t} \in \{0,1\}$ j=1,…,J; t=EF_j,…., LF_j

Equation 6-3: Resource-dependent project constraints

$\sum_{j=1}^{J} r_j^{hy} \sum_{\tau=1}^{t+p_j-1} z_{j,\tau} \leq R^{hy}$ t=1,…,$\overline{T}$[159]

$\sum_{j=1}^{J} r_j^{ha} \sum_{\tau=1}^{t+p_j-1} z_{j,\tau} \leq R^{ha}$ t=1,…, $\overline{T}$

With

[159] Equation applies to the constrained resources R^{lt}, R^{cw} compared to the required activity-related resources n_j^{lt} and r_j^{cw} respectively.

$z_{j,t}$: binary variable (1, if activity j is performed in period t; 0, else)

r_j^{hy}/r_j^{ha}: Number of units of resource hy/ha of activity j

R^{hy}: Capacity of available hydraulic excavator resource hy, $R^{hy} \in \{0; 1; 2\}$

R^{ha}: Capacity of available hand tool resource ha $R^{ha} \in \{0; 2; 4\}$

Pred(j): Set of all immediate and transitive predecessors of activity j in the project network

6.2 Adaption of the basic method

To answer the research questions, the basic method (RCPSP) is adapted by multiple alternative activity modes and space- and impact level-dependent restrictions.

6.2.1 Multiple modes

Each project activity can be performed in different technique modes ($m=\{1;2;\ldots;M_j\}$) (see section 4.3.2.3). These modes are modelled as 'time-resource-tradeoffs' in the so called 'multi-mode resource constrained project scheduling problem' (MRCPSP). MRCPSP is an adaption of RCPSP, additionally including activity alternatives (modes = 'time-resource-tradeoffs' (Alcaraz et al. (2003), Hartmann (2001)). In this research, mode changes and pre-emption is not possible. Hence, if an activity started in one mode, it has to be completed in this mode. It has to be ensured that one activity is performed exactly once. Consequently, the time-dependent activity execution constraints of the RCPSP are adapted (Equation 6-4) (according to Schultmann (1998, pp. 116 et seq.).

Equation 6-4: Adapted time-dependent activity execution constraints

$\sum_{m=1}^{M_j} \sum_{t=EF_j}^{LF_j} z_{j,m,t}$ j=1,…,J

$\sum_{m=1}^{M_i} \sum_{t=EF_i}^{LF_i} t * z_{i,m,t} \leq \sum_{m=1}^{M_j} \sum_{t=EF_j}^{LF_j} \left(t - p_{j,m}(sz)\right) z_{j,m,t}$ j=2,…,J; $i \in Pred(j)$

$z_{j,m,t} \in \{0,1\}$ j=1,…,J; m= 1,…, M_j; t=EF_j,…., LF_j

With

$z_{j,m,t}$: binary variable (1, if activity j in period t is performed in mode m; 0, else)

Depending on the mode, the duration and required resources of an activity, including the three activity segments, differ. Therefore, based on the definitions of the basic RCPSP, the duration of an activity performed in mode m is denoted $p_{j,m}(sz)$. $p_{j,m}(sz)$ is known and decimal numbered (double variable). Resources required to perform the activity j in mode m are also known, integer (integer variables) and given by $r^{po}_{j,m}$, $r^{hy}_{j,m}$, $r^{lt}_{j,m}$, $r^{cw}_{j,m}$, $r^{ha}_{j,m}$, $ad_{j,m}$, $ab_{j,m}$ (see Table 4-9). Due to the renewable resources of the basic method in terms of capacities of available basic unit types (R^{hy}, R^{lt}, R^{cw}, R^{ha}), only those activity modes and parallelisation are feasible, which require equal or less basic units (see appendix A1) compared to the available basic unit capacities. Equation 6-5 shows respectively adapted resource-dependent project constraints.

Equation 6-5: Adapted resource-dependent project constraints

$$\sum_{j=1}^{J}\sum_{m=1}^{M_j} r_{j,m}^{hy} \sum_{\tau=1}^{t+p_{j,m}(sz)-1} z_{j,m,\tau} \leq R^{hy} \qquad t=1,....\overline{T}$$ [160]

$$\sum_{j=1}^{J}\sum_{m=1}^{M_j} r_{j,m}^{ha} \sum_{\tau=1}^{t+p_{j,m}(sz)-1} z_{j,m,\tau} \leq R^{ha} \qquad t=1,....\overline{T}$$

With

$z_{j,m,\tau}$: binary variable (1, if activity j in period t is performed in mode m; 0, else)

$r_{j,m}^{hy}/r_{j,m}^{ha}$: Number of units of resource hy/ha of activity j in mode m

Besides resource-dependent project constraints, influencing the feasibility of modes and the sequence of activities, space- and impact level-dependent restrictions state further project constraints, which influence the applicability of modes and the activity sequence. Related adaption of the basic method by modelling space- and impact-level-dependent restrictions is described in the following.

6.2.2 Space-dependent restrictions

As the focus of this research is on deconstruction projects performed in urban areas, the space *around* the site is assumed to be limited in general. However, the space *on* site is assessed for deconstruction project planning. It is thereby distinguished between the three site conditions ‘very limited space’ (0), ‘limited space’ (1) and ‘open space’ (2) (DA (2015, p. 174)). These space-dependent restrictions state an additional project constraint, which refers to the overall deconstruction project and is constant over the project duration.

[160] Equation applies to the constrained resources R^{lt} and R^{cw} compared to the required activity-related resources $r^{lt}_{j,m}$ and $r^{cw}_{j,m}$ respectively.

Hence, it is modelled as a ‘renewable resource’, called maximal available space (SP). The available space for the specific deconstruction project can be entered as project constraint via the user interface into the model, described and illustrated in the context of the application of TEE-D-Plan in chapter 7, section 7.2.1.3.

The minimal required space on site of a project activity ($sp_{j,m}$) depends on the mode (see appendix A1). Hence, only those activity modes and parallelisation are applicable, which require equal or less space compared to available space on site (SP). The respectively modelled space-dependent project constraint is shown by Equation 6-6.

Equation 6-6: Space-dependent project constraint

$$\sum_{j=1}^{J} \sum_{m=1}^{M_j} sp_{j,m} \sum_{\tau=1}^{t+p_{j,m}(sz)-1} z_{j,m,\tau} \leq SP \qquad t=1,\ldots,\overline{T}$$

With

$z_{j,m,\tau}$: binary variable (1, if activity j in period t is performed in mode m; 0, else)

SP ∈ $\{0; 1; 2\}$

6.2.3 Impact-level-dependent restrictions

Depending on urban usage types, the neighbourhood of a deconstruction site differs in its sensitivity relating to noise level impacts. DIN 18005-1:2002-07, TA Lärm (1998) and AVV Baulärm (1970) define legal noise impact guideline values related to the neighbourhood usage types of the BauNVO (2013) (Table 6-1).

Table 6-1: Neighbourhood usage types according to BauNVO (2013) and related noise impact guidance values according to DIN 18005-1:2002-07, TA Lärm (1998) and AVV Baulärm (1970)

Neighbourhood usage types according BauNVO (2013) and TA Lärm (1998)		Legal (daytime) noise impact guideline values according DIN 18005-1:2002-07, TA Lärm (1998)
#	Name	dB(A)
	not specified	1000
a	Industrial area	70
b	Commercial area	65
c	City center, village districts and mixed areas	60
d	General housing area	55
e	Residential-only area	50
f	Health resort and hospitals	45

These noise impact guideline values are adopted in the model to define impact level-dependent restrictions, which state an additional project constraint.[161] The impact-level-dependent restrictions refer to the overall deconstruction project and are assumed constant over the project duration. The constraint is modelled as a 'renewable resource', called maximal allowed average noise impact level (LIM). LIM is set equal to the neighbourhood usage type-related legal noise impact guideline value (Table 6-1) depending on the neighbourhood usage type of the specific deconstruction project. The neighbourhood usage type of the project can be specified by the user, decision maker, via the user interface of the model. Information on the user input due to this project constraint is further described and illustrated in the context of the application of TEE-D-Plan in chapter 7, section 7.2.1.3.

The average noise impact level value of an activity ($lim_{j,m}(dc,n^l,sz)$) depends on the mode (and activity parallelisation) and is influenced

[161] In this study it is assumed that deconstruction projects are performed during the day (between 7 am and 8 pm) and within a working day of 8 hours on weekdays. Hence, noise impact guideline values related to day time according to DIN 18005-1:2002-07, AVV Baulärm (1970) and TA Lärm (1998) are included in the model.

by other parameters[162], which are fixed for the project. Hence, only those activity modes (and parallelisation) are applicable, which cause an equal or less activity-related average noise impact level value compared to the maximal allowed noise impact level (LIM). The respectively modelled noise impact level-dependent project constraint shows Equation 6-7

Equation 6-7: Noise impact level-dependent project constraint

$$\sum_{j=1}^{J} \sum_{m=1}^{M_j} lim_{j,m}(dc, n^l, sz) \sum_{\tau=1}^{t+p_{j,m}(sz)-1} z_{j,m,\tau} \leq LIM \qquad t=1,\dots,\overline{T}$$

With

$z_{j,m,\tau}$: binary variable (1, if activity j in period t is performed in mode m; 0, else)

LIM ∈ $\{45; 50; 55; 60; 65; 70; 1000\}$ [dB(A)]

Dependent on the resource-, space and impact level-dependent project constraints, sometimes no activity mode is applicable to perform the single activities. As each activity has to be performed exactly once (see Equation 6-4), this leads to no feasible solution for the problem. If each activity can be performed in at least one mode, there is a feasible solution. But to identify a solution due to the research question, costs across single activity durations, distinct non-linear-scaled noise impact values and time-dependent average impact level values have to be calculated, as they are objective variables. Hence, phase-related economic and environmental plan values are defined in section 6.2.4 as basis for the objective function.

162 The distance from the emission source dc, number of equipollent, coherent noise levels n^l and basic unit size sz.

Furthermore, the objective function of the basic method (Equation 6-1) is adapted in section 6.3.

6.2.4 Phase-related economic and environmental plan values

Phase-related economic and environmental plan values[163] are calculated for phase-related deconstruction alternatives. Based on the set of constraint-dependent feasible/applicable modes of each activity, constraint-dependent feasible alternative phase-related mode-series of each project phase g (ms_g, with ms_g={1;2;…;MS_g}) are built (see section 4.3.2.4).

Due to costs across single activity durations, distinct non-linear-scaled noise impact values and time-dependent average impact level values, these plan parameters have to be calculated for each project phase alternative, including all possible activity modes and parallelisation. Hence, complete enumeration due to all possible project phase alternatives has to be performed. Consequently, to keep the model calculations solvable and according to existing building structures, the deconstruction activities (j_g) of a project phase g (g={1;2;…;G}) are limited to six activities (j_g={1;2;…;J_g}, with J_g= {1;2;…;6}) (see section 4.3.2.4). Additionally, the sequence of the deconstruction activities is predefined. Parallelisation of activities is restricted to activities applied to components of the same types and out of the same materials. Respective parallelisation is modelled by modes. Overall, the set of alternative execution modes for an activity j can encompass up to 34 modes (Mj<=34). Hence, there are up to 34^6 alternatives of one building level-related project phase possible (MS_g<=34^6). Furthermore, the position (pos_g) of a project phase g within the overall deconstruction sequence of a project out of G phases is defined on

[163] Phase duration: $p_{g,msg}$(sz), phase-related costs: $c_{g,msg}$(sz, yr); percentage of phase-related average impact levels: $pc^{lim}_{g,msg}$(dc,n^l,sz), $pc^{sim}_{g,msg}$(sz), $pc^{vim}_{g,msg}$(dc,sz).

the basis of the defined top-down, building level-wise deconstruction sequence (see section 4.3.2.2).

Therefore, within this research all precedence relations between the activities, which are presented in an AoN network plan (see Figure 4 6, Figure 4 7), are fixed and are end-start relations. Depending on the building to be deconstructed and included components, each activity has a fixed position ($pos_j(g,ty)$, see Table 4-9) within the overall deconstruction sequence and an activity cannot start before all predecessors are completed. For each project, TEE-D-Plan generates this sequence and fixes it for all following calculations. As a result, $ES_j=LS_j$ and $EF_j=LF_j$ respectively. Moreover, TEE-D-Plan provides a project plan with information on the allocation of activity-related resources and activity start and finish times based on this ex-ante-fixed activity sequence. In the context of MRCPSP, TEE-D-Plan includes a simplification of current approaches to answer the research question and to keep the problem computational at the same time. In this regard, the activity sequence is not generated in combination with activity parallelisation and resources levelling. Nevertheless, TEE-D-Plan provides the project plan with selected activity-related deconstruction technique modes due to the minimisation of local environmental impacts. Start and finish times of the single activities are calculated via the activity positions in the overall deconstruction sequence and the mode-dependent activity durations. The solution process to provide a solution in the form of the overall deconstruction project plan, encompassing G project phases, due to the objective/s of this research is described in the following section.

6.3 Iterative solution process

Considering the project constraints, an iterative solution process in terms of an iterative objective function is implemented in TEE-D-Plan to find a deconstruction project plan due to the research question. The deconstruction project plan should be a project plan of the discrete project activities, each performed in the most suitable mode. This deconstruction project plan with respective activity-related modes depends on the environmental objectives defined to answer the research question: 'How can the distinct emissions of noise, dust and vibrations caused by a building deconstruction project and the related neighbourhood-dependent impacts on the local environment be mitigated, while considering technical parameters and economic objectives?' Hence, the answer to the research question can be a plan due to the project constraints, which emphases the minimisation of:

- One distinct impact on the local environment and in a second step this plan is evaluated due to the economic objectives (duration and time).
- All distinct impacts at the same time, whereas preferences of the decision maker due to the environmental objectives can be included.

In the following, alternative solution processes to find a solution due to different emphases on environmental and economic objectives are presented.

6.3.1 Minimisation of one distinct environmental impact

The minimisation of one distinct impact on the local environment caused by a deconstruction project (with G project phases) is the objective. Within this context, firstly the solution process due to the objective of minimising the noise level impact of the overall deconstruction project is defined. Thereby, the impact indicator to express the noise level impact is the percentage of the average noise impact level of each project phase[164] (see section 4.5.3.3). The related objective function is described by Equation 6-8. Within this context, the noise level impact of the overall deconstruction project is minimised by minimising the percentage noise impact level of each project phase selected out of the set of alternative mode-series of each project phase g (MS_g). Hence, within this research and in the following descriptions the term ‘solution’ is used in line with the sum of deconstruction phase-related solutions due to a certain objective.

Equation 6-8: Objective function to minimise the noise level impact

$$\mathrm{Min} \sum_{g=1}^{G} \sum_{ms_g=1}^{MS_g} {pc^{lim}}_{g,ms_g}(dc, n^l, sz) * z_{g,ms_g}$$

$$z_{g,ms_g} \in \{0; 1\} \qquad g=1,\ldots,G;\ ms_g= 1,\ldots, MS_g$$

With

$z_{g,msg}$: binary variable (1, if phase g is performed in alternative mode-series ms_g; 0, else)

As several alternative mode-series of one phase can have the same minimal percentage noise impact level, Equation 6-8 might not lead to a unique solution. To get a unique solution and to ensure that each phase and activity respectively is performed exactly once, the objective function is adapted. Within this context, the phase-related economic plan values, phase duration ($p_{g,msg}(sz)$) (see section 4.4.2.1), phase-related costs ($c_{g,msg}(sz,yr)$) (see section 4.4.3.2), are included in the solution process. Therefore, the following iterative solution process is applied to select one single alternative for each project phase as part of the overall project plan:

[164] The phase-related environmental plan value ${pc^{lim}}_{g,msg}(dc,n^l,sz)$.

1. The alternative mode-series with the minimal phase-related percentage noise impact levels ($MS_g^{(lim)}$)[165] are selected.
2. Out of this alternative set of the minimal phase-related percentage noise impact levels the phase alternatives with the minimal phase duration ($MS_g^{(lim;p)}$)[166] are selected.
3. Out of this alternative set of the minimal phase-related percentage noise impact levels and minimal phase duration the single phase alternative with the minimal costs ($ms_g^{(lim;p;c)}$) [167] is selected.

Finally, the respectively selected single alternatives of all project phases are summed (Equation 6-9), resulting in a deconstruction project plan including the discrete most suitable mode for each project activity.

Equation 6-9: Adapted objective function to minimise the noise impact level

$$\sum_{g=1}^{G} ms_g^{(lim;p;c)} * z_{g,ms_g^{(lim;p)}}$$

$$ms_g^{(lim;p;c)} = \left\{ ms_g \middle| ms_g \in MS_g^{(lim;p;c)} \right\}$$

$$MS_g^{(lim;p;c)} = \left\{ ms_g \middle| c_{g,ms_g}(sz,yr) = \min_{ms_g \in MS_g^{(lim;p)}} \left\{ c_{g,ms_g}(sz,yr) \right\} \right\}$$

[165] Due to better readability, the abbreviation (lim) for $pc^{lim}_{g,msg}(dc,n^l,sz)$ is partly used in the following.
[166] Due to better readability, the abbreviation (p) for $p_{g,msg}(sz)$ is partly used in the following.
[167] Due to better readability, the abbreviation (c) for $c_{g,msg}(sz,yr)$ is partly used in the following.

$$MS_g^{(lim;p)} = \left\{ ms_g \middle| p_{g,ms_g}(sz) = \min_{ms_g \in MS_g^{(lim)}} \left\{ p_{g,ms_g}(sz) \right\} \right\}$$

$$MS_g^{(lim)} = \left\{ ms_g \middle| pc_{g,ms_g}^{lim}(dc, n^l, sz) = \min_{ms_g \in MS_g} \left\{ pc_{g,ms_g}^{lim}(dc, n^l, sz) \right\} \right\}$$

$$MS_g = \left\{ ms_g \middle| ms_g \in \{1; 2; \dots; 34^6\} \right\}$$

$$z_{g,ms_g^{(lim;p)}} \in \{0; 1\}$$

g=1,...,G; $ms_g^{(lim;p)}$= 1,..., $MS_g^{(lim;p)}$

With

$z_{g,ms_g^{(lim;p)}}$: binary variable (1, if phase g is performed in alternative $ms_g^{(lim;p)}$; 0, else)

The deconstruction project plan calculated by Equation 6-9 is the solution to minimise the average percentage deconstruction project noise impact levels on the local environment. The economic objectives are included in a second step and the technical feasibility/suitability is considered by technical assessment and project constraints.

Equation 6-9 applies to the solution process due to the objective of minimising the dust emission levels and of minimising the vibration impact levels of the overall deconstruction project respectively. Thereby, the pressure indicator to express the dust emission levels is the average percentage dust emission level of each project phase[168].

[168] The phase-related environmental plan value $pc^{sim}_{g,msg}(sz)$.

Similarly, the average percentage vibration impact level of each project phase[169] is the impact indicator to express the vibration impact levels (see section 4.5.3.3).

6.3.2 Solution due to one distinct economic objective

In addition to the environmental emphasis, the minimisation of one distinct economic plan value, deconstruction project duration or costs, can be the objective of decision makers and are also implemented in the model.

The objective function due to the objective of minimising the overall deconstruction project duration is described by Equation 6-10. It is based on the phase-related economic plan values ($p_{g,msg}$(sz), $c_{g,msg}$(sz,yr)) (see sections 4.4.2.1, 4.4.3.2)) and ensures that each phase and activity respectively is performed exactly once.

Equation 6-10: Objective function to minimise the project duration

$$\sum_{g=1}^{G} ms_g^{(p;c)} * z_{g,ms_g^{(p)}}$$

$$ms_g^{(p;c)} = \left\{ ms_g \middle| ms_g \in MS_g^{(p;c)} \right\}$$

$$MS_g^{(p;c)} = \left\{ ms_g \middle| c_{g,ms_g}(sz,yr) = \min_{ms_g \in MS_g^{(p)}} \left\{ c_{g,ms_g}(sz,yr) \right\} \right\}$$

$$MS_g^{(p)} = \left\{ ms_g \middle| p_{g,ms_g}(sz) = \min_{ms_g \in MS_g} \left\{ p_{g,ms_g}(sz) \right\} \right\}$$

$$MS_g = \left\{ ms_g \middle| ms_g \in \{1; 2; \ldots; 34^6\} \right\}$$

[169] The phase-related environmental plan value $pc^{vim}_{g,msg}$(dc,sz).

$z_{g,ms_g^{(p)}} \in \{0;1\}$

g=1,...,G; $ms_g^{(p)}$= 1,..., $MS_g^{(p)}$

With

$z_{g,ms_g^{(p)}}$: binary variable (1, if phase g is performed in alternative $ms_g^{(p)}$; 0, else)

Equation 6-11 represents furthermore, the objective function due to the objective of minimising the overall deconstruction project costs. It is based on the phase-related economic plan values ($p_{g,msg}(sz)$, $c_{g,msg}(sz,yr)$ (see sections 4.4.2.1, 4.4.3.2)) as well and ensures that each phase and activity respectively is performed exactly once.

Equation 6-11: Objective function to minimise the project costs

$$\sum_{g=1}^{G} ms_g^{(p;c)} * z_{g,ms_g^{(p)}}$$

$$ms_g^{(c;p)} = \left\{ ms_g \middle| ms_g \in MS_g^{(c;p)} \right\}$$

$$MS_g^{(c;p)} = \left\{ ms_g \middle| p_{g,ms_g}(sz) = \min_{ms_g \in MS_g^{(c)}} \left\{ p_{g,ms_g}(sz) \right\} \right\}$$

$$MS_g^{(c)} = \left\{ ms_g \middle| c_{g,ms_g}(sz,yr) = \min_{ms_g \in MS_g} \left\{ c_{g,ms_g}(sz,yr) \right\} \right\}$$

$$MS_g = \left\{ ms_g \middle| ms_g \in \{1;2;\dots;34^6\} \right\}$$

$z_{g,ms_g^{(c)}} \in \{0;1\}$

g=1,…,G; $ms_g^{(c)}$ = 1,…, $MS_g^{(c)}$

With

$z_{g,ms_g^{(c)}}$: binary variable (1, if phase g is performed in alternative $ms_g^{(c)}$; 0, else)

6.3.3 Multi-objective solution based on weighted phase-related alternatives

Alternatively to the solution process due to a single environmental objective by minimising one distinct environmental plan value, a multi-objective solution process is presented in the following. Within this context, weighted phase-related deconstruction alternatives (weighted alternatives[170]) are calculated via Multi-Criteria Decision Analysis (MCDA). As described in section 3.4.2.5, MAVT is selected as the appropriate MCDA approach for this research.

The weighted alternatives are based on the phase-related environmental plan values, the phase-related percentage emission/impact levels of noise, dust and vibrations[171] and on preferences of the decision maker due to the environmental objectives.

The calculation of the weighted alternatives with the help of MAVT requires the following four steps (on the basis of Bertsch (2008, p. 15):

[170] In the following, the term ‘weighted alternatives’ is used for those alternative mode-series of each project phase g evaluated due to multi-objectives.
[171] $pc^{lim}_{g,msg}(dc,n^l,sz)$, $pc^{sim}_{g,msg}(sz)$, $pc^{vim}_{g,msg}(dc,sz)$ (see section 4.5.3.3).

1. Problem structuring
2. Preference elicitation
3. Aggregation
4. Sensitivity analysis

Problem structuring

According to general definitions of MCDA, values affecting the decision are called objectives or decision criteria. The aim of problem structuring is the hierarchical modelling of objectives/criteria and to break down high-level (e.g. strategic) objectives into measurable attributes with the help of an attribute tree (Belton and Stewart (2002, pp. 80, 81)). A two-level hierarchy (Figure 6-1) is applied to answer the research question, by dividing the overall objective, the mitigation of environmental impacts on the local environment, on the first level into three environmental sub-objectives in terms of measurable attributes (ia; with ia={1;2;...;IA) on the second/lowest level. These attributes are linked to the three types of environmental phase-related plan values (with IA=3). Hence, the attributes depict the phase-related percentage dust emission level (ia=2) and phase-related percentage impact levels of noise (ia=1) and vibrations (ia=3).

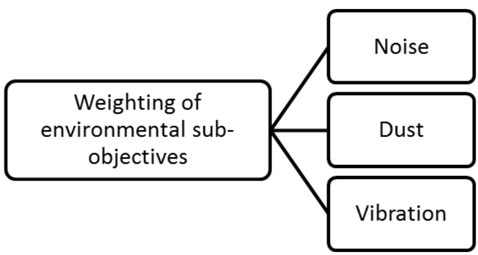

Figure 6-1: Attribute tree

The constraint-dependent feasible deconstruction-phase-related alternative mode-series (ms_g, with ms_g={0;1;…;MS_g}) represent the single alternatives of the decision problem. And the phase-related environmental plan values of each alternative (see section 6.2.4) are the scores of every alternative.

Preference elicitation

Preference elicitation, the second step of MAVT, consists of the following two components (Belton and Stewart (2002, pp. 121-143)):

1. Comparison of different units of different attributes on a common scale by value functions of each alternative related to each attribute (attribute-related value functions).
2. Comparison amongst different sub-objectives/criteria and attributes by weighting vectors/preferences (criteria- and attribute-related weighting vectors).

Attribute-related value functions

To compare the different units of different attributes, all scores (y_{ia}) (the phase-related economic and environmental plan values) are mapped to a common scale ranging from 0 to 1 by attribute-related value functions. According to Bertsch (2008), p. 18 a value function (vf_{ia}) for each attribute (ia) is generally defined by Equation 6-12.

Equation 6-12: Value function

$$vf_{ia}: \begin{cases} \mathbb{R} \rightarrow [0,1] \\ y_{ia} \rightarrow vf_{ia}(y_{ia}) \end{cases}$$

The value functions of the three environmental attributes, phase-related percentage emission/impact levels of noise (ia=1), dust (ia=2) and vibrations (ia=3), are discrete with linearly decreasing preferences.[172] Equation 6-13 and Figure 6-2 show the value function (vf_1) of the attribute phase-related percentage noise impact level (ia=1) as implemented in the model.

Equation 6-13: Value function of the phase-related percentage noise impact level [173]

$$vf_1(y_1) = \frac{y^1_{max} - y_1}{y^1_{max} - y^1_{min}}$$

With

$y^1_{min} = 0\%$

$y^1_{max} = 100\%$

$y_1 = pc^{lim}{}_{g,ms_g}(dc, n^l, sz)$ g=1,…,G, ms_g=1,…,MS_g

[172] The preferences decreases with a higher phase-related environmental plan value (y_{ia}).

[173] Equation applies to the phase-related value functions (vf_2 and vf_3) of the attributes phase-related percentage dust emission level (ia=2) and phase-related percentage vibration impact level (ia=3) respectively.

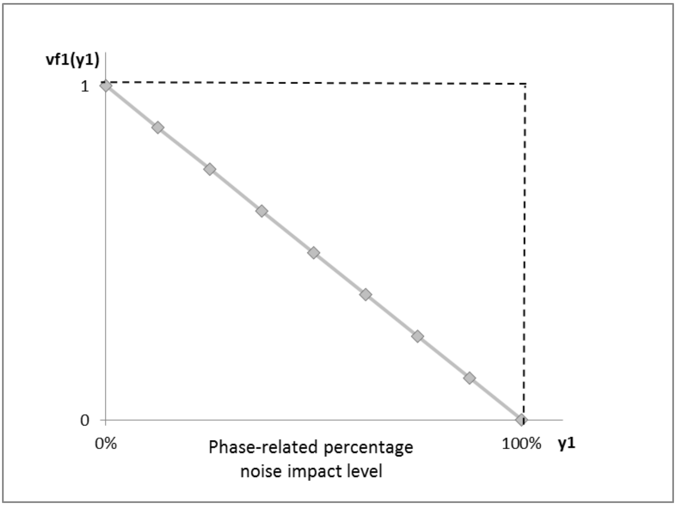

Figure 6-2: Value function with discrete data points of the phase-related percentage noise impact level[174]

In general, a linear relation between the phase-related value (vf_{ia}) and the phase-related environmental plan value (y_{ia}) is assumed. The non-linear-scaled environmental impact levels are assigned to discrete phase-related percentage emission/impact levels of noise, dust and vibration (see section 4.5.3.3), which represent the phase-related environmental plan values. Hence, the phase-related values (vf_{ia}) are discrete as well and the function is in fact an incremental function, as indicated by the data points in Figure 6-2 for noise.

For each environmental attribute, the maximum (y_{max}^{ia}) and minimum plan value (y_{min}^{ia}) are fixed and the same for each deconstruction project. The other normalised plan values of each phase alternative and each environmental attribute are calculated based on a linear scale between the maximum and minimum. Based on the attribute-

[174] Figure applies to the phase-related value functions (vf_2 and vf_3) of the attributes phase-related average impact level values of dust (ia=2) and vibrations (ia=3) respectively.

related value functions, the alternatives of a phase can be compared due to each specific phase-related environmental plan value.

Attribute-related weighting vectors

To make a comparison amongst different sub-objectives, attribute-related weighting vectors are specified in this second component of preference elicitation. According to Bertsch (2008, p. 20) the relative importance between the three sub-objectives is determined. This relative importance is modelled as weights based on qualitative expressed preferences of the decision maker, for instance depending on the neighbourhood characteristics of the individual deconstruction site. Figure 6-3 shows the user interface with the pre-setting of these weights in the model of this research. The pre-setting can be adapted by the preferences of the decision maker via the user interface. Here each valuation, resulting in a weight, depicts the importance of all elements of the second hierarchy level due to the objective of the first level. Similarly, in the pre-setting all environmental attributes on the second level (phase-related percentage impact levels of noise (ia=1) and vibrations (ia=3), phase-related percentage dust emission level (ia=2)) are assumed to have the same importance for the environmental overall objective (first level) (weights/valuations in Figure 6-3).

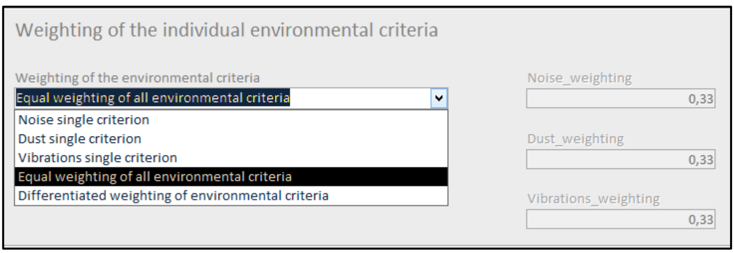

Figure 6-3: Screenshot of the user interface to enter the weights of environmental sub-objectives

The weight of an attribute is simultaneously the global weighting factor of an attribute (w_{ia}) in the model of this research. The weighting vector w = (w_{ia},..., w_{IA}) (with IA=5) summarises all attribute weighting factors. Equation 6-14 shows the constraint of the attribute weighting factor w_{ia} within this context (Hanne (1998, p. 17)).

Equation 6-14: Attribute weighting factor constrains

$\sum_{ia=1}^{IA} w_{ia} = 1$, $w_{ia} \geq 0$ for all ia

Aggregation

After problem structuring and preference elicitation, the overall weighted value of each project phase alternative is calculated by aggregation in the third step of MAVT. Due to clarity and transparency the most widely used additive aggregation (Hanne (1998, p. 17)) is applied within this study to calculate the overall weighted value of a phase alternative vf(ms_g) (also called weighted phase-related deconstruction alternatives or weighted alternatives in the following). Taking into account the attribute weighting factors w_{ia} and value functions vf_{ia} weighted phase-related deconstruction alternatives are calculated by Equation 6-15.

Equation 6-15: Weighted phase-related deconstruction alternatives

$$vf(ms_g) = \sum_{ia=1}^{IA} w_{ia} * vf_{ia}(y_{ia})$$

According to Keeney and Raiffa (1976) all attributes need to be ‘mutually preferentially independent’ to apply the additive aggregation. Hence, in this study mutual preferential independence is presumed for all attributes. According to the definition of preferential independence of Keeney and Raiffa (1976), French (1986), Clemen and Reilly (2001) applied to this research, this means for instance, the preference for a certain outcome with respect to ai=1 (the preference for a minimal phase-related percentage noise impact level) does not depend on the level of outcome with respect to the attribute phase-related percentage dust emission level (ai=2) (on the minimal achieved phase-related percentage dust emission level) and vice versa. After aggregation the overall weighted value of each project phase alternative can be compared. For each phase the alternative with the highest phase-related overall weighted value represents the phase alternative leading to the deconstruction project plan due to the research question and/or the preferences of the decision maker.

As several alternatives of one phase can have the 'highest' phase-related overall weighted value, the multi-objective solution might not lead to a feasible solution, where each phase and activity respectively is performed exactly once. Hence, to ensure that each phase and activity respectively are performed exactly once, the iterative solution process introduced in section 6.3.1 is applied to select one single alternative for each project phase. Within this context the first process step is adapted by selecting the phase alternatives with the highest phase-related overall weighted value ($MS_g^{(vf)}$)[175]. Then, according to section 6.3.1, the phase-related economic plan values, phase duration ($p_{g,msg}(sz)$) (see section 4.4.2.1), phase-related costs ($c_{g,msg}(sz,yr)$) (see section 4.4.3.2), are included in the solution process. The resulting adapted objective function due to multi-objectives is described by Equation 6-16.

[175] Due to better readability, the abbreviation (vf) for max*vf(ms*$_g$) is partly used in the following.

Equation 6-16: Multi-objective function

$$\sum_{g=1}^{G} ms_g^{(vf;p;c)} * z_{g,ms_g^{(vf;p)}}$$

$$ms_g^{(vf;p;c)} = \left\{ms_g \middle| ms_g \in MS_g^{(vf;p;c)}\right\}$$

$$MS_g^{(vf;p;c)} = \left\{ms_g \middle| \underset{ms_g \in MS_g^{(vf;p)}}{c_{g,ms_g}(sz,yr) = min} \left\{c_{g,ms_g}(sz,yr)\right\}\right\}$$

$$MS_g^{(vf;p)} = \left\{ms_g \middle| \underset{ms_g \in MS_g^{(vf)}}{p_{g,ms_g}(sz) = min} \left\{p_{g,ms_g}(sz)\right\}\right\}$$

$$MS_g^{(vf)} = \left\{ms_g \middle| \underset{ms_g \in MS_g}{vf\left(ms_g\right) = max}\left\{vf\left(ms_g\right)\right\}\right\}$$

$$MS_g = \left\{ms_g \middle| ms_g \in \{1; 2; \dots; 34^6\}\right\}$$

$$z_{g,ms_g^{(vf;p)}} \in \{0; 1\}$$

g=1,…,G; $ms_g^{(vf;p)}$= 1,…, $MS_g^{(vf;p)}$

With

$z_{g,ms_g^{(vf;p)}}$: binary variable (1, if phase g is performed in alternative $ms_g^{(vf;p)}$; 0, else)

The robustness of the solution is explored by sensitivity analysis, which is the fourth/last step of MAVT. Here the weighting factors of the different environmental sub-objectives are varied. Sensitivity analysis is performed and presented in chapter 7, section 7.6 within the scope of model application.

7 Application of TEE-D-Plan

In this chapter TEE-D-Plan is applied to different deconstruction projects. Firstly, the model parameters are validated based on two realised deconstruction projects in section 7.1. Secondly, the issues of the main and the deducted applied research questions are analysed on the basis of an existing building to be deconstructed. In this regard, in section 7.2 the base deconstruction project scenario is defined founded on this existing building. Then, different influences are analysed by varying the single parameters of the base deconstruction project scenario. In section 7.3 different building characteristics are varied. Surrounding scenarios are analysed in section 7.4. In section 7.5 the results of TEE-D-Plan due to different project constraints are examined. Finally, in the influence of varying preferences is investigated in section 7.6.

7.1 Validation of the model parameters

The model is tested based on two realised deconstruction projects in Germany in 2015. Within this content, economic model parameters and the calculation of economic plan parameters are validated. Additionally, the significance of model results due to the environmental plan parameters is verified.

7.1.1 Project descriptions

First test project for validation[176]

The first test deconstruction project includes the deconstruction of the structure of a residential building of the type c, masonry – wood construction, in Table 4-1 (section 4.3.1.2). It has masonry outer and inner walls out of brick and wooden slabs and roof. The three building levels above ground and the bottom plate out of reinforced concrete are deconstructed. A building in the neighbourhood borders on the building to be deconstructed. Hence, the shortest distance between the building to be deconstructed and the closest building of the neighbourhood is 0 m. Two reflecting exterior building walls exist adjacent to the building to be deconstructed and facing the closest building[177]. Furthermore, there is space for a single equipment and few site facilities on site. Space on site can be defined by 'very limited space' according to DA (2015, p. 174). Therefore, deconstruction of the upper two building levels (including the roof) as well as material pre-separation and pre-crushing is performed by hand. This is specified as the first deconstruction period. The lowest building level and the bottom plate are specified as the second deconstruction period. Here a 24 t hydraulic crawler excavator with a deconstruction grab, a hydraulic hammer, demolition tongs and a scrap shear as attachments are applied for deconstruction, material pre-separation and pre-crushing.

[176] A former version of the model was tested using the example of this deconstruction project within the research project, this study is related to. Parts of the following descriptions of the model test on the example of this deconstruction project follow the documentation in Kühlen et al. 2016.
[177] Reflecting exterior building walls adjacent to the building to be deconstructed and facing the closest building are for instance shown in Figure 7-12.

Second test project for validation

The second test deconstruction project includes the deconstruction of the structure of an office building of the type e, reinforced-concrete-industrialised building, in Table 4-1 (section 4.3.1.2). It has reinforced concrete outer walls, inner walls out of brick and precast reinforced concrete units as slabs. The four building levels above ground are deconstructed. The bottom plate out of reinforced concrete remains. The next building in the neighbourhood borders on the building to be deconstructed. Hence, the distance from the deconstruction site is 0 m. One reflecting exterior building wall is adjacent to the building to be deconstructed and facing the bordering building. Furthermore, there is space for a medium-sized longfront excavator and some site facilities on site. Space on site can be defined by ‘limited space’ according to DA (2015, p. 174). A 40 t hydraulic crawler excavator with a deconstruction grab and demolition tongs as attachments are applied for deconstruction, material pre-separation and pre-crushing.

7.1.2 Input data

First test project for validation

According to the two periods, deconstruction by hand and by hydraulic crawler excavator, the input data is divided into deconstruction of

1. the upper two building levels (including the roof)
2. the lowest building level and the bottom plate.

The materials, types, dimensions and locations of the single structure components of the first and second period are determined based on plant layouts and building descriptions. Respective information is entered via the input masks of TEE-D-Plan (Figure 4 3 and Figure 4 4 in section 4.3.1.3). Table 7-1 and Table 7-2 show excerpts of the lists of components of the first and second phase. These lists are generated by the model based on the input data.

Table 7-1: Excerpt of the components list of the first period

Building level		Building component type (ty_k)	Material (b_k)	Max. component thickness (th_k)	Material volume (u_k)	Height above ground (hg_k)
#	Name			m	m^3	m
3	Top level	Roof	Wood	0.1	0.8	10.3
3	Top level	Exterior wall	Brick	0.5	29.5	10.3
3	Top level	Interior wall	Brick	0.13	2.7	10.3
2	2nd level	Slab	Wood	0.03	2.3	5.3
2	2nd level	Exterior wall	Brick	0.5	37.7	5.3
2	2nd level	Interior wall	Brick	0.5	4.3	5.3

Table 7-2: Excerpt of the components list of the second period

Building level		Building component type (ty_k)	Material (b_k)	Max. component thickness (th_k)	Material volume (u_k)	Height above ground (hg_k)
#	Name			m	m^3	m
1	1st level	Slab	Wood	0.03	13.8	2.6
1	1st level	Exterior wall	Brick	0.5	42.4	2.6
1	1st level	Interior wall	Brick	0.5	6.8	2.6
1	1st level	Bottom plate	Reinforced concrete	0.2	8.0	0

Deconstruction site constraints and surrounding conditions are drawn from the land-use plan of the area around the deconstruction object and project descriptions. The following information is entered to describe project constraints and surrounding conditions via input masks in the model user interface (Figure 7-13, Figure 7-14, Figure 7-15 in sections 7.2.1.2 and 7.2.1.3):

- Number of available basic units: 1 hydraulic crawler excavator and 1 longfront crawler excavator[178]
- Size of both available basic units: 170kW (40 t)[179]

[178] Hand tools for deconstruction by hand are assumed generally available in this research and in the model.

- Investment year: 2014
- Specific diesel costs per litre: 1.20 €/l[180]
- Available space on site: first period: 'very limited space' (0); second period: 'limited space' (1)
- Shortest distance from the building to be deconstructed to the closest building in the neighbourhood: 0m.
- Number of reflecting objects adjacent to the building to be deconstructed and facing the closest building: 2

To calculate labour costs, the pre-set average salary ASL of 41.10€/h (see section 4.4.2.2) is adapted and set equal to 28.00€/h[181], according to the average salary of the specific project presumed by the deconstruction company, which performed the deconstruction project. The pre-set specific hourly contingency costs per basic unit and specific hourly type-number-related attachment contingency costs of the model (see section 4.4.2.3) are confirmed by the test projects.

Second test project for validation

As in the first test project, materials, types, dimensions and locations of the single structure components of this second deconstruction project are determined based on plant layouts and building descriptions. Respective information is entered via the input masks of TEE-D-Plan (Figure 4 3 and Figure 4 4 in section 4.3.1.3). Excerpts of the building component list generated by the model based on the input data are shown in Table 7-3.

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[179] The size of hand tools (with compressor) is assumed fixed with 20kg in this research and in the model.
[180] User specific adaption of the pre-set and adaptable specific diesel costs per litre (see section 4.4.2.4).
[181] User specific adaption of the pre-set and adaptable average salary ASL in €/h to calculate the labour costs (see section 4.4.2.2).

Table 7-3: Excerpt of the components list of the second test project

Building level		Building component type (ty_k)	Material (b_k)	Max. component thickness (th_k)	Material volume (u_k)	Height above ground (hg_k)
#	Name			m	m^3	m
4	Top level	Roof	Precast reinforced concrete units	0.25	65.4	12.4
4	Top level	Exterior wall	Reinforced concrete	0.4	49.8	12.2
4	Top level	Exterior column	Reinforced concrete	0.25	8.3	12.2
4	Top level	Interior wall	Brick	0.25	37.7	12.2
3	3rd level	Slab	Precast reinforced concrete units	0.25	65.4	9.3
3	3rd level	Exterior wall	Reinforced concrete	0.4	44.3	9.1
3	3rd level	Exterior column	Reinforced concrete	0.25	8.3	9.1
3	3rd level	Interior wall	Brick	0.25	36.8	9.1
2	2nd level	Slab	Precast reinforced concrete units	0.25	65.4	**6.2**
2	2nd level	Exterior wall	Reinforced concrete	0.4	44.3	6
2	2nd level	Exterior column	Reinforced concrete	0.25	8.3	6
2	2nd level	Interior wall	Brick	0.25	32.5	6
1	1st level	Slab	Precast reinforced concrete units	0.25	65.4	3.1
1	1st level	Exterior wall	Reinforced concrete	0.4	38.3	2.9
1	1st level	Exterior column	Reinforced concrete	0.25	7.4	2.9
1	1st level	Interior wall	Brick	0.3	29	2.9

Deconstruction site constraints and surrounding conditions are drawn from the land-use plan of the area around the deconstruction object and project descriptions. The following information is entered to describe project constraints and surrounding conditions via input masks in the model user interface (Figure 7-13, Figure 7-14, Figure 7-15 in sections 7.2.1.2 and 7.2.1.3):

- Number of available basic units: 1 hydraulic crawler excavator
- Size of available basic units: 170kW (40 t)

- Investment year: 2014
- Specific diesel costs per litre: 1.20 €/l[182]
- Available space on site: 'limited space' (1)
- Shortest distance from the building to be deconstructed to the closest building in the neighbourhood: 0 m.
- Number of reflecting objects adjacent to the building to be deconstructed and facing the closest building: 1

To calculate labour costs, the pre-set average salary ASL of 41.10€/h (see section 4.4.2.2) is adapted and set equal to 28.00€/h[183], according to the average salary of the specific project presumed by the deconstruction company, which performed the deconstruction project. The pre-set specific hourly contingency costs per basic unit and specific hourly type-number-related attachment contingency costs of the model (see section 4.4.2.3) are confirmed for the validation.

7.1.3 Output data

In the following, information provided by TEE-D-Plan is introduced, which is used for the validation of the model.

First test project for validation

Firstly, TEE-D-Plan displays information on the overall deconstruction project period in a table. Table 7-4 lists this overall project information of period 1 and 2. Information includes duration, costs and maximum number of equipment and employees in the overall project. Additionally, the average levels of noise and vibration impacts and of dust emissions are is described.

[182] User specific adaption of the pre-set and adaptable specific diesel costs per litre (see section 4.4.2.4).
[183] User specific adaption of the pre-set and adaptable average salary ASL in €/h to calculate the labour costs (see section 4.4.2.2).

Table 7-4: Information of the first overall deconstruction test project

Period	Overall period duration [h]	Overall period costs [€]	Period-related average percentage noise impact levels next to the site and related meaning according to tables 4-12, 4-18	Period-related average percentage dust emission levels next to the site and related meaning according to tables 4-13, 4-18	Period-related average percentage vibration impact levels next to the site and related meaning according to tables 4-14, 4-18	Resources
1	152 (304 man-hours)	11,742	0.875: annoying and hearing damages when longer exposed to painful and hearing damages even when shortly exposed	0.625: medium dust exposure and breathing protection recommended to high dust exposure and breathing protection required	0.375: little vibration noticeable to noticeable vibration with little impulse	2 employees 2 hand tools 1 compressor
2	5 (10 man-hours)	1,030	1: painful and hearing damages even when shortly exposed	0.5: medium dust exposure and breathing protection recommended	0.625: noticeable vibration with little impulse to strongly noticeable vibration with strong impulse	2 employees 1 hydraulic crawler excavator Attachments: deconstruction grab, hydraulic hammer, demolition tongs, scrap shear
Sum	**Sum: 314**	**Sum: 12,772**				

As documented in Table 7-4, period 1 takes 152 h (304 man-hours) and costs 11,742 €. Two employees and two hand tools with one compressor are applied. The calculated impact levels occur at the next building to the site, which borders on the building to be deconstructed, as described above (section 5.1.1 and 5.1.2). Within this context, the average noise impact level of the period is between ‘annoying’ and ‘painful’ and on the interface between causing ‘hearing damages when longer exposed’ and ‘hearing damages even when shortly exposed’. The average dust emission level of the period is between ‘medium and breathing protection is recommended’ and ‘high and breathing protection is required’. The average vibration impact level of the period is ‘little noticeable’ to ‘noticeable with little impulse’.

Period 2 takes 5 h (10 man-hours) and costs 1,030 €. Two employees, one hydraulic crawler excavator and as attachments a deconstruction grab, hydraulic hammer, demolition tongs and scrap shears are applied. The average noise and vibration impact levels of period 2 are higher than those of period 1. The average noise impact level is ‘painful’ and causes ‘hearing damages even when shortly exposed’.

The average vibration impact level of the period is ‘noticeable with little impulse’ to ‘strongly noticeable with strong impulse’. The average dust emission level of period 2 is less than this of period 1 and is ‘medium’ and ‘breathing protection is recommended’.

Secondly, TEE-D-Plan displays the deconstruction project plan[184] due to minimal project duration and minimal project costs. This plan is presented in the form of a Gantt chart based on the single building-component-related activity segments (d_j, o_j, q_j) of the deconstruction process and activity-related most appropriate deconstruction techniques (modes m). Furthermore, histograms of levels of the specific environmental plan values in terms of percentage emission/impact levels between 1 and 0 and of the number of resources over time related to the single activity segments are shown by TEE-D-Plan. Respective Gantt charts and histograms of period 1 and 2 are illustrated in Figure 7-1, Figure 7-2, Figure 7-3, Figure 7-4, Figure 7-5, Figure 7-6.

[184] As outlined in section 6.3.1, this plan is a solution in line with the sum of deconstruction phase-related solutions due to a certain objective within this research.

Activity #(j)	Building level #	Building component type (ty_c)	Mode (m)	Activity segement (ej,m/oj,m/zj,m)	Activity duration (Dej,m/oj,m/zj,m) [h]	Overall project duration [h] Start (ESej,m/ oj,m/zj, m)	Finish (EFej,m/ oj,m/zj, m)
1	3	Roof	Dec_HA_1	Deconstruction	0.9	0	0.9
1	3	Roof	Dec_HA_1	Pre-sorting	0	0.9	0.9
1	3	Roof	Dec_HA_1	Pre-crushing	0	0.9	0.9
2	3	Exterior wall	Dec_HA_1	Deconstruction	59	0.9	59.9
2	3	Exterior wall	Dec_HA_1	Pre-sorting	0	59.9	59.9
2	3	Exterior wall	Dec_HA_1	Pre-crushing	0	59.9	59.9
3	3	Interior wall	Dec_HA_1	Deconstruction	5.4	59.9	65.3
3	3	Interior wall	Dec_HA_1	Pre-sorting	0	65.3	65.3
3	3	Interior wall	Dec_HA_1	Pre-crushing	0	65.3	65.3
4	2	Slab	Dec_HA_1	Deconstruction	2.8	65.3	68.1
4	2	Slab	Dec_HA_1	Pre-sorting	0	68.1	68.1
4	2	Slab	Dec_HA_1	Pre-crushing	0	68.1	68.1
5	2	Exterior wall	Dec_HA_1	Deconstruction	75.5	68.1	143.5
5	2	Exterior wall	Dec_HA_1	Pre-sorting	0	143.5	143.5
5	2	Exterior wall	Dec_HA_1	Pre-crushing	0	143.5	143.5
6	2	Interior wall	Dec_HA_1	Deconstruction	8.7	143.5	152.2
6	2	Interior wall	Dec_HA_1	Pre-sorting	0	152.2	152.2
6	2	Interior wall	Dec_HA_1	Pre-crushing	0	152.2	152.2

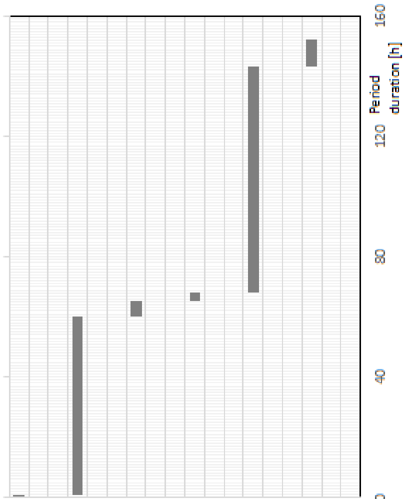


Figure 7-1: Gantt chart with activity-related technique modes of period 1 of the first test deconstruction project

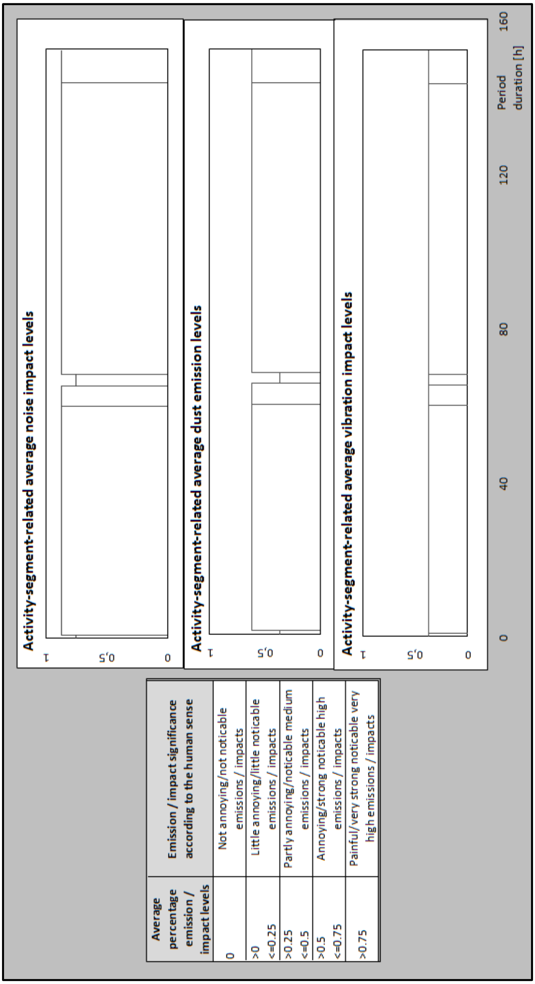


Figure 7-2: Histograms of the levels of the specific environmental plan values in terms of average percentage emission/impact levels between 0 and 1 (0 to 100%) over time related to the single activity segments of period 1 of the first test deconstruction project

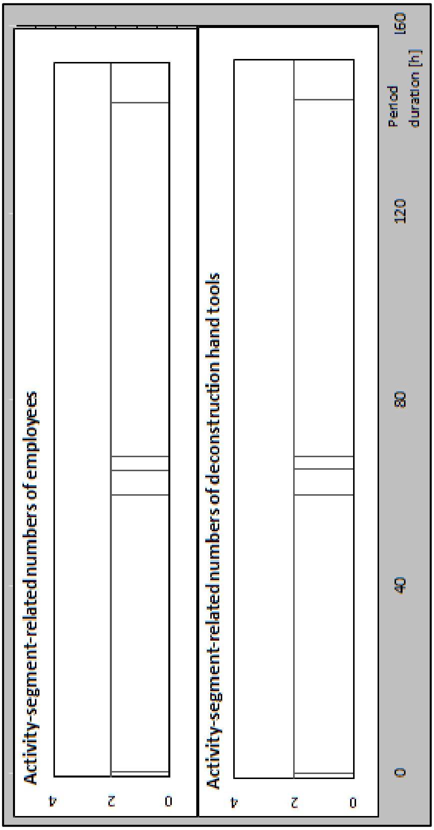


Figure 7-3: Histograms of the numbers of resources over time related to the single activity segments of period 2 of the first test deconstruction project

As shown in the Gantt chart of period 1 (Figure 7-1), the components of the upper two building levels (including the roof) can be deconstructed by hand with hand tools and one compressor only, due to the 'very limited' available space on site.

Activity # (j)	Building level #	Building component type (ty_c)	Mode (m)	Activity segement (ej,m/oj,m/zj,m)	Activity duration (Dej,m/oj,m/zj,m) [h]	Overall project duration [h]: Start (ESej,m/oj,m/zj,m)	Overall project duration [h]: Finish (EFej,m/oj,m/zj,m)
1	1	Slab	Cut_HY_1	Deconstruction	1.1	0	1.1
1	1	Slab	Cut_HY_1	Pre-sorting	0.3	1.1	1.4
1	1	Slab	Cut_HY_1	Pre-crushing	0	1.4	1.4
2	1	Exterior wall	Press_HY_1	Deconstruction	1.2	1.4	2.6
2	1	Exterior wall	Press_HY_1	Pre-sorting	0.8	2.6	3.4
2	1	Exterior wall	Press_HY_1	Pre-crushing	0	3.4	3.4
3	1	Interior wall	Press_HY_1	Deconstruction	0.2	3.4	3.6
3	1	Interior wall	Press_HY_1	Pre-sorting	0.1	3.6	3.8
3	1	Interior wall	Press_HY_1	Pre-crushing	0	3.8	3.8
4	1	Bottom plate	Mort_HY_1	Deconstruction	0.5	3.8	4.2
4	1	Bottom plate	Mort_HY_1	Pre-sorting	0.2	4.2	4.4
4	1	Bottom plate	Mort_HY_1	Pre-crushing	0.3	4.4	4.7

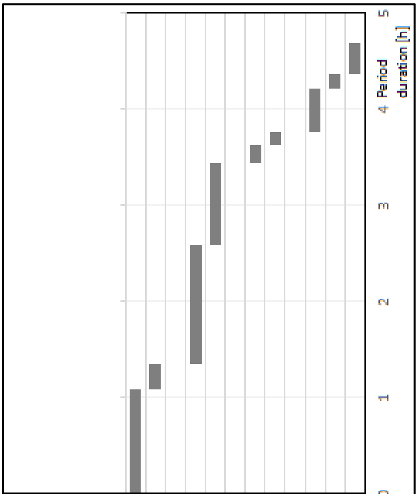
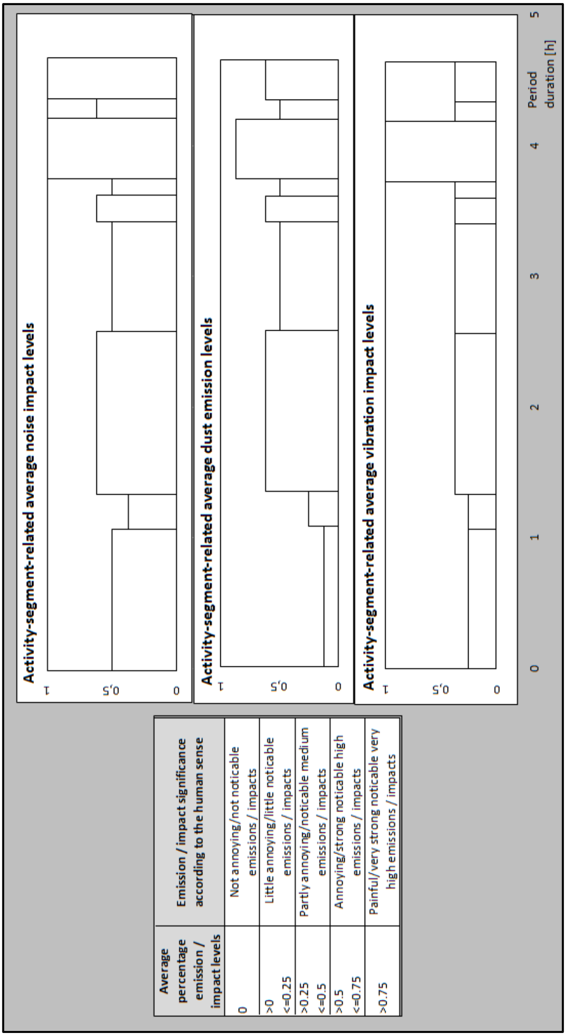


Figure 7-4: Gantt chart with activity-related technique modes of period 2 of the first test deconstruction project



Average percentage emission / impact levels	Emission / impact significance according to the human sense
0	Not annoying/not noticable emissions / impacts
>0 <=0.25	Little annoying/little noticable emissions / impacts
>0.25 <=0.5	Partly annoying/noticable medium emissions / impacts
>0.5 <=0.75	Annoying/strong noticable high emissions / impacts
>0.75	Painful/very strong noticable very high emissions / impacts

Figure 7-5: Histograms of the levels of the specific environmental plan values in terms of average percentage emission/impact levels between 0 and 1 (0 to 100%) over time related to the single activity segments of period 2 of the first test deconstruction project

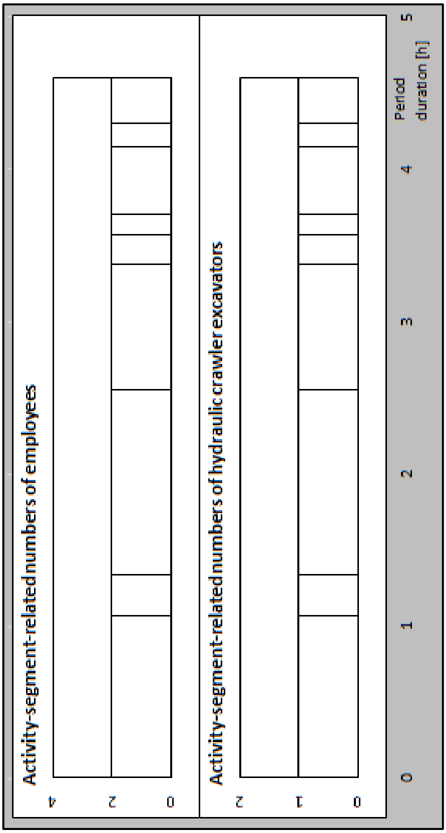


Figure 7-6: Histograms of the numbers of resources over time related to the single activity segments of period 2 of the first test deconstruction project

The Gantt chart of period 2 (Figure 7-4) includes the different activity-related deconstruction techniques (modes), which are recommended by TEE-D-Plan to deconstruct the components of the lowest building level and the bottom plate. Under the conditions of 'limited space' on site, one available 170kW-(40 t-)hydraulic crawler excavator and the minimisation of the overall project costs or duration respectively, cutting of the wooden slab, press-cutting of the outer and inner walls out of brick and mortising of the bottom plate are suggested.

Second test project for validation

Information about the overall deconstruction project, displayed by TEE-D-Plan, including duration, costs, maximal number of equipment and employees of the overall project and the average level of noise, dust and vibration impact/emission, is listed in Table 7-5.

Table 7-5: Information about the second overall deconstruction test project

Overall project duration [h]	Overall project costs [€]	Overall-project-related average percentage noise impact levels next to the site and related meaning according to tables 4-12, 4-18	Overall-project-related average percentage dust emission levels next to the site and related meaning according to tables 4-13, 4-18	Overall-project-related average percentage vibration impact levels next to the site and related meaning according to tables 4-14, 4-18	Resources
84 (168 man-hours)	19,140	0.75: annoying and hearing damages when longer exposed	0.75: high dust exposure and breathing protection required	0.5: noticeable vibration with little impulse	2 employees 1 hydraulic crawler excavator 1 longfront crawler excavator Attachments: deconstruction grab, demolition tongs

As documented in Table 7-5, the project takes 84 h (168 man-hours) and costs 19,140 €. Two employees, one hydraulic crawler excavator, one longfront crawler excavator and attachments in the form of a deconstruction grab and demolition tongs are applied. The calculated impact levels occur at the next building to the site, which borders on the building to be deconstructed, as described above (section 7.1.1 and 7.1.2). Within this context, the average noise impact level of the period is ‘annoying’ and causes ‘hearing damages when longer exposed’. The average dust emission level of the period is ‘high’ and ‘breathing protection is required’. The average vibration impact level of the period is ‘noticeable with little impulse’.

Furthermore, the minimum cost-related and minimum duration-related deconstruction plan of this second test project is displayed as a Gantt chart by TEE-D-Plan with respective histograms, as described above for the first test project. These Gantt chart and histograms of the second test project are illustrated in Figure 7-7, Figure 7-8, Figure 7-9.

						Overall project duration [h]	
Activity #(j)	Building level #	Building component type (ty_c)	Mode (m)	Activity segement (ej,m/oj,m/zj,m)	Activity duration (Dej,m/oj,m/zj,m) [h]	Start (ESej,m/oj,m/zj,m)	Finish (EFej,m/oj,m/zj,m)
1	4	Roof	Press_LT_1	Deconstruction	12.2	0	12.2
1	4	Roof	Press_LT_1	Pre-sorting	1.3	12.2	13.5
1	4	Roof	Press_LT_1	Pre-crushing	0.6	13.5	14.1
2	4	Exterior wall	Press_LT_1	Deconstruction	9.3	14.1	23.4
2	4	Exterior wall	Press_LT_1	Pre-sorting	1	23.4	24.4
2	4	Exterior wall	Press_LT_1	Pre-crushing	0.4	24.4	24.8
3	4	Exterior pillar	Press_LT_1	Deconstruction	1.6	24.8	26.4
3	4	Exterior pillar	Press_LT_1	Pre-sorting	0.1	26.4	26.5
3	4	Exterior pillar	Press_LT_1	Pre-crushing	0.1	26.5	26.6
4	4	Interior wall	Press_LT_1	Deconstruction	3.7	26.6	30.3
4	4	Interior wall	Press_LT_1	Pre-sorting	0.8	30.3	31.1
4	4	Interior wall	Press_LT_1	Pre-crushing	0	31.1	31.1
5	3	Slab	Press_LT_1	Deconstruction	12.2	31.1	43.3
5	3	Slab	Press_LT_1	Pre-sorting	1.3	43.3	44.6
5	3	Slab	Press_LT_1	Pre-crushing	0.6	44.6	45.2
6	3	Exterior wall	Press_LT_1	Deconstruction	8.2	45.2	53.4
6	3	Exterior wall	Press_LT_1	Pre-sorting	0.9	53.4	54.3
6	3	Exterior wall	Press_LT_1	Pre-crushing	0.4	54.3	54.7
7	3	Exterior pillar	Press_LT_1	Deconstruction	1.5	54.7	56.3
7	3	Exterior pillar	Press_LT_1	Pre-sorting	0.1	56.3	56.4
7	3	Exterior pillar	Press_LT_1	Pre-crushing	0.1	56.4	56.5
8	3	Interior wall	Press_LT_1	Deconstruction	3.6	56.5	60.1
8	3	Interior wall	Press_LT_1	Pre-sorting	0.7	60.1	60.8
8	3	Interior wall	Press_LT_1	Pre-crushing	0	60.8	60.8
9	2	Slab	Press_HY_1	Deconstruction	3.8	60.8	64.6
9	2	Slab	Press_HY_1	Pre-sorting	1.3	64.6	65.9
9	2	Slab	Press_HY_1	Pre-crushing	0.7	65.9	66.6
10	2	Exterior wall	Press_HY_1	Deconstruction	2.6	66.6	69.2
10	2	Exterior wall	Press_HY_1	Pre-sorting	0.9	69.2	70.1
10	2	Exterior wall	Press_HY_1	Pre-crushing	0.4	70.1	70.5
11	2	Exterior pillar	Press_HY_1	Deconstruction	0.5	70.5	80
11	2	Exterior pillar	Press_HY_1	Pre-sorting	0.1	80	71.1
11	2	Exterior pillar	Press_HY_1	Pre-crushing	0.1	71.1	71.2
12	2	Interior wall	Press_HY_1	Deconstruction	1	71.2	72.2
12	2	Interior wall	Press_HY_1	Pre-sorting	0.6	72.2	72.8
12	2	Interior wall	Press_HY_1	Pre-crushing	0	72.8	72.8
13	1	Slab	Press_HY_1	Deconstruction	3.8	72.8	76.6
13	1	Slab	Press_HY_1	Pre-sorting	1.3	76.6	77.9
13	1	Slab	Press_HY_1	Pre-crushing	0.7	77.9	78.6
14	1	Exterior wall	Press_HY_1	Deconstruction	2.2	78.6	80.8
14	1	Exterior wall	Press_HY_1	Pre-sorting	0.8	80.8	81.6
14	1	Exterior wall	Press_HY_1	Pre-crushing	0.4	81.6	82
15	1	Exterior pillar	Press_HY_1	Deconstruction	0.4	82	82.4
15	1	Exterior pillar	Press_HY_1	Pre-sorting	0.1	82.4	82.5
15	1	Exterior pillar	Press_HY_1	Pre-crushing	0.1	82.5	82.6
16	1	Interior wall	Press_HY_1	Deconstruction	0.9	82.6	83.5
16	1	Interior wall	Press_HY_1	Pre-sorting	0.6	83.5	84.1
16	1	Interior wall	Press_HY_1	Pre-crushing	0	84.1	84.1

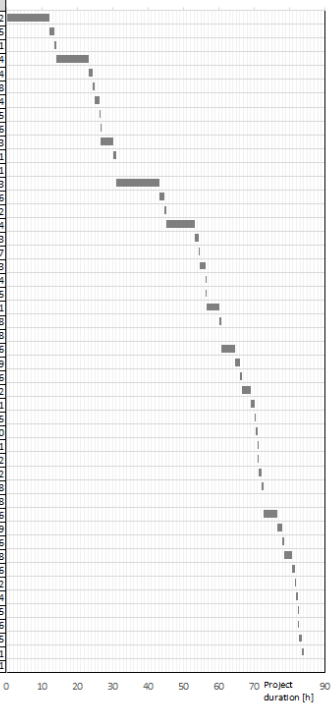


Figure 7-7: Gantt chart with activity-related technique modes of the second test deconstruction project

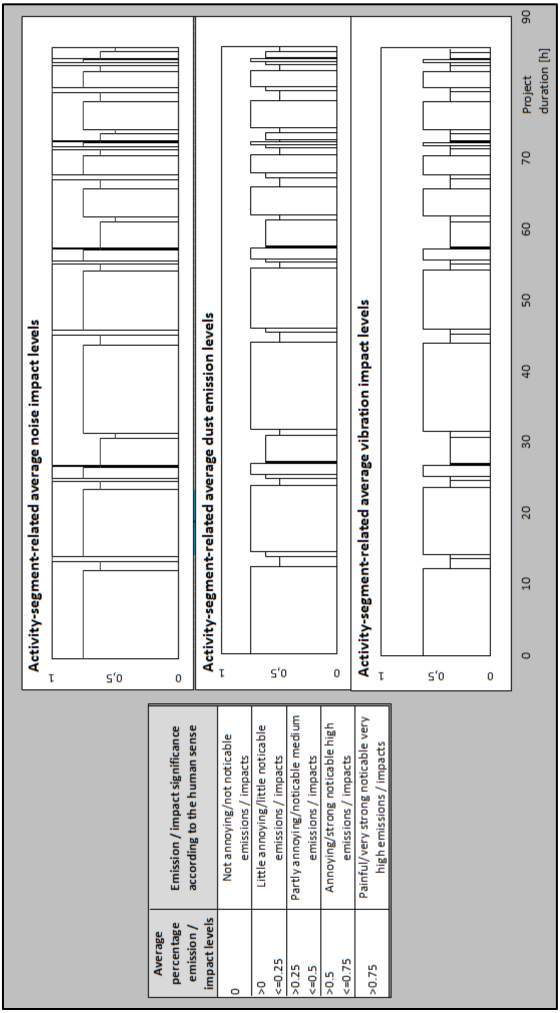


Figure 7-8: Histograms of the levels of the specific environmental plan values in terms of average percentage emission/impact levels between 0 and 1 (0 to 100%) over time related to the single activity segments of the second test deconstruction project

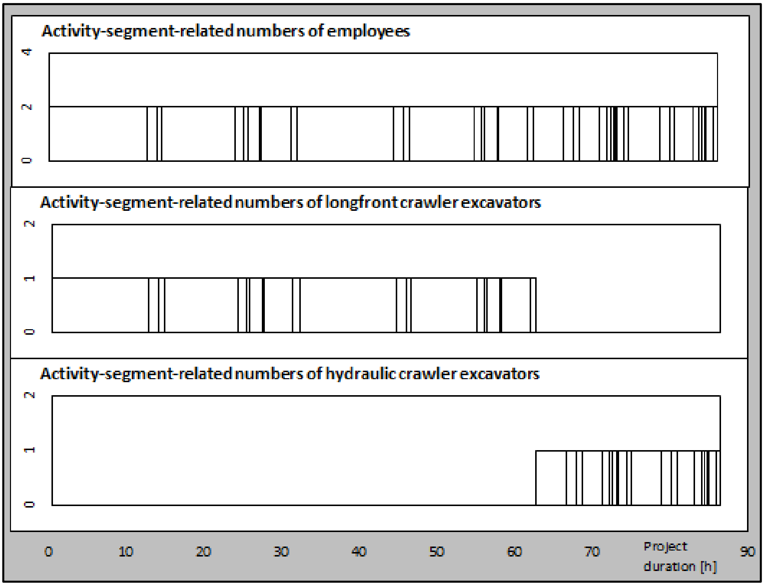


Figure 7-9: Histograms of the numbers of resources over time related to the single activity segments of the second test deconstruction project

As shown in the Gantt chart of the second test project (Figure 7-7), TEE-D-Plan recommends to deconstruct all building components on all levels with the technique (mode) 'press-cutting' under the conditions of 'limited space' on site and the minimisation of the overall project costs or duration respectively. As illustrated, the 170kW-(40 t-)longfront crawler excavator has to be applied to deconstruct the upper two building levels, due to great heights above ground. For deconstruction of the lower two building levels the 170kW-(40 t-)hydraulic crawler excavator is recommended.

7.1.4 Comparison of results and conclusion

For both deconstruction project tests/examples the results of TEE-D-Plan in terms of calculated economic plan parameters are similar to the realised economic values of the project. Applied resources outlined by TEE-D-Plan in the context of cost minimisation match those used on site in practice. Permanent measurements of impacts throughout the deconstruction project would be necessary to compare the distributions of impacts over time during the deconstruction project duration and single impact levels at those buildings closest to the sites, displayed by TEE-D-Plan. In general, to date, required permanent measurements of noise, dust and vibrations respectively are not performed on regular deconstruction sites (Reinhardt et al. (2014)). Hence, for both realised deconstruction projects, respective data is not available and the validation of related model parameters and results cannot be carried out. Nevertheless, in some cases, limited validation of percentage noise level impacts levels is possible by comparison with generic literature values of noise level impacts of selected deconstruction activities.

Costs

TEE-D-Plan calculates the costs of single production factors/resources, as described in sections 4.4.2 and 4.4.3. The calculated costs of resources, including staff, equipment contingency and operation-related equipment costs, of the first test/example project are 12.772 € (see Table 7-4). In reality, the costs of the deconstruction project based on these single resources were 14.170 €. Hence, in this case the model results are 10% lower than the realised costs. The calculated resource costs of the second test/example project are 19,140 € (see Table 7-5) and therefore 11% higher than the realised costs of 17,130 €.

This cost deviation of TEE-D-Plan of around 10 % higher or lower realised project costs is accepted. In addition, as described in section 4.4.2, the user can individually modify specific costs of labour and equipment via the user interface, to analyse their influence on the overall project costs.

Duration

Furthermore, TEE-D-Plan calculates 314 man-hours for the deconstruction of the first test/example project (see Table 7-4). 317 man-hours were required to perform the deconstruction project in reality. The deviation in hours is minor at less than 1%. The calculated man-hours of 168 (see Table 7-5) of the second test/example project are 5% higher than the realised 160 man-hours. This time deviation of TEE-D-Plan of around 5% higher or lower realised project man-hours is also accepted.

Resources

The selected resources of TEE-D-Plan for period 1 and 2 of the first test/example project, two employees, two hand tools, one compressor, one hydraulic crawler excavator and attachments in the form of a deconstruction grab, hydraulic hammer, demolition tongs and scrap shears and are the same as actually applied. The same statement is valid for of the second test/example. In this context, firstly, a longfront crawler excavator was applied to deconstruct the upper two building levels, due to the great heights above ground. Secondly, the lower two building levels were deconstructed with a hydraulic crawler excavator. Within this context attachments in the form of a deconstruction grab and demolition tongs are used.

Environmental impacts

As mentioned above, validation of the environmental model results is limited. Merely the meaning of the average percentage noise impact levels of period 1 of the first test/example project can be compared with the generic noise level impacts in literature. The comparison is possible as only hand tools are applied throughout the overall period and the closest building to site borders the deconstruction object so that the noise emission level plus noise reflections of two walls[185] results in the relevant impact level. According to BGBAU- Noise (2016) and LfU (2013, p. 7), the average noise level of a pneumatic hammer is 100 dB(A) and of a compressor 90 dB(A). Hence, the average noise level of deconstruction by hand with two hand tools and one compressor is between 100 and 110 dB(A) (on the basis of Sengpiel (2016a)). With the noise level increase of about 10 dB(A), according to Equation 4 14 in section 4.5.3.1., due to the two reflecting walls, this results in an average noise level between 110 and 120 dB(A). This noise level is between 'annoying and hearing damages when longer exposed' to 'painful and hearing damages even when shortly exposed' according Table 4-12 in section 4.5.2.1. As shown in Table 7-4, TEE-D-Plan displays a period-related average noise impact level of between 'annoying' and 'painful' and on the interface between causing 'hearing damages when longer exposed' to 'hearing damages even when shortly exposed'.

Consequently, economic model parameters and the calculation of economic plan parameters are validated based on the two test/example deconstruction projects by comparing results related to project costs, durations and applied resources. Furthermore, the significance of model results due to the environmental plan parameters is verified.

In the following sections, TEE-D-Plan is applied to different deconstruction scenarios and respective model results are compared to answer the main and the deducted applied research questions. The

[185] According to Equation 4 14 in section 4.5.3.1, two reflecting walls cause a noise level increase of about 10 dB(A).

base deconstruction scenario, founded on an existing building to be deconstructed, is defined in section 7.2. It includes distinct building characteristics, surrounding conditions, project constraints and preferences/objectives. Afterwards different influences are analysed by varying single parameters of the base scenario. Within this context, firstly the preferences/objectives are varied in section 7.3 in terms of preference/objective scenarios. Secondly, the differing building characteristics are examined as building scenarios in section 7.4. Thirdly, the surrounding conditions are varied in terms of surrounding scenarios in section 7.5. Finally, diverse project constraints are analysed via project scenarios in section 7.6.

7.2 Base deconstruction scenario

In this section the base deconstruction scenario, which is founded on an existing building to be deconstructed, is defined.

7.2.1 Scenario input parameters

All information of the base deconstruction scenario is entered via the single masks of the model user interface. The single scenario parameters are described in the following in terms of distinct building characteristics, surrounding conditions, project constraints and preferences/objectives.

7.2.1.1 Building characteristics

In the base scenario the building to be deconstructed represents the existing building to be deconstructed and is a residential building of the type c, masonry – wood construction, in Table 4-1 (section 4.3.1.2). The characteristics of the building structure, including materials, types, dimensions and locations of the single structure components, are determined based on plant layouts (Figure 7-10,

Figure 7-11) and building descriptions. Figure 7-10 shows the plan view of the 1st and 2nd level of the building structure. Figure 7-11 maps the building structure section.

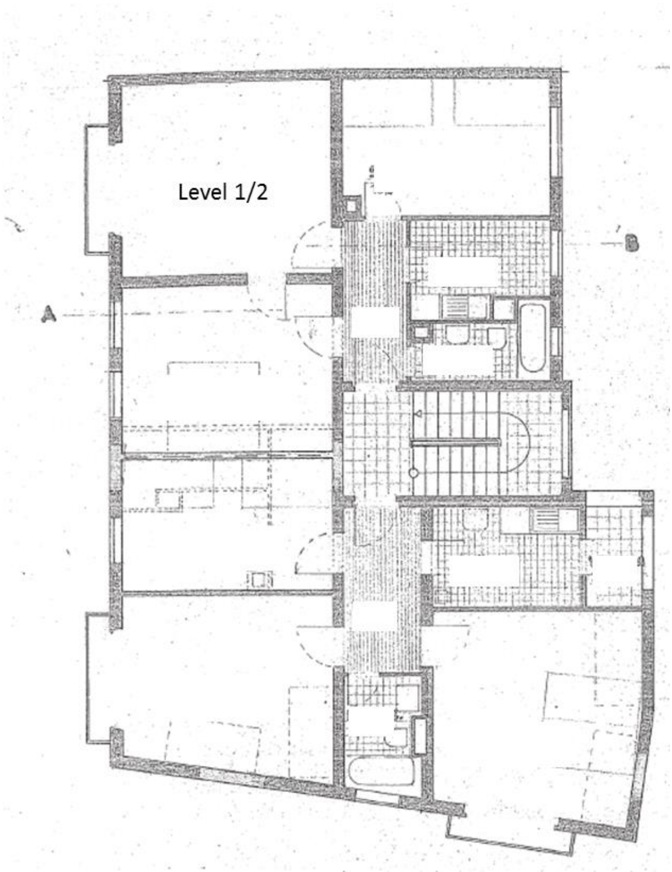


Figure 7-10: Building structure plan view of the 1st and 2nd level

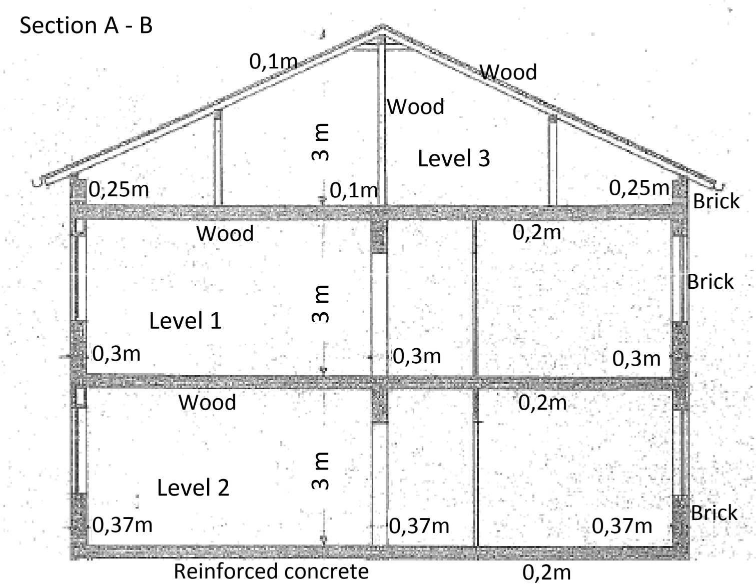


Figure 7-11: Building structure section

Selected building structure characteristics of the base scenario related to the single building components are listed in Table 7-6. In total the building has a rounded up material volume of 235 m^3.

Table 7-6: List of components of the base scenario

Building level		Building component type (ty_k)	Material (b_k)	Max. component thickness (th_k)	Material volume (u_k)	Height above ground (hg_k)
#	Name			m	m^3	m
3	Top level	Roof	Wood	0.1	5.4	9
3	Top level	Exterior wall	Brick	0.25	33.1	9
3	Top level	Interior wall	Wood	0.1	1.5	9
2	2nd level	Slab	Wood	0.2	39	6
2	2nd level	Exterior wall	Brick	0.3	35.3	6
2	2nd level	Interior wall	Brick	0.3	25.4	6
1	1st level	Slab	Wood	0.2	39	3
1	1st level	Exterior wall	Brick	0.37	34.4	3
1	1st level	Interior wall	Brick	0.37	32.2	3
1	1st level	Bottom plate	Reinforced concrete	0.2	39	0

The building characteristics are entered into the model as a text file, specific formatted, as shown in Figure 4-5 (section 4.3.1.3).

7.2.1.2 Surrounding conditions

The surrounding conditions around the deconstruction site of the base scenario are drawn from the land-use plan of the area, where the existing building is located (Figure 7-12).

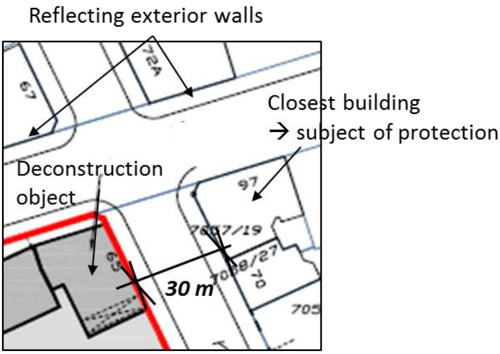


Figure 7-12: Land-use plan around the deconstruction object (bottom left) with the subject of protection (right) and reflecting exterior walls (top left, top middle, right)

As shown in Figure 7-12, the shortest distance from the building to be deconstructed to the closest building in the neighbourhood is 30 m. Furthermore, two reflecting objects in terms of exterior building walls adjacent to the building to be deconstructed and facing to the closest building exist. The surrounding conditions are entered via the model input mask shown in Figure 7-13.

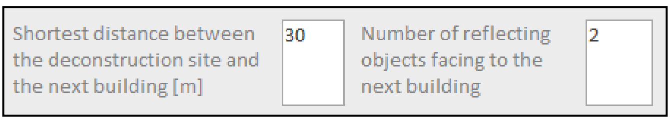


Figure 7-13: Input mask for surrounding conditions: left input box for the shortest distance to the next building and right input box for the number of reflecting objects

7.2.1.3 Project constraints

Firstly, the available resources on site are defined in terms of available number and sizes of basic unit types. In the base scenario all basic units implemented in TEE-D-Plan can be theoretically used, including two hydraulic crawler excavators, two longfront crawler excavators and two cable-operated excavators. The two hydraulic crawler excavators and two longfront crawler excavators are of the size 170 kW (40 t). The two cable-operated excavators have the unit size 600 tm. Furthermore, the investment year (yr) is 2014 to calculate the contingency costs of basic units. Available basic units and the investment year are entered via the model input mask shown in Figure 7-14.

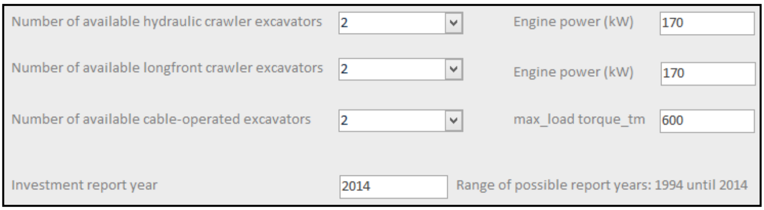


Figure 7-14: Input mask for the specification of available basic units (upper six input boxes) and the investment year (lowest input box)

The pre-set specific diesel costs of 1.17€/l, specific hourly contingency costs per basic unit and specific hourly type-number-related attachment contingency costs of TEE-D-Plan are accepted in the base scenario. Respectively, the pre-set average salary ASL of 41.10€/h is confirmed to calculate labour costs. In general, these specific hourly costs can be adapted by the decision maker via input masks. Figure 7-15 illustrates an extract of the input mask for the adaption of specific hourly type-number-related attachment contingency costs in the right column. Nevertheless, for the model application within this research the model-inherent specific costs, calculated in sections 4.4.2.2 to 4.4.2.4, are confirmed.

FS_ID_a	VW_DB_a	BR_ka_e
1	1 deconstruction grab for HY	23,78 €
2	1 steel mass for CE	0,75 €
3	1 long stick / backhoe for HY	3,59 €
4	1 hydraulic hammer for HY	38,49 €
5	1 demolition tongs for HY	23,78 €
6	1 steel-/scrap shear for HY	23,78 €

Figure 7-15: Extract of the input mask for the adaption of specific hourly type-number-related attachment contingency costs in the right column

Available space on site of the base scenario can be deducted from the land-use plan as well. As shown in Figure 7-12, there is a relative large area behind the building on the far side of the street, where deconstruction equipment can be easily placed. Hence, 'open space' (2) (Figure 7-16, bottom list item) is selected from the three site description options of the model user interface.

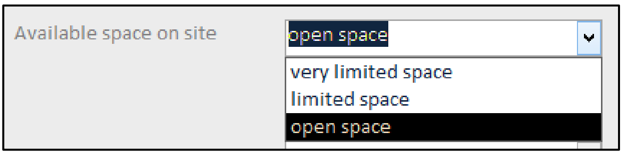


Figure 7-16: Input mask for the specification of available space on site selected from a list of three site description options

Additionally, the general sensitivity of the neighbourhood of the deconstruction site related to noise level impacts is considered in terms of a maximum noise level impact, which cannot be exceeded.

This neighbourhood sensitivity and the related maximal noise level impact depend on the urban usage type of the neighbourhood. The urban usage type can be deducted from the land-use plan of the area of and around the deconstruction site. The urban usage type of and around the existing building to be deconstructed is not specified in the respective land-use plan. Hence, in the base scenario the option of the urban usage type 'not defined' (Figure 7-17, top list item) is selected from the seven urban usage type options of the user interface. This results in no restrictions in terms of a maximal noise level impact.

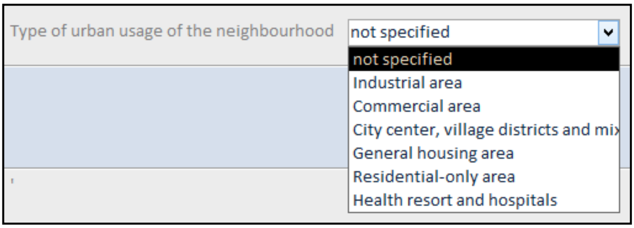


Figure 7-17: Input mask for the specification of the urban usage type selected from a list of seven usage type options

7.2.1.4 Preferences/objectives

To find a deconstruction project plan due to the main research question and by focusing on the mitigation of noise impacts on the local environment, the objective of the base scenario is the minimisation the overall deconstruction project average noise impact levels. The respective objective function represented by Equation 6-10 (see section 6.3.1). The minimisation the overall average noise impact levels as the single environmental objective to calculate the deconstruction plan is pre-set in TEE-D-Plan. The influence of different preference scenarios with varying objectives is analysed in section 7.6.

7.2.2 Model results

Based on the input parameters TEE-D-Plan calculates the deconstruction project plan for the base deconstruction scenario. Table 7-7, Figure 7-18, Figure 7-19 and Figure 7-20 show the model results, summarised and presented via the user interface in output masks. Information about the overall project of the proposed deconstruction project plan for the base deconstruction scenario is listed in Table 7-7. This information includes duration, costs, maximum number of equipment and employees of the overall project and the average level of noise, dust and vibration impact/emission.

Table 7-7: Information about the overall deconstruction project of the base scenario

Overall project duration [h]	Overall project costs [€]	Overall-project-related average percentage noise impact levels next to the site and related meaning according to tables 4-12, 4-18	Overall-project-related average percentage dust emission levels next to the site and related meaning according to tables 4-13, 4-18	Overall-project-related average percentage vibration impact levels next to the site and related meaning according to tables 4-14, 4-18	Resources
23 (46 man hours)	5,460	0.25: little annoying	0.5: medium dust exposure and breathing protection recommended	0: no vibration noticeable	2 employees 1 hydraulic crawler excavators Attachments: 1 deconstruction grab, 1 long stick/backhoe, 1 pair of demolition tongs, 1 pair of scrap shears

As outlined in Table 7-7, the project plan of the overall base scenario takes 23 h/3 days and costs approximately 5,460 €. Two employees, one hydraulic crawler excavator and as attachments one deconstruction grab, one longstick/backhoe, one pair of demolition tongs and one pair of scrap shears are applied. The calculated impact levels occur at the closest building to the site, which is 30 m away from site (see section 7.2.1.2, Figure 7-12). At this closest building the average noise impact level related to the overall project is little annoying. The average dust emission level of the project is medium and breathing protection is recommended. Overall-project-related no vibrations are noticeable.

The deconstruction project plan of the base scenario due to minimum overall project average noise impact levels is illustrated in Figure 7-18 in the form of a Gantt chart with activity-related technique modes.

Activity # (j)	Building level #	Building component type (ty_c)	Mode (m)	Activity segement (ej,m/oj,m/zj,m)	Activity duration (Dej,m/oj,m/zj,m) [h]	Overall project duration [h] Start (ESej,m/oj,m/zj,m)	Finish (EFej,m/oj,m/zj,m)
1	3	Roof	Grip_HY_1	Deconstruction	0.15	0	0.15
1	3	Roof	Grip_HY_1	Pre-sorting	0.10	0.15	0.25
1	3	Roof	Grip_HY_1	Pre-crushing	0.10	0.25	0.35
2	3	Exterior wall	Press_HY_1	Deconstruction	0.97	0.35	1.32
2	3	Exterior wall	Press_HY_1	Pre-sorting	0.66	1.32	1.98
2	3	Exterior wall	Press_HY_1	Pre-crushing	0	1.98	1.98
3	3	Interior wall	Grip_HY_1	Deconstruction	0.04	2.02	2.02
3	3	Interior wall	Grip_HY_1	Pre-sorting	0.03	2.02	2.05
3	3	Interior wall	Grip_HY_1	Pre-crushing	0.03	2.05	2.08
4	2	Slab	Cut_HY_1	Deconstruction	3.05	2.08	2.13
4	2	Slab	Cut_HY_1	Pre-sorting	0.78	5.13	5.91
4	2	Slab	Cut_HY_1	Pre-crushing	0	5.91	5.91
5	2	Exterior wall	Press_HY_1	Deconstruction	1.03	5.91	6.94
5	2	Exterior wall	Press_HY_1	Pre-sorting	0.70	6.94	7.64
5	2	Exterior wall	Press_HY_1	Pre-crushing	0	7.64	7.64
6	2	Interior wall	Press_HY_1	Deconstruction	0.74	7.64	8.38
6	2	Interior wall	Press_HY_1	Pre-sorting	0.5	8.38	8.88
6	2	Interior wall	Press_HY_1	Pre-crushing	0	8.88	8.88
7	1	Slab	Cut_HY_1	Deconstruction	3.05	8.88	11.93
7	1	Slab	Cut_HY_1	Pre-sorting	0.78	11.93	12.71
7	1	Slab	Cut_HY_1	Pre-crushing	0	12.71	12.71
8	1	Exterior wall	Press_HY_1	Deconstruction	1.00	12.71	13.71
8	1	Exterior wall	Press_HY_1	Pre-sorting	0.68	13.71	14.39
8	1	Exterior wall	Press_HY_1	Pre-crushing	0	14.39	14.39
9	1	Interior wall	Grip_HY_1	Deconstruction	0.94	14.39	15.33
9	1	Interior wall	Grip_HY_1	Pre-sorting	0.64	15.33	15.97
9	1	Interior wall	Grip_HY_1	Pre-crushing	0.64	15.97	16.61
10	1	Bottom plate	Ripp_HY_1	Deconstruction	3.05	16.61	19.66
10	1	Bottom plate	Ripp_HY_1	Pre-sorting	1.56	19.66	21.22
10	1	Bottom plate	Ripp_HY_1	Pre-crushing	1.56	21.22	22.78

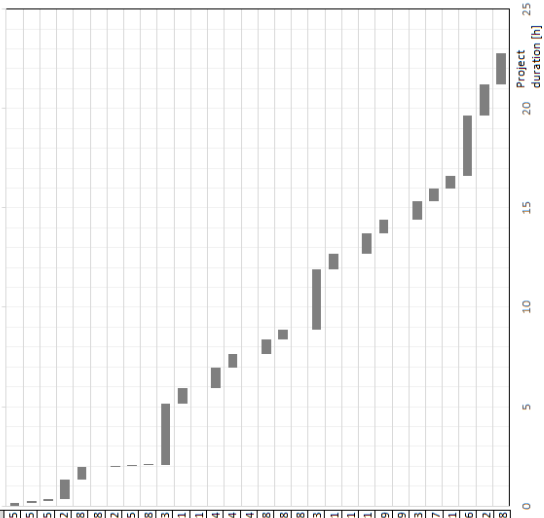


Figure 7-18: Gantt chart with activity-related techniques (modes) of the base deconstruction project scenario

Figure 7-19, Figure 7-20 present the histograms of levels of the specific environmental plan values in terms of percentage emission/impact levels between 0 and 1 (0 to 100%) and of the number of resources over time related to the single activity segments.

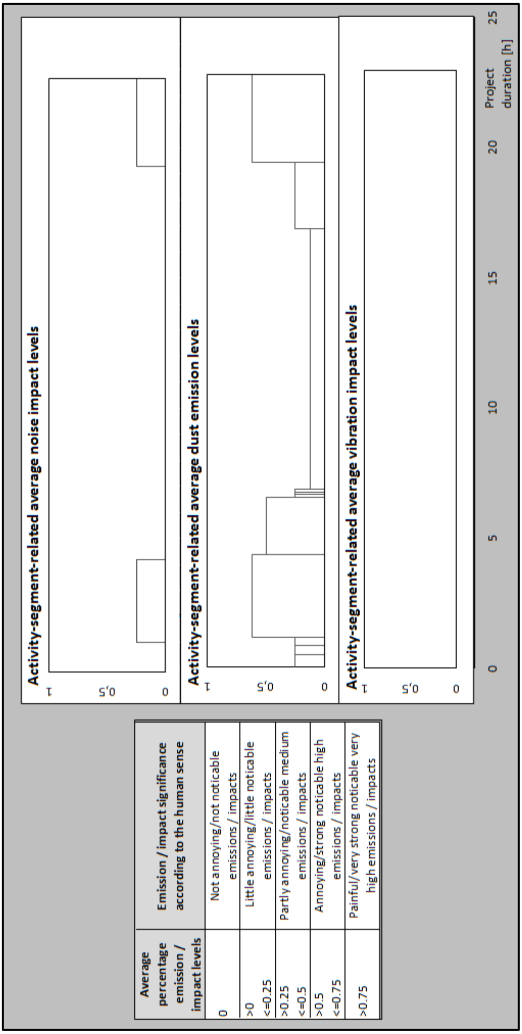


Figure 7-19: Histograms of the levels of the specific environmental plan values in terms of average percentage impact levels between 0 and 1 (0 to 100%) over time related to the single activity segments of the base deconstruction project scenario

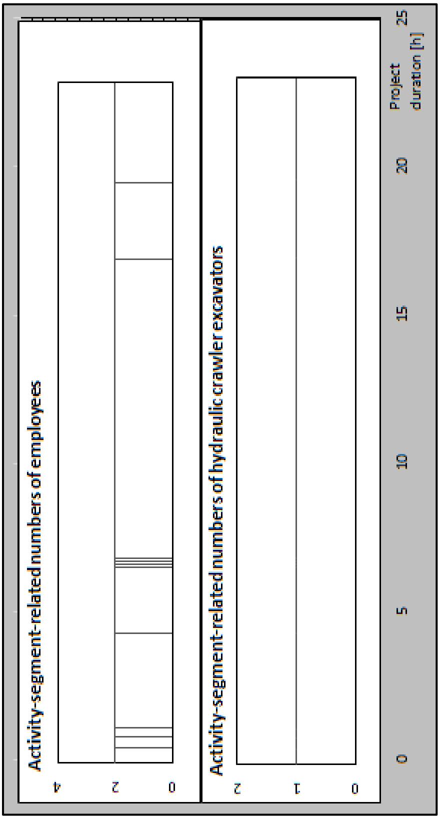


Figure 7-20: Histograms of the numbers of resources over time related to the single activity segments of the base deconstruction project scenario

Figure 7-18, Figure 7-19, Figure 7-20 demonstrate that two employees working with one hydraulic crawler excavator are expected to work for the deconstruction project to reach the objective of minimising the overall project average noise impact levels. The examination of durations of the single deconstruction project activities (j, j=1-J, with

J=10) and of respective single activity segments (d_j, o_j, q_j) shows that additional pre-crushing of material (q_j) is not required related to the modes press-cutting and cutting with a hydraulic excavator[186]. Ripping of the bottom plate, activity j=10, takes the longest and about a quarter of the overall project duration with more than 6 h. Furthermore, cutting of the slabs, activities j=4 and j=7 have the second longest durations with nearly 4 h. The shortest activity is the gripping of the interior wall of the top level (j=3). Regularly, in all activities, the actual deconstruction of the single building components[187] takes longer than the following activity segments material pre-separation and pre-crushing[188].

The analysis of the proposed deconstruction technique modes and of the proposed average impacts on the environment at the closest building in the neighbourhood shows that the wooden roof and the interior walls of the top level (level 3) and of level 1[189] are scheduled to be gripped with a deconstruction grab. The wooden slabs should be cut with scrap shears. Independent of the mode, deconstruction (including all activity segments) of the wooden building components[190] results in not annoying noise impact levels and no noticeable vibrations. The dust emissions vary depending on the

[186] The pre-crushing activity segment q_j has a duration $p_{qj,m}$ of 0.
[187] The deconstruction activity segment d_j of activity j.
[188] The pre-separation activity segment o_j and the pre-crushing activity segment q_j of activity j.
[189] For the interior walls of the 1st building level gripping (Grip_HA_1) is recommended instead of press-cutting (Press_HY_1) (compare interior walls of the 2nd level) in the optimal deconstruction plan due to minimise the average noise impact levels of the overall project. This is the case, as the average noise impact level represents an average noise level over time, based on Equation 4 21 in section 4.5.3, and ripping (Ripp_HY_1) of the bottom plate has relative high average noise impact levels. Both, Grip_HA_1 and Press_HY_1 have lower noise impact levels than Ripp_HY_1, but Grip_HA_1 takes longer than Press_HY_1 and therefore has a greater influence on the average noise impact level of the phase and of the overall project than Press_HY_1. Hence, the average noise level is more reduced by Grip_HA_1 than by Press_HY_1. This case is also explained in section 7.6.3.
[190] The deconstruction of the roof (j=1), the interior walls of the top level (j=3) and the slabs (j=4, j=7).

mode. Gripping causes little dust exposures throughout all activity segments. Cutting of the slabs result in not-noticeable to little dust exposures during the deconstruction activity segment and in little dust exposures throughout material pre-sorting. All exterior walls and the interior walls of the 2nd level out of brick should be press-cut with demolition tongs. The environmental impacts of the deconstruction of brick building components are regularly higher than of those out of wood. The actual deconstruction segments affect little annoying noise impact levels and medium to high dust exposures, where breathing protection is between recommended and required. Pre-sorting of brick results in not-annoying noise impact levels and medium dust exposures with recommended breathing protection. Brick pre-crushing from the interior walls of level 1 additionally causes little annoying noise impacts and high dust exposure with required breathing protection. There is no vibration noticeable throughout all these activity segments. Finally, the reinforced-concrete bottom plate is planned to be ripped with a long stick/backhoe as attachment. This deconstruction activity generally creates the greatest noise impacts compared to the other project activities. Ripping of the bottom plate results in little to partly annoying noise impact levels and reinforced-concrete pre-crushing causes even partly annoying noise impact levels. Pre-sorting of reinforced-concrete only creates little annoying noise levels. The dust exposures of the three segments vary between medium and medium to high impact levels, where breathing protection is on the interface between recommended and required at the closest building of the neighbourhood. No vibration is noticeable throughout the three activity segments as well.

In the following, different influences are analysed by varying the single parameters of the base deconstruction project scenario to answer the main and the deduced applied research questions.

7.3 Building scenarios

In this section, the project plan results according to different building characteristics are compared in terms of 'building scenarios' (BS) to answer the sub-question:

1 How do different building characteristics influence the proposed/adequate deconstruction plan due to the mitigation of distinct emissions and impacts in terms of applied deconstruction techniques and resulting emissions/impacts?

In section 7.3.1 the adaption of model input parameters in the form of varying building characteristics for the building scenarios are described. Then the results provided by TEE-D-Plan are analysed in terms of influences on the proposed deconstruction plan in section 7.3.2 to answer sub-question 1. Within this context, firstly, the solution space of each activity in terms of the number of technically feasible modes is identified. Secondly, the suggested deconstruction plan of each building scenario is compared to the base scenario by comparing the overall project durations, costs and the average percentage levels of the distinct environmental impacts of the plans. Additionally, the recommended activity-related deconstruction technique modes are compared to the plan of the base scenario.

7.3.1 Variations of building characteristics

In the 1st building scenario[191], which is based on the base scenario, the building to be deconstructed is a residential building of the type c with components out of brick and wood (b-brick-wood). It has a total material volume of 235 m^3 and includes 3 levels with a total building height above ground of 9 m (hg-9) (see section 7.2.1.1). Within the 2nd and 3rd building scenarios the component materials are modified. The

[191] BS(b-brick-wood_hg-9).

2nd building scenario[192] is a residential building of the type b with components out of sand lime brick (slbrick) and reinforced concrete (rfconcrete). Selected building characteristics of this building scenario related to the single building components are listed in Table 7-8.

Table 7-8: List of components of the 2nd building scenario with adapted materials

Building level		Building component type (ty_k)	Material (b_k)	Max. component thickness (th_k)	Material volume (u_k)	Height above ground (hg_k)
#	Name			m	m^3	m
3	Top level	Roof	Reinforced concrete	0.1	5.4	9
3	Top level	Exterior wall	Sand lime brick	0.25	33.1	9
3	Top level	Interior wall	Sand lime brick	0.1	1.5	9
2	2nd level	Slab	Reinforced concrete	0.2	39	6
2	2nd level	Exterior wall	Sand lime brick	0.3	35.3	6
2	2nd level	Interior wall	Sand lime brick	0.3	25.4	6
1	1st level	Slab	Reinforced concrete	0.2	39	3
1	1st level	Exterior wall	Sand lime brick	0.37	34.4	3
1	1st level	Interior wall	Sand lime brick	0.37	32.2	3
1	1st level	Bottom plate	Reinforced concrete	0.2	39	0

The 3rd building scenario[193] is an industrialised building of the type e with components out of precast reinforced concrete units. Selected building characteristics of this building scenario related to the single building components are listed in Table 7-9.

[192] BS(b-slbrick-rfconcrete_hg-9).
[193] BS(b-rfconcrete_hg-9).

Table 7-9: List of components of the 3rd building scenario with adapted materials

Building level		Building component type (ty_k)	Material (b_k)	Max. component thickness (th_k)	Material volume (u_k)	Height above ground (hg_k)
#	Name			m	m^3	m
3	Top level	Roof	Precast reinforced concrete unit	0.1	5.4	9
3	Top level	Exterior wall	Precast reinforced concrete unit	0.25	33.1	9
3	Top level	Interior wall	Precast reinforced concrete unit	0.1	1.5	9
2	2nd level	Slab	Precast reinforced concrete unit	0.2	39	6
2	2nd level	Exterior wall	Precast reinforced concrete unit	0.3	35.3	6
2	2nd level	Interior wall	Precast reinforced concrete unit	0.3	25.4	6
1	1st level	Slab	Precast reinforced concrete unit	0.2	39	3
1	1st level	Exterior wall	Precast reinforced concrete unit	0.37	34.4	3
1	1st level	Interior wall	Precast reinforced concrete unit	0.37	32.2	3
1	1st level	Bottom plate	Precast reinforced concrete unit	0.2	39	0

Additionally, the number of building levels, the total building height above ground and the total material volume respectively are increased. Selected building characteristics of this 4th building scenario[194] related to the single building components are listed in Table 7-10.

[194] BS(b-brick-wood_hg-18).

Table 7-10: List of components of the 4th building scenario with increased building levels, height above ground and material volume

Building level		Building component type (ty_k)	Material (b_k)	Max. component thickness (th_k)	Material volume (u_k)	Height above ground (hg_k)
#	Name			m	m^3	m
6	Top level	Roof	Wood	0.1	5.4	18
6	Top level	Exterior wall	Brick	0.25	33.1	18
6	Top level	Interior wall	Wood	0.1	1.5	18
5	5th level	Slab	Wood	0.2	39	15
5	5th level	Exterior wall	Brick	0.3	35.3	15
5	5th level	Interior wall	Brick	0.3	25.4	15
4	4th level	Slab	Wood	0.2	39	12
4	4th level	Exterior wall	Brick	0.3	35.3	12
4	4th level	Interior wall	Brick	0.3	25.4	12
3	3rd level	Slab	Wood	0.2	39	9
3	3rd level	Exterior wall	Brick	0.3	35.3	9
3	3rd level	Interior wall	Brick	0.3	25.4	9
2	2nd level	Slab	Wood	0.2	39	6
2	2nd level	Exterior wall	Brick	0.3	35.3	6
2	2nd level	Interior wall	Brick	0.3	25.4	6
1	1st level	Slab	Wood	0.2	39	3
1	1st level	Exterior wall	Brick	0.37	34.4	3
1	1st level	Interior wall	Brick	0.37	32.2	3
1	1st level	Bottom plate	Reinforced concrete	0.2	39	0

Like the building characteristics of the base scenario, the building scenarios are entered into the model as text files.

7.3.2 Influences on the deconstruction plan

In this section the influences of building characteristics on the deconstruction plan are studied to answer sub-question 1. Therefore, first the solution space of each deconstruction project phase is calculated for each building scenario. Based on these solution spaces, which are calculated from the amount of technically feasible modes of each activity due to modified building characteristics, the combinations of modes of the deconstruction plans are selected.

Hence, these project phase solution spaces of each scenario are compared to each other (Table 7-11).

Table 7-11: Comparison of solution spaces of deconstruction project phases of each building scenario

Building-level-related project phase #	Building level #	Project phase solution spaces of the project scenarios [amount of mode combinations/ alternatives]			
		1st	2nd	3rd	4th
		BS(b-brick-wood_hg-9)	BS(b-slbrick-rfconcrete_hg-9)	BS(b-rfconcrete_hg-9)	BS(b-brick-wood_hg-18)
1	3/6	5,096	9,464	10,648	896
2	2/5	4,056	12,168	5,832	1024
3	1/4	56,784	170,352	81,648	1024

Firstly, Table 7-11 presents that compared to the building characteristics of the base scenario, which is the 1st building scenario[195], the solution spaces of all project phases is increased by material variations in the form of reinforced concrete and masonry instead of wood in the 2nd building scenario [196].There are more performable modes available to deconstruct components out of reinforced concrete and masonry than out of wood. The variation of masonry material types, such as sand lime brick instead of brick, has no influence on the solution spaces. Secondly, the solution spaces of project phases 2 and 3 of the 3rd building scenario [197] decrease compared to those of the 2nd building scenario. Hence, more performable modes for the deconstruction of masonry walls with thicknesses between 0.3 m and 0.37 m exist (see Table 7-6 and Table 7-9) than for the deconstruction of respective reinforced concrete components. The solution space of the 1st project phases slightly increases in the 3rd scenario, as there are more feasible modes (e.g. pushing and pulling with respective excavators) to deconstruct the roof out of precast reinforced concrete units, than for a cast-in-place

[195] BS(b-brick-wood_hg-9).
[196] BS(b-slbrick-rfconcrete_hg-9).
[197] BS(b-rfconcrete_hg-9).

reinforced concrete roof. Thirdly, when comparing the solution spaces of project phases 1 to 3 of the 1st and 4th [198] building scenario, it is recognisable that the increase of the deconstruction height above ground can highly reduce the project phase solution spaces. As hydraulic excavators are not applicable in deconstruction heights above ground of more than 9 m[199], less activity-related modes are performable in the upper building levels of the 4th building scenario.

Besides the influence on the solution spaces, building characteristics have an influence on the recommended activity-related deconstruction technique modes and on the plan values of the deconstruction plan. The following tables show respective modes recommended by TEE-D-Plan and calculated plan values in the form of durations, operation costs and average emission/impact levels of noise, dust and vibrations of the deconstruction plans of the four building scenarios.

[198] BS(b-brick-wood_hg-18).
[199] Compare the related mode attribute 'maximal height above ground' (hg_m) in appendix A1)

Table 7-12: Activity-related technique modes and plan values of the deconstruction plan of the 1st building scenario, the base scenario

Activities				Activitiy-related modes and plan values of BS(b-brick-wood_hg-9) (base scenario)					
Column #				1	2	3	4	5	6
Activity #	Level	Type of the deconstructed component	Component material	Mode (definition see appendix A1)	Duration [h]	Activity-related operation costs [€]	Activity-related average percentage noise impact level	Activity-related average percentage dust emission level	Activity-related average percentage vibration impact level
1	3	Roof	Wood	Grip_HY_1	0.4	52	0	0.25	0
2	3	Exterior wall	Brick	Press_HY_1	1.6	226	0.125	0.625	0
3	3	Interior wall	Wood	Grip_HY_1	0.1	14	0	0.25	0
4	2	Slab	Wood	Cut_HY_1	3.8	531	0	0.125	0
5	2	Exterior wall	Brick	Press_HY_1	1.7	241	0.125	0.625	0
6	2	Interior wall	Brick	Press_HY_1	1.3	174	0.125	0.625	0
7	1	Slab	Wood	Cut_HY_1	3.8	531	0	0.125	0
8	1	Exterior wall	Brick	Press_HY_1	1.7	235	0.125	0.625	0
9	1	Interior wall	Brick	Grip_HY_1	2.2	309	0.125	0.625	0
10	1	Bottom plate	Reinforced concrete	Ripp_HY_1	6.2	793	0.375	0.625	0

Table 7-13: Activity-related technique modes and plan values of the deconstruction plan of the 2nd building scenario

Activities				Activitiy-related modes and plan values of BS(b-slbrick-rfconcrete_hg-9)					
Column #				1	2	3	4	5	6
Activity #	Level	Type of the deconstructed component	Component material	Mode (definition see appendix A1)	Duration [h]	Activity-related operation costs [€]	Activity-related average percentage noise impact level	Activity-related average percentage dust emission level	Activity-related average percentage vibration impact level
1	3	Roof	Reinforced concrete	**Press_HY_1**	0.5	66	**0.375**	0.75	0
2	3	Exterior wall	Sand lime brick	**Grip_HY_1**	3	409	0.125	0.75	0
3	3	Interior wall	Sand lime brick	**Press_HY_1**	0.1	14	**0.125**	0.75	0
4	2	Slab	Reinforced concrete	**Press_HY_1**	3.5	479	**0.375**	0.75	0
5	2	Exterior wall	Sand lime brick	Press_HY_1	**2.4**	338	0.125	**0.75**	0
6	2	Interior wall	Sand lime brick	Press_HY_1	**1.8**	243	0.125	**0.75**	0
7	1	Slab	Reinforced concrete	**Press_HY_1**	3.5	479	**0.375**	0.75	0
8	1	Exterior wall	Sand lime brick	Press_HY_1	**2.4**	329	0.125	**0.75**	0
9	1	Interior wall	Sand lime brick	Grip_HY_1	**2.9**	398	0.125	**0.75**	0
10	1	Bottom plate	Reinforced concrete	Ripp_HY_1	6.2	793	0.375	0.625	0

Table 7-14: Activity-related technique modes and plan values of the deconstruction plan of the 3rd building scenario

Activities				Activitiy-related modes and plan values of BS(b-rfconcrete_hg-9)					
Column #				1	2	3	4	5	6
Activity #	Level	Type of the deconstructed component	Component material	Mode (definition see appendix A1)	Duration [h]	Activity-related operation costs [€]	Activity-related average percentage noise impact level	Activity-related average percentage dust emission level	Activity-related average percentage vibration impact level
1	3	Roof	Precast reinforced concrete unit	**Press_HY_1**	0.5	66	0.375	0.75	0
2	3	Exterior wall	Precast reinforced concrete unit	Press_HY_1	2.9	407	0.375	0.75	0
3	3	Interior wall	Precast reinforced concrete unit	Press_HY_1	0.1	18	**0.375**	**0.75**	0
4	2	Slab	Precast reinforced concrete unit	**Press_HY_1**	3.5	479	0.375	0.75	0
5	2	Exterior wall	Precast reinforced concrete unit	Press_HY_1	**3.1**	434	**0.375**	**0.75**	0
6	2	Interior wall	Precast reinforced concrete unit	Press_HY_1	**2.3**	312	**0.375**	**0.75**	0
7	1	Slab	Precast reinforced concrete unit	**Press_HY_1**	3.5	479	0.375	0.75	0
8	1	Exterior wall	Precast reinforced concrete unit	Press_HY_1	**3.1**	423	**0.375**	**0.75**	0
9	1	Interior wall	Precast reinforced concrete unit	**Press_HY_1**	2.9	396	0.375	0.75	0
10	1	Bottom plate	Precast reinforced concrete unit	Ripp_HY_1	6.2	793	0.375	0.625	0

Table 7-15: Activity-related technique modes and plan values of the deconstruction plan of the 4th building scenario

Activities				Activitiy-related modes and plan values of BS(b-brick-wood_hg-18)					
Column #				1	2	3	4	5	6
Activity #	Level	Type of the deconstructed component	Component material	Mode (definition see appendix A1)	Duration [h]	Activity-related operation costs [€]	Activity-related average percentage noise impact level	Activity-related average percentage dust emission level	Activity-related average percentage vibration impact level
1	6	Roof	Wood	**Grip_LT_1**	**0.7**	**103**	0	**0.375**	0
2	6	Exterior wall	Brick	**Press_LT_1**	**3.9**	**542**	0.125	**0.875**	0
3	6	Interior wall	Wood	**Grip_LT_1**	**0.2**	**29**	0	**0.375**	0
4	5	Slab	Wood	**Cut_LT_1**	**10.7**	**1486**	0	0.125	0
5	5	Exterior wall	Brick	**Press_LT_1**	**4.2**	**578**	0.125	0.625	0
6	5	Interior wall	Brick	**Press_LT_1**	**3**	**416**	0.125	0.625	0
7	4	Slab	Wood	**Cut_LT_1**	**10.7**	**1486**	0	0.125	0
8	4	Exterior wall	Brick	**Press_LT_1**	**4.2**	**578**	0.125	0.625	0
9	4	Interior wall	Brick	**Press_LT_1**	**3**	**416**	0.125	0.625	0
10	3	Slab	Wood	Cut_HY_1	3.8	531	0	0.125	0
11	3	Exterior wall	Brick	Press_HY_1	1.7	241	0.125	0.625	0
12	3	Interior wall	Brick	Press_HY_1	1.3	174	0.125	0.625	0
13	2	Slab	Wood	Cut_HY_1	3.8	531	0	0.125	0
14	2	Exterior wall	Brick	Press_HY_1	1.7	241	0.125	0.625	0
15	2	Interior wall	Brick	Press_HY_1	1.3	174	0.125	0.625	0
16	1	Slab	Wood	Cut_HY_1	3.8	531	0	0.125	0
17	1	Exterior wall	Brick	Press_HY_1	1.7	235	0.125	0.625	0
18	1	Interior wall	Brick	Grip_HY_1	2.2	309	0.125	0.625	0
19	1	Bottom plate	Reinforced concrete	Ripp_HY_1	6.2	793	0.375	0.625	0

Table 7-12, Table 7-13 and Table 7-14 present the influence on the change of modes in and on the activity plan values of the deconstruction plan due to the variation of materials. The modes are selected out of the modes of the phase solution spaces. For instance, instead of gripping and cutting, press-cutting with a hydraulic excavator is the primarily selected mode, when the building components are out of reinforced concrete (b-rfconcrete) instead of wood (b-wood) (compare column 1, activities 1, 4 and 7 of the three tables) or instead of brick (b-brick) (compare column 1, activity 9 of the three tables). Besides mode changes, the material variation itself, from masonry materials to reinforced concrete, highly increases the activity duration, costs and average noise impact level. For instance, the average noise level increases from between not-annoying and little annoying to between little and partly annoying. Additionally, the dust emission level is increased to high dust exposure with required breathing protection compared to the softer masonry type brick with medium to high dust exposure. When the masonry type varies, sometimes the mode can change to meet the objective due to the overall project plan (compare column 1, activity 2[200] in Table 7-12 and Table 7-13). Nevertheless, in this case usually modes stay the same, but the plan values change (compare column 1, activities 5, 6, 8 and 9 in Table 7-12 and Table 7-13). In the example especially the duration and the average dust emission level of these activities increase, as the material sand lime brick is more solid and causes higher dust emissions with press-cutting than brick[201] (compare column 2 and 5 of activities 5, 6, 8 and 9 in Table 7-12 and Table 7-13)). The dust emission level increase is as well from between medium and high dust exposure to high dust exposure with required breathing protection.

[200] In the example project, the influence of the low noise impact level of the activity on the average noise impact level of the phase and the overall project increases with the longer duration of the activity.
[201] This fact is also verified by the experimental results in section 5.3.3.

Besides material variation the variation of the height above ground influences the selected modes. Within this context the change of modes is mainly influenced by the reduced project phase solution spaces. Table 7-12 and Table 7-15 illustrate the change of modes with hydraulic excavator to modes performed with longfront excavators due to the increased building components heights above ground. Deconstruction with longfront excavators instead of hydraulic excavators generally more than doubles the duration and costs of single activities (compare column 1, 2 and 3 of activities 1 to 6 in Table 7-12 and 1 to 9 in Table 7-15). Additionally, the average impact levels can increase due to high deconstruction heights above ground. In the example, especially the average dust emission level increases at heights of more than 15 m above ground (compare column 5 of activities 1 to 3 Table 7-12 and Table 7-15). The increase is from little to between little and medium dust exposures and from between medium and high dust exposures to between high and very high dust exposures, where high quality breathing protection and dust reduction measures are required. In general, the tables illustrate that all activity-related average percentage vibration impact levels are not noticeable at the closest building in the neighbourhood, independent of the building scenarios and the selected deconstruction plans.

As a consequence of different building characteristics and/or of different selected modes, the overall project durations, costs and the average percentage levels of the distinct emissions and environmental impacts of the suggested deconstruction plan can change. Figure 7-21, Figure 7-22, Figure 7-23, Figure 7-24, Figure 7-25 present the change in the plan values of the deconstruction project plan due to the building scenarios.

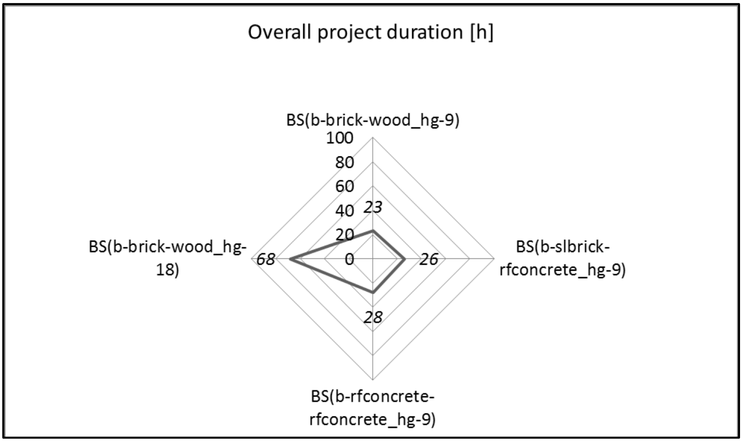


Figure 7-21: Change in the overall project durations of the deconstruction plans of the building scenarios (BS)

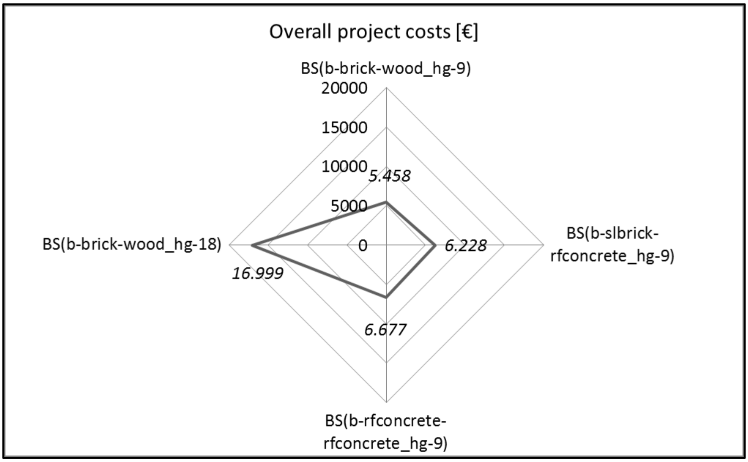


Figure 7-22: Change in the overall project costs of the deconstruction plans of the building scenarios (BS)

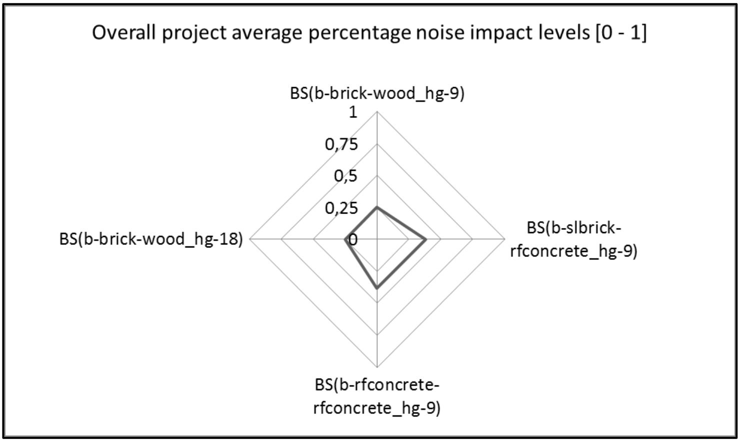


Figure 7-23: Change in the overall project average noise impact levels of the deconstruction plans of the building scenarios (BS)

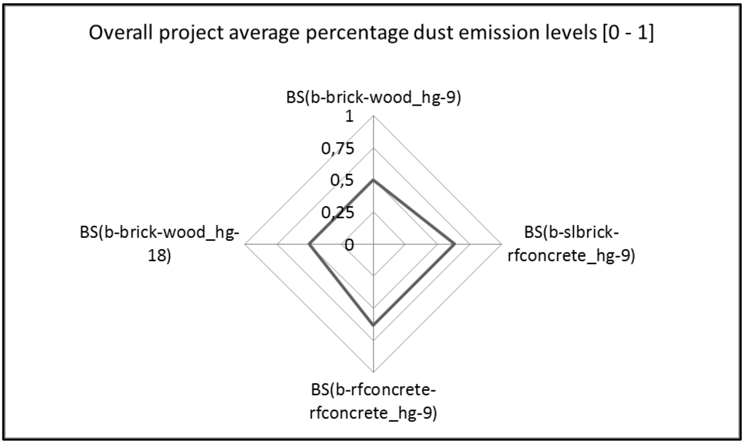


Figure 7-24: Change in the overall project average dust emission levels of the deconstruction plans of the building scenarios (BS)

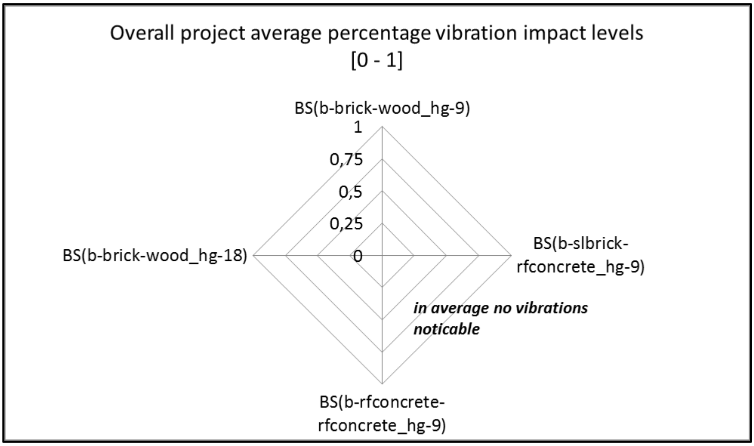


Figure 7-25: Change in the overall project average vibration impact levels of the deconstruction plans of the building scenarios (BS)

In addition to the statements above on the influence of building characteristics, Figure 7-21, Figure 7-22, Figure 7-23, Figure 7-24, Figure 7-25 demonstrate that the component material generally influences the overall project plan values, except the average vibration impact levels. This influence on the plan values is recognisable by comparing the values of the 1st [202] and of the 2nd and 3rd project scenario[203]. The existence of a more solid masonry type and of reinforced concrete instead of the building materials brick and wood increase the overall project durations and costs between 14 and 22%. The average noise impact levels of the overall deconstruction project increase from little annoying to between little and partly annoying. The overall project average dust exposures are between medium and high instead of medium dust exposures. By comparing

[202] BS(b-brick-wood_hg-9).

[203] 2nd: BS(b-slbrick-rfconcrete_hg-9), 3rd: BS(b-rfconcrete_hg-9)

the values of the 1st and 4th [204] building scenario, it is obvious that the overall project duration and costs are increased by the application of longfront excavators. Even the deconstruction material volume increases 75% in the 4th building scenario, the overall project duration and costs are three times those of the 1st building scenario. Moreover, the increase of average dust emission levels of the deconstruction activities in the top building level, mentioned above[205], have no influence on the average dust emission levels of the overall project.

7.4 Surrounding scenarios

In this section, the project plan results due to different surrounding conditions are compared in terms of 'surrounding scenarios' (SU) to answer the sub-question:

2 How do surrounding conditions influence the levels of impacts?

In section 7.4.1 the adaption of model input parameters in the form of varying surrounding conditions for the surrounding scenarios are described. Then the results provided by TEE-D-Plan are analysed in terms of influences on the level of impact in section 7.4.2 to answer sub-question 2. Within this context, the average percentage levels of the overall project distinct emissions and environmental impacts in each surrounding scenario are compared to the base scenario.

7.4.1 Variations of surrounding conditions

In the based scenario, the 1st surrounding scenario[206], the shortest distance from the building to be deconstructed to the subject of protection, which is assigned to the closest building of the

[204] BS(b-brick-wood_hg-18).
[205] Compare column 5 of activities 1 to 3 Table 7 12 and Table 7 15.
[206] SU(dc-30_rf-2).

neighbourhood, is 30 m (dc-30) and there are two reflecting objects (rf-2). Within the surrounding scenarios this distance to the closest building and the number of reflecting objects is modified. In the 2nd, 3rd and 4th surrounding scenario[207] the distance to the closest building of the neighbourhood is adapted to 10 m (dc-10), 5 m (dc-5) and 0 m (dc-0) and the reflecting numbers of walls remain two (rf-2). In the 5th, 6th and 7th surrounding scenario[208] the distance remains 30 m (dc-30) and the number of reflecting objects is varied to zero (rf-0), four (rf-4) and six (rf-6). Like the surrounding conditions of the base scenario, the adapted surrounding conditions are entered via the model input mask shown in Figure 7-13.

7.4.2 Influences on the level of impact

In this section the influences of surrounding conditions on the level of impact are examined to answer sub-question 2. Therefore, the average percentage levels of overall project distinct emissions and environmental impacts in each surrounding scenario are calculated and compared to each other.

Figure 7-26, Figure 7-27, Figure 7-28 present the average percentage impact levels of the deconstruction project plan depending on the scenarios described above.

[207] 2nd: SU(dc-10_rf-2), 3rd: SU(dc-5_rf-2), 4th: SU(dc-0_rf-2).
[208] 5th: SU(dc-30_rf-0), 6th: SU(dc-30_rf-4), 7th: SU(dc-30_rf-6).

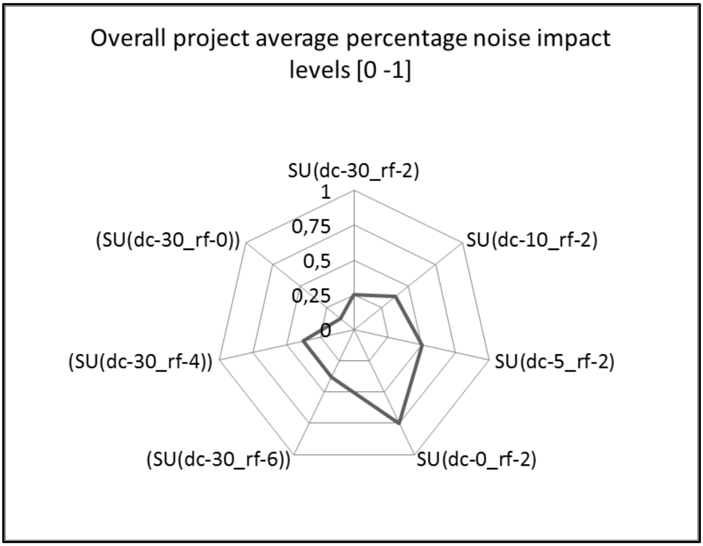


Figure 7-26: Change in the overall project average percentage noise impact levels of the deconstruction plan depending on the surrounding conditions

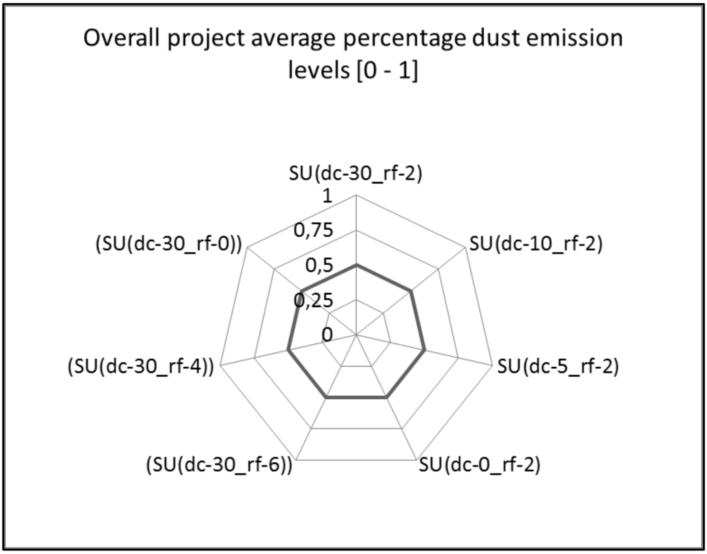


Figure 7-27: Change in the overall project average percentage dust emission levels of the deconstruction plan depending on the surrounding conditions

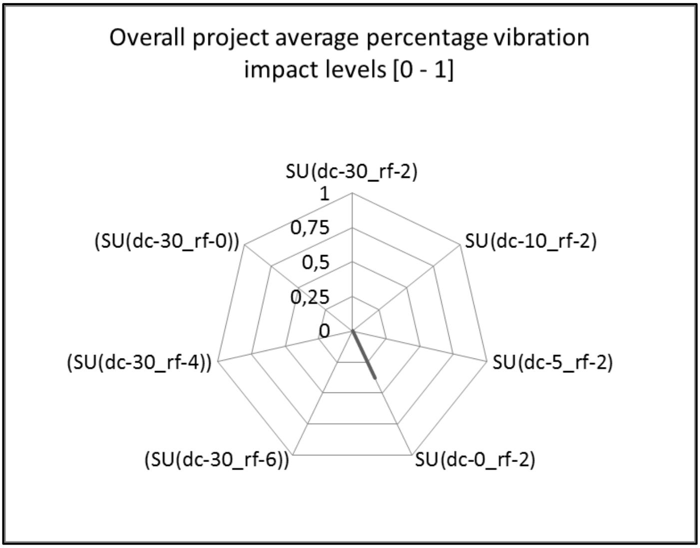


Figure 7-28: Change in the overall project average percentage vibration impact levels of the deconstruction plan depending on the surrounding conditions

Figure 7-26 shows that the distance between the emission source and the subject of protection (dc) and the number of reflecting walls (rf) have a large influence on the average noise impact levels. As expected, the closer the next building in the neighbourhood to the deconstruction site, the higher the average noise impact levels are. This influence is especially high in the short distance between 0 m and 10 m to the subject of protection. For instance, the average noise impact levels increase from partly annoying (0.5) to annoying and hearing damages when longer exposed (0.75) between a distance of 5 m to 0 m. As also expected, the more walls reflect the noise emissions, the higher the average noise impact levels at the subject of protection are. This influence is relatively higher for numbers of reflecting walls between zero and four. For instance, the average noise impact levels increase from little annoying (0.25) to between little and partly annoying (0.375) between two and four reflecting walls.

Figure 7-28 shows that the distance between the emission source and the subject of protection has an influence on the average vibration impact levels. This influence is very high especially in the very short distance between 0 m and 5 m to the subject of protection. Here the average vibration impact levels increase from no vibration noticeable (0) to between little and noticeable vibration with little impulse (0.375). Moreover, as for noise, the closer the next building in the neighbourhood to the deconstruction site is, the higher the average vibration impact levels are. Furthermore, due to impact assessment implemented in TEE-D-Plan (see section 4.5.3) variations in surrounding conditions have no influence on the dust emission levels. Hence, the pressure indicator 'average percentage dust emission level' is used in EIA (Figure 7-27).

7.5 Project scenarios

In this section, the project plan results due to different project constraints are compared in terms of 'project scenarios' (PS) to answer the sub-question:

3 How do different project constraints influence the proposed/adequate deconstruction plan due to the mitigation of distinct emissions and impacts in terms of applied deconstruction techniques and resulting emissions/impacts?

In section 7.5.1 the adaption of model input parameters in the form of varying project constraints for the project scenarios are described. Then the results provided by TEE-D-Plan are analysed in terms of influences on the deconstruction plan in section 7.5.2 to answer sub-question 3. Within this context, firstly, the solution space of each deconstruction project phase calculated from the amount of technically feasible and project-constraint-dependent performable modes of each activity is identified. Secondly, the suggested deconstruction plan of each project scenario is compared to the base scenario by comparing the overall project durations, costs and the average percentage levels of the distinct emissions/environmental impacts of the plans. Additionally, the recommended activity-related deconstruction technique modes are compared to the plan of the base scenario.

7.5.1 Variations of project constraints

In the 1st project scenario[209], which is based on the base scenario, all basic units can theoretically be used. The two hydraulic crawler excavators (Rhy-2) and two longfront crawler excavators (Rlt-2) are of the size 170 kW (40 t) (sz-170). Available space on site of the base scenario is open ('open space' (SP-2)) and the urban usage type is 'not defined' so that there is no noise impact level-dependent constraint (LIM-1000). Within the following project scenarios the number and sizes of available basic units, the available space on site and the urban usage type are adapted. Hence, in the 2nd project scenario[210] the size of the excavators is increased to 300 kW (70 t) (sz-300). In the 3rd scenario[211] the resources are constrained and only one hydraulic crawler excavator (Rhy-1) and one longfront crawler excavator (Rlt-1) are available. In the 4th and 5th scenario[212] there are space-dependent constraints and the available space on site is adapted to 'limited space' (SP-1) and 'very limited space' (SP-0). In the 6th and 7th

[209] PS(sz-170_Rhy-2_Rlt-2_SP-2_LIM-1000).
[210] PS(sz-300_Rhy-2_Rlt-2_SP-2_LIM-1000).
[211] PS(sz-170_Rhy-1_Rlt-1_SP-2_LIM-1000).
[212] 4th: PS(sz-170_Rhy-2_Rlt-2_SP-1_LIM-1000), 5th: PS(sz-170_Rhy-2_Rlf-2_SP-0_LIM-1000).

scenario[213] there are noise impact level-dependent constraints due to the urban usage type of the neighbourhood. In the 6th scenario the neighbourhood of the deconstruction site is an industrial area, where the average noise impact level is limited to 70 dB(A) (LIM-70). The urban usage type in the 7th scenario a general housing area with a maximal allowed average noise impact level of 55 dB(A) (LIM-55). Like the project constraints of the base scenario, the adapted project constraints are entered via the model input masks shown in section 5.2.1.3.

7.5.2 Influences on the deconstruction plan

In this section the influences of project constraints on the proposed deconstruction plan are studied to answer sub-question 3. Therefore, first the solution space of each deconstruction project phase is calculated for each scenario. Based on these solution spaces, which are calculated from the amount of technically feasible and project-constraint-dependent performable modes of each activity, the combinations of modes of the deconstruction plans are selected. Hence, these project phase solution spaces of each scenario are compared to each other (Table 7-16).

[213] 6th: PS(sz-170_Rhy-2_Rlt-2_SP-2_LIM-70), 7th: PS(sz-170_Rhy-2_Rlt-2_SP-2_LIM-55).

Table 7-16: Comparison of solution spaces of deconstruction project phases of each project scenario

Building-level-related project phase #	Building level #	Project phase solution spaces of the project scenarios [amount of mode combinations/ alternatives]						
		1st	2nd	3rd	4th	5th	6th	7th
		PS(sz-170_ Rhy-2_Rlt-2_ SP-2_ LIM-1000)	PS(sz-300_ Rhy-2_Rlt-2_ SP-2_ LIM-1000)	PS(sz-170_ Rhy-1_Rlt-1_ SP-2_ LIM-1000)	PS(sz-170_ Rhy-2_Rlt-2_ SP-1_ LIM-1000)	PS(sz-170_ Rhy-2_Rlt-2_ SP-0_ LIM-1000)	PS(sz-170_ Rhy-2_Rlt-2_ SP-2_ LIM-70)	PS(sz-170_ Rhy-2_Rlt-2_ SP-2_ LIM-55)
1	3	5,096	5,096	768	504	8	3,042	-
2	2	4,056	4,056	576	1,176	8	1,805	-
3	1	56,784	56,784	3,456	7,056	16	3,240	-

Table 7-16 shows that compared to the project constraints of the base scenario, which is the 1st project scenario[214], the project phase solution spaces are reduced firstly by resource constraints in the form of less available basic units (3rd project scenario[215]). The reason for solution space reductions are smaller amounts of performable modes of each activity due to fewer available basic units. The sizes of available basic units have no influence on the solution spaces. Secondly, space-dependent constraints greatly reduce the project phase solution spaces, as less activity-related modes are performable, when the available space on site is limited (4th and 5th project scenario[216]). Finally, noise impact level-dependent constraints due to the urban usage type of the neighbourhood reduce the project phase solution spaces as well (6th and 7th project scenario[217]). In this regard, only those modes can be performed, which cause an equal or lower activity-related average noise impact level value compared to the neighbourhood-usage-type-dependent maximal allowed noise impact level. In the 7th project scenario no technically feasible mode for the deconstruction of the bottom plate can meet the maximal allowed average noise impact level of 55 dB(A). Hence, there is no feasible solution and no deconstruction plan can be provided by TEE-D-Plan.

As depicted in section 5.3.2, the phase solution spaces can have an influence on the modes of the deconstruction plan. To show this influence, Table 7-17 lists the activity-related deconstruction technique modes recommended by TEE-D-Plan of selected project scenarios with reduced solution spaces.

[214] PS(sz-170_Rhy-2_Rlt-2_SP-2_LIM-1000).
[215] PS(sz-170_Rhy-1_Rlt-1_SP-2_LIM-1000).
[216] 4th: PS(sz-170_Rhy-2_Rlt-2_SP-1_LIM-1000), 5th: PS(sz-170_Rhy-2_Rlf-2_SP-0_LIM-1000).
[217] 6th: PS(sz-170_Rhy-2_Rlt-2_SP-2_LIM-70), 7th: PS(sz-170_Rhy-2_Rlt-2_SP-2_LIM-55).

Table 7-17: Activity-related technique modes of the deconstruction plans of selected project scenarios

Activities				Activitiy-related modes to minimise the overall project noise impact levels		
Column #				1	2	3
Activity #	Level	Type of the deconstructed component	Component material	1st: PS(sz-170_ Rhy-2_Rlt-2_ SP-2_ LIM-1000) 3rd: PS(sz-170_ Rhy-1_Rlt-1_ SP-2_ LIM-1000) 6th: PS(sz-170_ Rhy-2_Rlt-2_ SP-2_ LIM-70)	4th: PS(sz-170_ Rhy-2_Rlt-2_ SP-1_ LIM-1000)	5th: PS(sz-170_ Rhy-2_Rlt-2_ SP-0_ LIM-1000)
1	3	Roof	Wood	Grip_HY_1	**Cut_HY_1**	**Dec_HA_1**
2	3	Exterior wall	Brick	Press_HY_1	Press_HY_1	**Dec_HA_1**
3	3	Interior wall	Wood	Grip_HY_1	**Cut_HY_1**	**Dec_HA_1**
4	2	Slab	Wood	Cut_HY_1	Cut_HY_1	**Dec_HA_1**
5	2	Exterior wall	Brick	Press_HY_1	Press_HY_1	**Dec_HA_1**
6	2	Interior wall	Brick	Press_HY_1	Press_HY_1	**Dec_HA_1**
7	1	Slab	Wood	Cut_HY_1	**Dec_HA_1**	**Dec_HA_1**
8	1	Exterior wall	Brick	Press_HY_1	Press_HY_1	**Dec_HA_1**
9	1	Interior wall	Brick	Grip_HY_1	**Press_HY_1**	**Dec_HA_1**
10	1	Bottom plate	Reinforced concrete	Ripp_HY_1	**Mort_HY_1**	**Dec_HA_1**

As presented in Table 7-17, especially space-dependent constraints have an influence on the change of modes in the deconstruction plan in the example. These modes are selected out of the modes of the phase solution spaces. For instance, instead of gripping, cutting and press-cutting and instead of ripping, mortising with a hydraulic excavator are selected modes, when the space on site is limited (SP-1) (compare columns 1 and 2 of Table 7-17[218]) In general, deconstruction

[218] For the slab of the 1st building level deconstruction by hand (Dec_HA_1) is recommended instead of cutting (Cut_HY_1) in the optimal deconstruction plan in order to minimise the average noise impact levels of the overall project. This is the case, as the average noise impact level represents an average noise level over time, based on Equation 4 21 in section 4.5.3, and mortising (Mort_HY_1) of the bottom plate has very high average noise impact levels. Both, Dec_HA_1 and Cut_HY_1 have lower noise

by hand is selected for the overall deconstruction project, when the space on site is very limited (SP-0) (see column 3 in Table 7-17). The modes are changed to meet the space constraints, whereas the mode attribute 'minimal required space' (sp_m) (see appendix A1) complies with the available space on site. Additionally, Table 7-18 illustrates the influence on the modes and on related noise impact levels of the deconstruction plans that minimise the overall project duration based on the project constraints of the 1st (the base scenario)[219] and of the 6th project scenario[220].

Table 7-18: Activity-related modes and noise impact levels of the deconstruction plans due to minimise the overall project duration based on the project constraints of the 1st and of the 6th project scenario

Activities				Activitiy-related modes and noise impact levels to minimise the overall project duration			
Column #				1	2	3	4
Activity #	Level	Type of the deconstructed component	Component material	1st: PS(sz-170_ Rhy-2_Rlt-2_ SP-2_ LIM-1000)		6th: PS(sz-170_ Rhy-2_Rlt-2_ SP-2_ LIM-70)	
				Mode	Average noise impact levels [dB(A)]	Mode	Average noise impact levels [dB(A)]
1	3	Roof	Wood	Grip_HY_2	51	Grip_HY_2	51
2	3	Exterior wall	Brick	Press_HY_2	63	Press_HY_2	63
3	3	Interior wall	Wood	Grip_HY_2	51	Grip_HY_2	51
4	2	Slab	Wood	Cut_HY_2	54	Cut_HY_2	54
5	2	Exterior wall	Brick	Press_HY_2	63	Press_HY_2	63
6	2	Interior wall	Brick	Press_HY_2	63	Press_HY_2	63
7	1	Slab	Wood	Cut_HY_2	54	Cut_HY_2	54
8	1	Exterior wall	Brick	Press_HY_2	63	Press_HY_2	63
9	1	Interior wall	Brick	Press_HY_2	63	Press_HY_2	63
10	1	Bottom plate	Reinforced concrete	Mort_HY_2	92	**Ripp_HY_1**	**70**

impact levels than Mort_HY_1, but Dec_HA_1 takes much longer than Cut_HY_1 and therefore has a greater influence on the average noise impact level of the phase and of the overall project than Cut_HY_1. Hence, the average noise level is more reduced by Dec_HA_1 than by Cut_HY_1. This case is also explained in section 5.6.3.

[219] PS(sz-170_Rhy-2_Rlt-2_SP-2_LIM-1000).

[220] PS(sz-170_Rhy-2_Rlt-2_SP-2_LIM-70).

Table 7-18 shows by the example of minimising the project duration that a distinct urban usage type has an influence on the change of modes in deconstruction plans (with other objectives than minimising noise) so that the noise impact level of each activity is reduced to meet the noise level limits when necessary. In this case for instance, TEE-D-Plan recommends to rip the bottom plate with one hydraulic excavator instead of mortising with two hydraulic excavators to meet the noise level limit of 70 dB(A) (see activity 10 in Table 7-18). This mode change even highly reduces the average noise impact levels of the overall deconstruction project from between partly annoying and annoying with hearing damages when longer exposed (0.625) to between little to partly annoying (0.375). Moreover, when the noise level limit related to the urban usage type of the neighbourhood cannot be met by any technically feasible mode of a single activity there is no feasible solution for the deconstruction project. As mentioned above this is the case in the 7th project scenario[221].

As a consequence of different selected modes as well as due to available unit sizes, the overall project durations, costs and the average percentage levels of the distinct emissions/environmental impacts of the suggested deconstruction plan can change. Figure 7-29, Figure 7-30, Figure 7-31, Figure 7-32, Figure 7-33 present the change in the plan values of the deconstruction project plans due to the project constraints of the 1st to the 6th project scenario.

[221] PS(sz-170_Rhy-2_Rlt-2_SP-2_LIM-55).

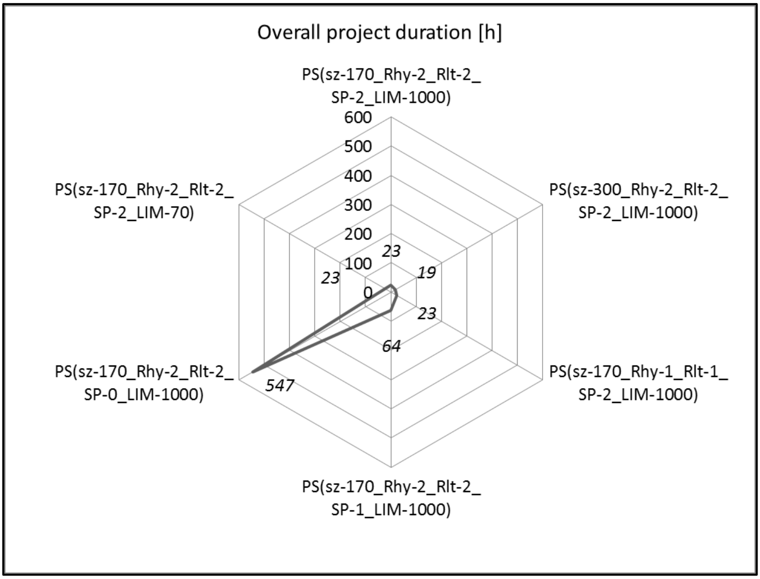


Figure 7-29: Change in the overall project durations of the deconstruction plans of the different project scenarios (PS)

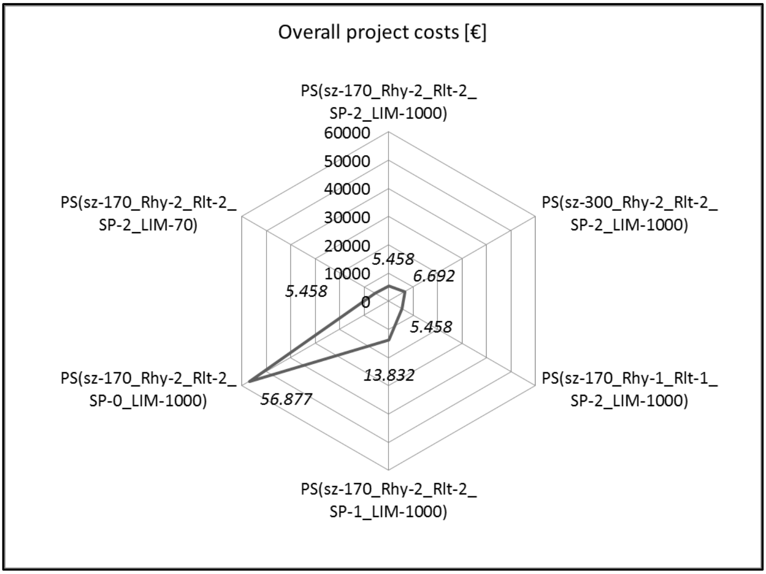


Figure 7-30: Change in the overall project costs of the deconstruction plans of the different project scenarios (PS)

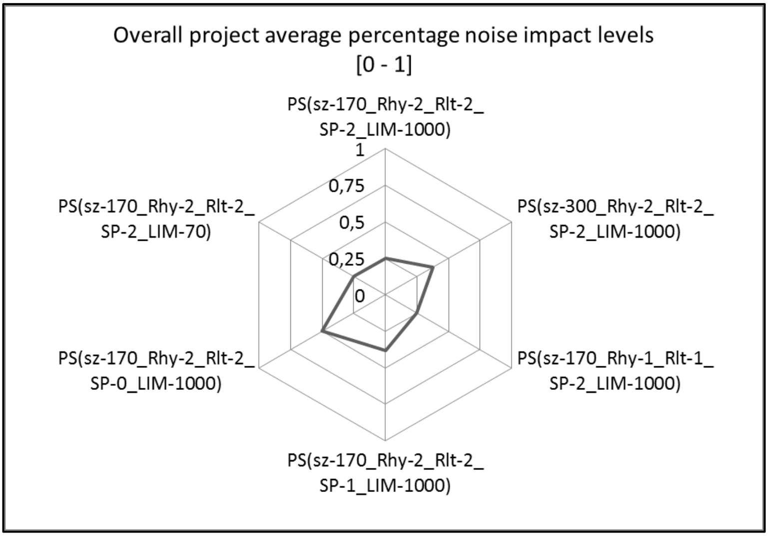


Figure 7-31: Change in the overall project average noise impact levels of the deconstruction plans of the different project scenarios (PS)

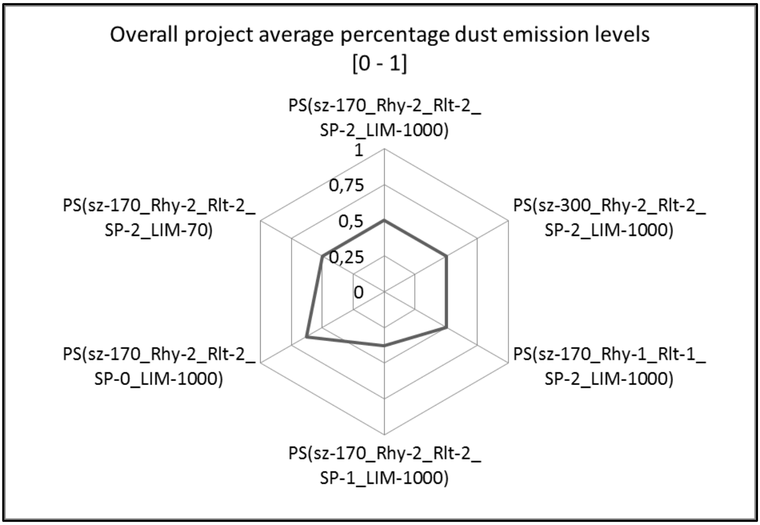


Figure 7-32: Change in the overall project average dust emission levels of the deconstruction plans of the different project scenarios (PS)

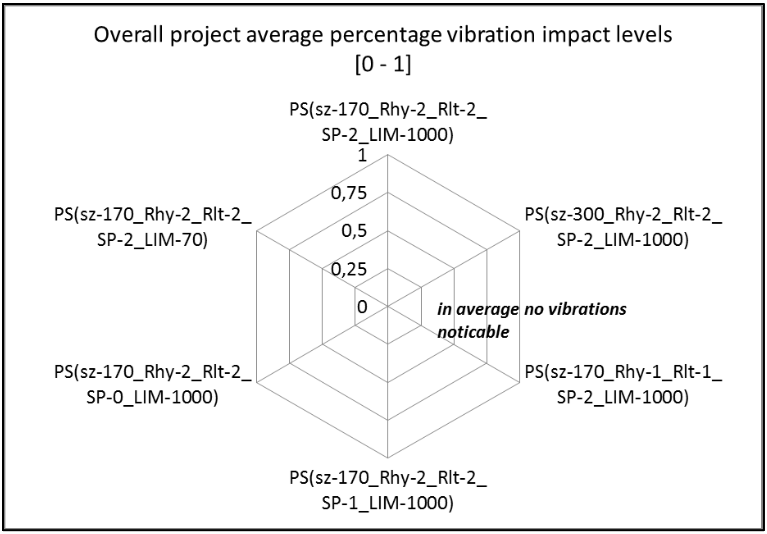


Figure 7-33: Change in the overall project average vibration impact levels of the deconstruction plans of the different project scenarios (PS)

In addition to the statements above on the influence of project constraints, Figure 7-29, Figure 7-30, Figure 7-31 show that the basic unit size has an influence on the plan values (compare the plan values of the 1st [222] and of the 2nd project scenario[223]. As expected, greater unit sizes such as in the 2nd project scenario (sz-300) slightly reduce the duration, increase the costs and can increase the average emission/impact levels of the overall project. In the example the noise impact levels are increased by the greater unit sizes.

[222] PS(sz-170_Rhy-2_Rlt-2_SP-2_LIM-1000).
[223] PS(sz-300_Rhy-2_Rlt-2_SP-2_LIM-1000).

7.6 Preference scenarios

In this section, the project plan results due to different economic and environmental objectives are compared in terms of preference scenarios/different objectives to answer sub-questions:

4 Which economic and environmental objectives are conflicting?

5 How does the deconstruction plan vary in the form of applied deconstruction techniques due to different economic and environmental objectives?

Firstly, the adaption of model input parameters for the preference scenarios are described in section 7.6.1. Secondly, the results provided by TEE-D-Plan are analysed. In sections 7.6.2 they are analysed in the form of durations, costs and the average percentage levels of the distinct emissions/environmental impacts of the overall project and due to the objectives of the scenarios to answer sub-question 4. In sections 7.6.3 they are analysed in terms of changes in the deconstruction plan with respect to the recommended activity-related deconstruction technique modes to answer sub-question 5.

7.6.1 Variation of objectives

In the base scenario the overall deconstruction project average noise impact levels, as the single environmental objective of deconstruction project planning, are minimised (see section 7.2.1.4). Within the preferences scenarios, furthermore, the project duration and project costs are minimised as single economic objectives. Moreover, the minimisation of dust emssions and vibration impacts on the local environment are two single environmental objectives of deconstruction project planning. In general, TEE-D-Plan calculates alternative best deconstruction plans due to each single economic and environmental objective in parallel. Respective implemented objective functions represent Equation 6-12 (project costs minimisation) (see section 6.3.2) and Equation 6-10 (minimization of one distinct project impact level) (see section 6.3.1).

Additionally, the multi-objective approach, introduced in section 6.3.3, and different variants of multi objectives are applied to the example project to analyse resulting variations in the deconstruction plan. This part corresponds to the sensitivity analysis, the fourth/last step of MAVT (see section 6.3.3). Here the robustness of the results is explored by varying the weighting factors of the different environmental sub-objectives. Respective weighting factors of environmental sub-objectives are entered via the user interface and the bottom list item ‘differentiated weighting of environmental criteria’ shown in Figure 6-3 (see section 6.3.3). Based on these inputs TEE-D-Plan calculates the deconstruction project plan for each preference scenario. Respective results of TEE-D-Plan are provided and discussed in the following sections.

7.6.2 Objective conflicts

In this section the conflicts between economic and environmental objectives are identified to answer sub-question 4. These conflicts are identified in the form of the plan values duration, costs and the overall project average percentage levels of the distinct emissions/environmental impacts of the respective deconstruction project plan.

Figure 7-34, Figure 7-35, Figure 7-36, Figure 7-37, Figure 7-38 illustrate these plan values of the deconstruction project plans due to the single economic and environmental objectives:

- Minimisation of the overall project duration (Φ(Min p), base scenario),
- Minimisation of the overall project costs (Φ(Min c)),

- Minimisation of the overall project average noise impact levels (Φ(Min pc-lim))[224],
- Minimisation of the overall project average dust emission levels (Φ(Min pc-sim))[225] and
- Minimisation of the overall project average vibration impact levels (Φ(Min pc-vim))[226].

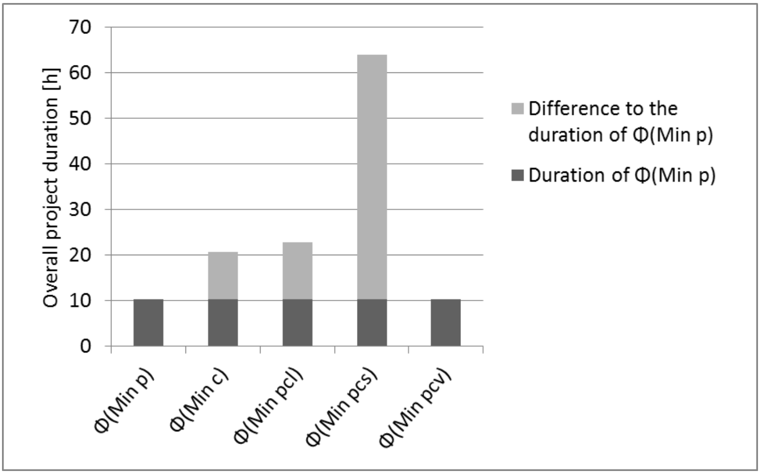


Figure 7-34: Overall project durations of the deconstruction plans due to different economic and environmental objectives

[224] Due to better readability, the abbreviation pcl for pc-lim is used in the following.
[225] Due to better readability, the abbreviation pcs for pc-sim is used in the following.
[226] Due to better readability, the abbreviation pcv for pc-vim is used in the following.

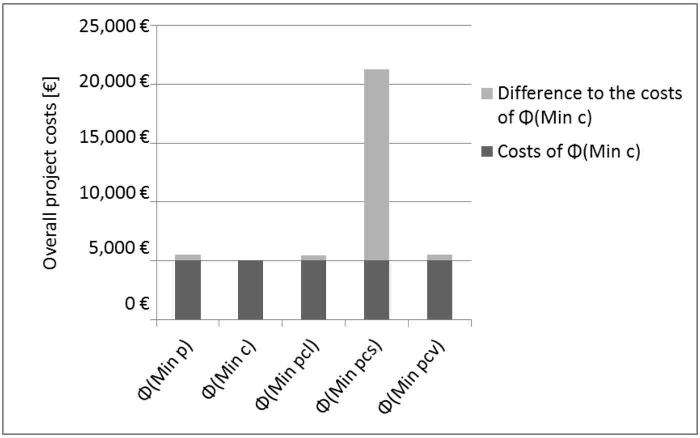


Figure 7-35: Overall project costs of the deconstruction plans due to different economic and environmental objectives

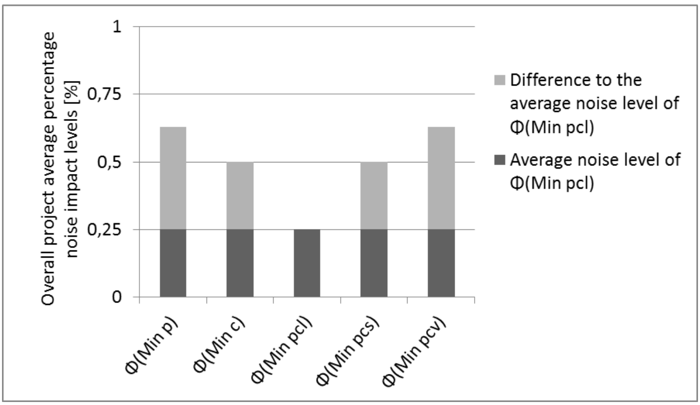


Figure 7-36: Overall project average percentage noise impact levels of the deconstruction plans due to different economic and environmental objectives

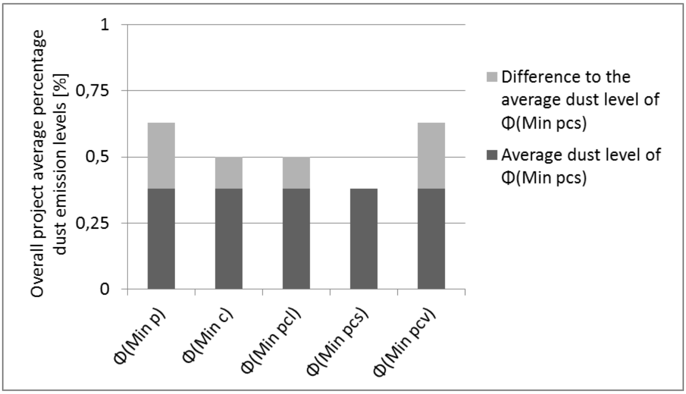


Figure 7-37: Overall project average percentage dust emission levels of the deconstruction plans due to different economic and environmental objectives

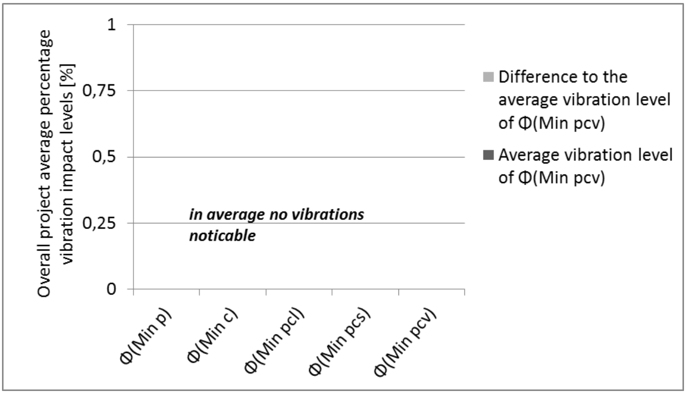


Figure 7-38: Overall project average percentage vibration impact levels of the deconstruction plans due to different economic and environmental objectives

Figure 7-34 shows that the objective to minimise the overall project duration (Φ(Min p)) conflicts with the other objectives, except the minimisation of the overall project average vibration impact levels (Φ(Min pcv)). As documented in Figure 7-35, Figure 7-36, Figure 7-37, Figure 7-38, also the other values of the deconstruction plan due to the objective to minimise the overall project duration and due to the objective to minimise the overall project average vibration impact levels are the same in the example project. As illustrated in Figure 7-38, the average percentage vibration impact levels at the closest building in the neighbourhood, which is 30 m from site in the base scenario, are assigned to zero. Hence, they are not noticeably independent of the objective function and the selected deconstruction plan by TEE-D-Plan. Hence, to minimise the overall project average vibration impact levels the same deconstruction project plan is chosen as to minimise the project overall duration, due to the iterative solution process and Equation 6-10 in section 6.3.1. The difference in the overall duration of the deconstruction project plan due to the minimised overall project duration compared to the deconstruction plan due to the minimisation of the overall project average dust emission levels (Φ(Min pcs)) is the highest. In the base scenario of the example project the overall project due to the minimised dust level takes with 64 h more than six times as long as the deconstruction project with minimised overall project duration. The deconstruction plans due to minimised overall project costs and average noise impact levels take around twice as long as the minimised overall project duration.

The objective to minimise the overall project costs (Φ(Min c)) conflicts with the four alternative objectives, as presented in Figure 7-35. Equally to the minimisation of the overall project duration (see Figure 7-34), the conflict with the minimisation of the overall project average dust emission levels (Φ(Min pcs)) is the highest. In the base scenario of the example project the overall project costs due to the minimisation of the overall project average dust emission levels are with 21,300 **€** four times as much as the deconstruction project with minimised overall project costs. The difference in the overall costs of the deconstruction project plan due to minimised overall project costs compared to the other proposed deconstruction plans is small and around 10%.

Figure 7-36 shows that the objective to minimise the overall project average noise impact levels (Φ(Min pcl)) is highly conflicting with all the other objectives. The deconstruction plans due to minimised overall project durations (Φ(Min p)), costs (Φ(Min c)), average dust emission levels (Φ(Min pcs)) and average vibration impact levels (Φ(Min pcv)) result in partly annoying (0.5) and partly annoying to annoying average noise impacts and hearing damages when longer exposed (0.625). On the other hand, the deconstruction plan due to minimised overall project average noise impact levels merely end in little annoying average noise impacts at the closest building of the neighbourhood.

Such as the deconstruction plans due to minimised overall project average noise impact and dust emission levels are opposed to each other in terms of minimised average noise impact levels; they collide due to minimised average dust emission levels. As presented in Figure 7-37, the deconstruction plan due to minimised overall project average noise impact levels (Φ(Min pcl)) does not meet the objective to minimise the overall project average dust emission levels (Φ(Min pcs)). Moreover, Figure 7-37 shows that the objective to minimise the overall project average dust levels conflicts with all alternative four objectives. Thereby, the deconstruction plan due to minimised average dust emission levels results in little to medium dust exposures at the closest building of the neighbourhood and breathing protection is partly recommended (0.375), the deconstruction plans due to minimised overall project costs (Φ(Min c)) and average noise impact levels (Φ(Min pcl)) end in medium dust exposures with recommended breathing protection (0.5). Moreover, the deconstruction plans due to minimised overall project duration (Φ(Min p)) and average vibration impact levels (Φ(Min pcv)) result even in medium to high overall project average dust emission levels, where breathing protection is between recommended and required (0.625).

In addition to the minimisation of the single environmental objectives separately, the multi-objective approach with different weightings of the three environmental objectives is applied in the following. This variation of the weightings depicts also the sensitivity analysis, the fourth/last step of MAVT (see section 6.3.3). Figure 7-39, Figure 7-40, Figure 7-41, Figure 7-42, Figure 7-43 illustrate the change in the plan values of the deconstruction project plans of the preference scenarios due to the minimisation of the single overall project average emission/impact levels[227] and based on the following five variations of weightings:

- Equal weighting of all three environmental objectives: Φ(Min pcl_pcs_pcv-equally),
- Weighting of minimising noise by 90% and of minimising dust by 10% and vibration not considered: Φ(Min pcl-90_pcs-10_pcv-0),
- Weighting of minimising noise by 30% and of minimising dust by 70% and vibration not considered: Φ(Min pcl-30_pcs-70_pcv-0),
- Weighting of minimising noise by 10% and of minimising vibration by 90% and dust not considered: Φ(Min pcl-10_pcs-0_pcv-90) and
- Weighting of minimising dust by 10% and of minimising vibration by 90% and noise not considered: Φ(Min pcl-0_pcs-10_pcv-90).

[227] Φ(Min pcl), Φ(Min pcs), Φ(Min pcv).

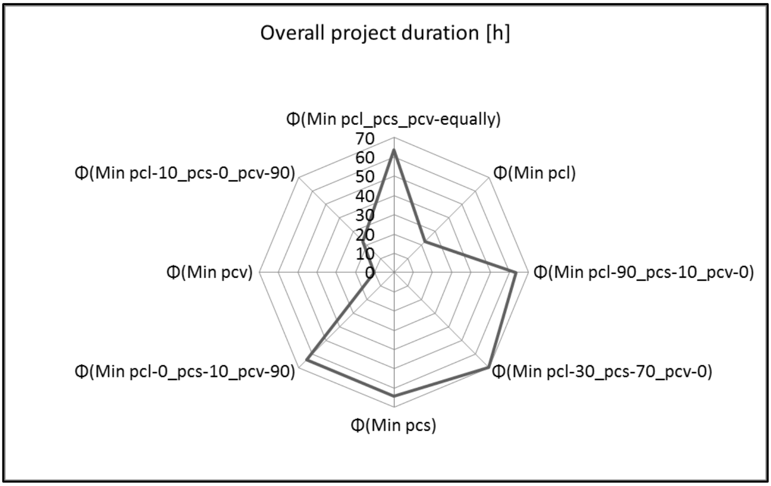


Figure 7-39: Change in the overall project durations of the deconstruction plans due to variations in the weighting of environmental objectives

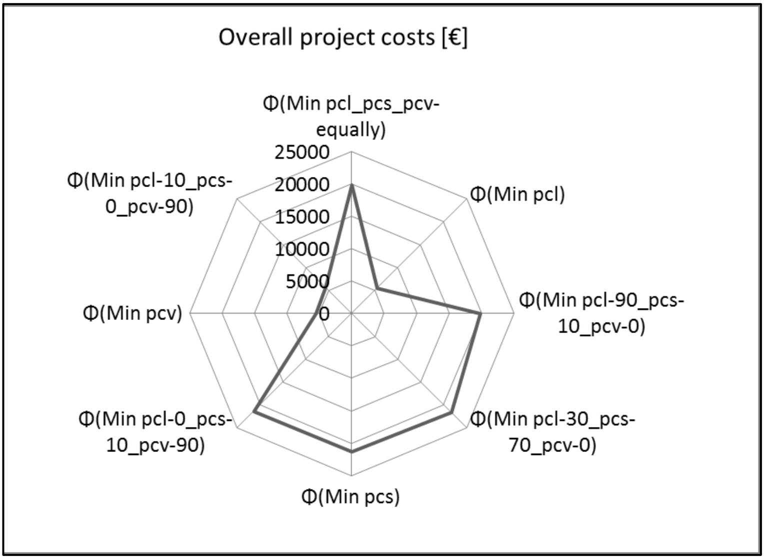


Figure 7-40: Change in the overall project costs of the deconstruction plans due to variations in the weighting of environmental objectives

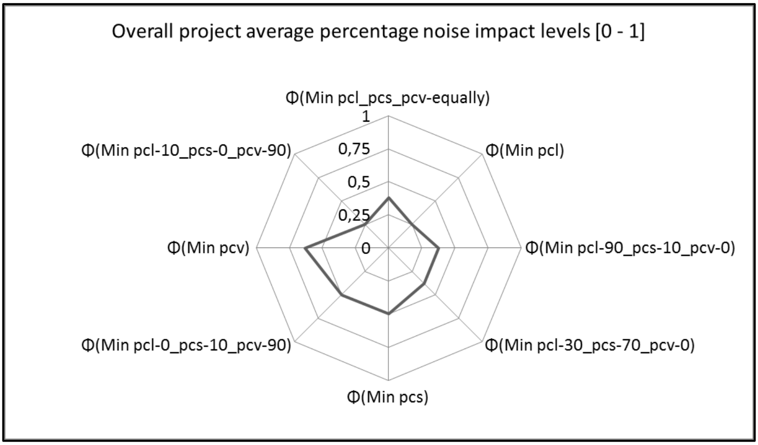


Figure 7-41: Change in the overall project average percentage noise impact levels of the deconstruction plans due to variations in the weighting of environmental objectives

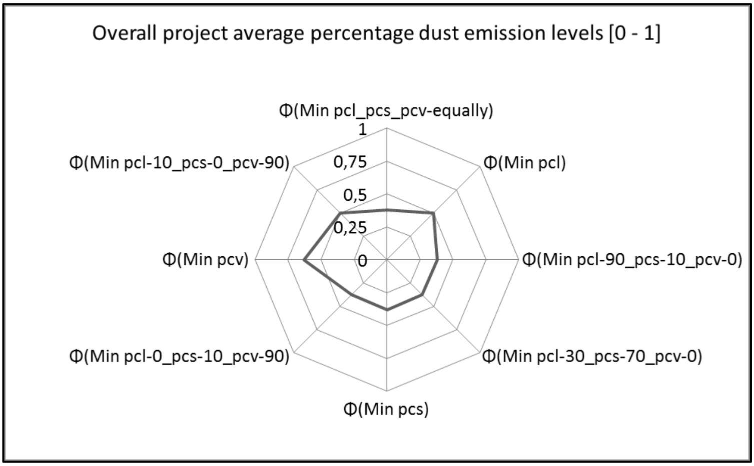


Figure 7-42: Change in the overall project average percentage dust emission levels of the deconstruction plans due to variations in the weighting of environmental objectives

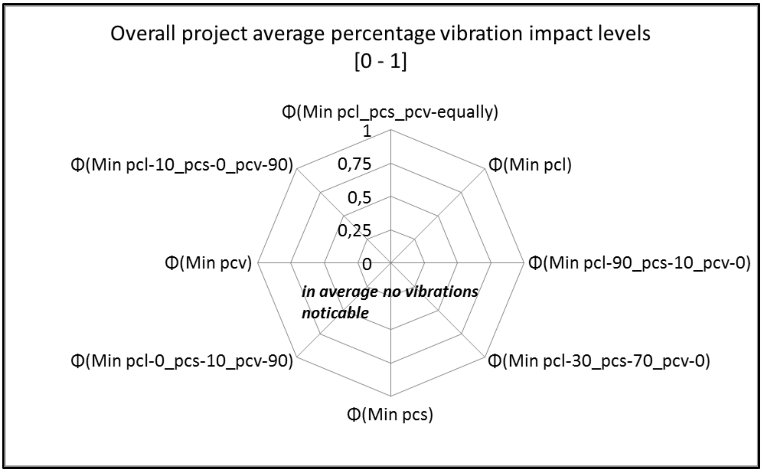


Figure 7-43: Change in the overall project average percentage vibration impact levels of the deconstruction plans due to variations in the weighting of environmental objectives

In addition to the statements of objective conflicts above and their endorsement, Figure 7-39, Figure 7-40 show a strongly correlation between the overall project duration and costs due to the different weightings of the three environmental objectives. Figure 7-39, Figure 7-40 and Figure 7-42 show that the degree of importance of minimising the overall project average dust emission levels highly influences the economic plan values, i.e. overall project duration and costs. This influence in the form of increasing duration and costs is high, whereas the change in the overall project average dust emission levels is marginal. For instance, the overall project average dust emission levels singly decreases from medium dust exposures where breathing protection is recommended (see Figure 7-42, Φ(Min pcl)) to between little and medium dust exposures (see Figure 7-42, Φ(Min pcl-90_pcs-10_pcv-0)). In contrary, the overall duration is with 64 h in the variation of weightings Φ(Min pcl-90_pcs-10_pcv-0) nearly three times as much as in the preference scenario Φ(Min pcl) (see Figure 7-39) and the costs increase more than three times to 19.800 € (see Figure 7-40).

7.6.3 Changes in the deconstruction plan

To answer sub-question 5, the variations in the deconstruction plan due to the five single economic and environmental objectives are analysed. They are analysed with respect to the recommended deconstruction technique modes of each activity in this section. The following tables show the activity-related deconstruction technique modes recommended by TEE-D-Plan and respective plan values in the form of durations, operation costs and average emission/impact levels of noise, dust and vibrations of the deconstruction plans due to different economic and environmental objectives.

Table 7-19: Activity-related technique modes and plan values of the deconstruction plan due to minimise the overall project duration

Activities				Activitiy-related modes and plan values due to minimise the overall project duration (base scenario)					
Column #				1	2	3	4	5	6
Activity #	Level	Type of the deconstructed component	Component material	Mode (definition see appendix A1)	Duration [h]	Activity-related operation costs [€]	Activity-related average percentage noise impact level	Activity-related average percentage dust emission level	Activity-related average percentage vibration impact level
1	3	Roof	Wood	**Grip_HY_2**	**0.2**	61	0.125	0.375	0
2	3	Exterior wall	Brick	**Press_HY_2**	**0.8**	265	0.25	0.75	0
3	3	Interior wall	Wood	**Grip_HY_2**	**0.1**	17	0.125	0.375	0
4	2	Slab	Wood	**Cut_HY_2**	**1.9**	622	0.125	0.125	0
5	2	Exterior wall	Brick	**Press_HY_2**	**0.9**	283	0.25	0.75	0
6	2	Interior wall	Brick	**Press_HY_2**	**0.6**	203	0.25	0.75	0
7	1	Slab	Wood	**Cut_HY_2**	**1.9**	622	0.125	0.125	0
8	1	Exterior wall	Brick	**Press_HY_2**	**0.9**	276	0.25	0.75	0
9	1	Interior wall	Brick	**Press_HY_2**	**0.8**	258	0.25	0.75	0
10	1	Bottom plate	Reinforced concrete	**Mort_HY_2**	**2.3**	819	0.625	0.75	0

Table 7-20: Activity-related technique modes and plan values of the deconstruction plan due to minimise the overall project costs

Activities				Activitiy-related modes and plan values due to minimise the overall project costs					
Column #				1	2	3	4	5	6
Activity #	Level	Type of the deconstructed component	Component material	Mode (definition see appendix A1)	Duration [h]	Activity-related operation costs [€]	Activity-related average percentage noise impact level	Activity-related average percentage dust emission level	Activity-related average percentage vibration impact level
1	3	Roof	Wood	**Grip_HY_1**	0.4	**52**	0	0.25	0
2	3	Exterior wall	Brick	**Press_HY_1**	1.6	**226**	0.125	0.625	0
3	3	Interior wall	Wood	**Grip_HY_1**	0.1	**14**	0	0.25	0
4	2	Slab	Wood	**Cut_HY_1**	3.8	**531**	0	0.125	0
5	2	Exterior wall	Brick	**Press_HY_1**	1.7	**241**	0.125	0.625	0
6	2	Interior wall	Brick	**Press_HY_1**	1.3	**174**	0.125	0.625	0
7	1	Slab	Wood	**Cut_HY_1**	3.8	**531**	0	0.125	0
8	1	Exterior wall	Brick	**Press_HY_1**	1.7	**235**	0.125	0.625	0
9	1	Interior wall	Brick	**Press_HY_1**	1.6	**220**	0.125	0.625	0
10	1	Bottom plate	Reinforced concrete	**Mort_HY_1**	4.6	**675**	0.5	0.625	0

Table 7-21: Activity-related technique modes and plan values of the deconstruction plan due to minimise the overall project average noise impact levels

Activities				Activitiy-related modes and plan values due to minimise the overall project average noise impact levels					
Column #				1	2	3	4	5	6
Activity #	Level	Type of the deconstructed component	Component material	Mode (definition see appendix A1)	Duration [h]	Activity-related operation costs [€]	Activity-related average percentage noise impact level	Activity-related average percentage dust emission level	Activity-related average percentage vibration impact level
1	3	Roof	Wood	Grip_HY_1	0.4	52	**0**	0.25	0
2	3	Exterior wall	Brick	Press_HY_1	1.6	226	**0.125**	0.625	0
3	3	Interior wall	Wood	Grip_HY_1	0.1	14	**0**	0.25	0
4	2	Slab	Wood	Cut_HY_1	3.8	531	**0**	0.125	0
5	2	Exterior wall	Brick	Press_HY_1	1.7	241	**0.125**	0.625	0
6	2	Interior wall	Brick	Press_HY_1	1.3	174	**0.125**	0.625	0
7	1	Slab	Wood	Cut_HY_1	3.8	531	**0**	0.125	0
8	1	Exterior wall	Brick	Press_HY_1	1.7	235	**0.125**	0.625	0
9	1	Interior wall	Brick	**Grip_HY_1**	**2.2**	309	**0.125**	0.625	0
10	1	Bottom plate	Reinforced concrete	**Ripp_HY_1**	6.2	793	**0.375**	0.625	0

Table 7-22: Activity-related technique modes and plan values of the deconstruction plan due to minimise the overall project average dust emission levels

Activities				Activitiy-related modes and plan values due to minimise the overall project average dust emission levels					
Column #				1	2	3	4	5	6
Activity #	Level	Type of the deconstructed component	Component material	Mode (definition see appendix A1)	Duration [h]	Activity-related operation costs [€]	Activity-related average percentage noise impact level	Activity-related average percentage dust emission level	Activity-related average percentage vibration impact level
1	3	Roof	Wood	**Dec_HA_1**	**6.5**	617	0.375	**0.375**	0
2	3	Exterior wall	Brick	**Press_HY_2**	**0.8**	265	0.25	**0.75**	0
3	3	Interior wall	Wood	**Grip_HY_2**	**0.1**	17	0.125	**0.375**	0
4	2	Slab	Wood	**Cut_HY_1**	**3.8**	531	0	**0.125**	0
5	2	Exterior wall	Brick	**Press_HY_2**	**0.9**	283	0.25	**0.75**	0
6	2	Interior wall	Brick	**Press_HY_2**	**0.6**	203	0.125	**0.625**	0
7	1	Slab	Wood	**Dec_HA_1**	**46.8**	4454	0.375	**0.375**	0
8	1	Exterior wall	Brick	**Press_HY_2**	**0.9**	276	0.25	**0.75**	0
9	1	Interior wall	Brick	**Press_HY_2**	**0.8**	258	0.25	**0.75**	0
10	1	Bottom plate	Reinforced concrete	**Mort_HY_2**	**2.3**	819	0.625	**0.75**	0

Table 7-23: Activity-related technique modes and plan values of the deconstruction plan due to minimise the overall project average vibration impact levels

Activities				Activitiy-related modes and plan values due to minimise the overall project average vibration impact levels					
Column #				1	2	3	4	5	6
Activity #	Level	Type of the deconstructed component	Component material	Mode (definition see appendix A1)	Duration [h]	Activity-related operation costs [€]	Activity-related average percentage noise impact level	Activity-related average percentage dust emission level	Activity-related average percentage vibration impact level
1	3	Roof	Wood	**Grip_HY_2**	0.2	61	0.125	0.375	**0**
2	3	Exterior wall	Brick	**Press_HY_2**	0.8	265	0.25	0.75	**0**
3	3	Interior wall	Wood	**Grip_HY_2**	0.1	17	0.125	0.375	**0**
4	2	Slab	Wood	**Cut_HY_2**	1.9	622	0.125	0.125	**0**
5	2	Exterior wall	Brick	**Press_HY_2**	0.9	283	0.25	0.75	**0**
6	2	Interior wall	Brick	**Press_HY_2**	0.6	203	0.25	0.75	**0**
7	1	Slab	Wood	**Cut_HY_2**	1.9	622	0.125	0.125	**0**
8	1	Exterior wall	Brick	**Press_HY_2**	0.9	276	0.25	0.75	**0**
9	1	Interior wall	Brick	**Press_HY_2**	0.8	258	0.25	0.75	**0**
10	1	Bottom plate	Reinforced concrete	**Mort_HY_2**	2.3	819	0.625	0.75	**0**

To reach the objective of minimising the overall project duration, deconstruction methods with short durations, such as gripping and press-cutting, are suggested. Additionally, parallelisation of activities is implemented in the project plan when possible by the recommendation of modes with two basic units (see column 1 of Table 5 17). Consequently, short durations per activity are gained (see column 2 of Table 5 17), which result in the minimal overall project duration (see Figure 7-34).

To minimise the overall project costs, in general the same deconstruction methods are chosen as for the mitigation of the project overall duration. Often time and costs are connected in deconstruction projects, as especially equipment contingency costs are related to the project duration. Nevertheless, activity parallelisation is not suggested to reach the objective of minimised overall project costs. Deconstruction with one basic unit results in limited obstructions rather than working with two basic units on site. Consequently, the operation costs per activity of the modes with one basic unit are less than of those modes with two basic units. This can be recognised by comparing column 3 of Table 5 17 and Table 5 18.

To minimise the average noise impact levels of the overall project, activity modes are chosen, which reduce the noise impact level of the project phase and the overall project. Often these modes also have a lower activity-related average noise impact level compared to other methods/modes, for instance ripping instead of mortising (activity 10) and generally deconstruction with one basic unit rather than with two basic units, as documented by comparing column 1 and 4 of Table 7-19 and Table 7-21. Furthermore, modes in the deconstruction plan can also change even if they have the same activity-related average noise impact levels, but longer durations (compare column 1, 2 and 4 of Table 5 18 and Table 7-21 related to activity 9). This happens, when the average impact level of the project phase is decreased by performing the activity in the long-lasting mode. In this context, recommended modes in the deconstruction plan can also have higher activity-related average noise impact levels than not suggested modes, when the difference between the two noise levels is little. This can be the case, when the duration of the examined activity performed in the recommended mode is likewise longer than that of not suggested modes and other activities in the same deconstruction phase have to have higher activity-related average noise impact levels than the examined activity. The reason for these cases is that the average noise impact level represents an average noise level over a period of time, based on Equation 4 21 in section 4.5.3.3. Hence, the mitigation effect of the activity-related average noise impact level on the phase-related and project-related average noise impact levels respectively, depends on the noise impact level, the potential lowest impact level and the activity duration. This effect increases when the noise level and/or the duration of the examined activity highly differ from the noise levels and/or the durations of the other phase and project activities respectively.

To minimise the average dust emission levels of the overall project, activity modes are chosen, which reduce the dust emission level of the project phase and the overall project. Analogous to noise, the average dust emission level represents an average dust level over time, based on Equation 4 22 in section 4.5.3.3. Hence, the relevant descriptions above apply to dust as well. Consequently, for those activities, which can most influence the reduction of the dust emission of the overall project, usually modes with very longer durations and relatively low dust levels (e.g. deconstruction by hand) are recommended for the deconstruction plan. These activities have the lowest dust emission level of the project phase, such as activity 1, 4 and 7 in Table 7-22. Those modes can have higher activity-related average dust emission levels than not suggested modes, which can be recognised by comparing column 1 and 5 of Table 7-19, Table 7-21 and Table 7-22 related to activity 1 and 7. Nevertheless, the average dust emission levels of the overall project are minimised, as Figure 7-37 documents. This fact again points out the trade-off between the duration and the potential impact level reduction of the single activity, addressed above due to the noise impact. The mitigation effect of the activity-related average dust emission level on the phase-related and project-related average dust emission levels respectively, depends on the dust emission level, the potential lowest emission level and the activity duration. For all the other activities of the phase and the project respectively, those modes with the shortest duration are suggested by TEE-D-Plan, when the difference to the potential lowest impact of the activity is limited. This is shown by comparing column 1, 2 and 5 of for instance Table 7-19, Table 7-21 and Table 7-22, related to all activities, except activity 1, 4 and 7.

To minimise the average vibration impact levels of the overall project, activity modes are chosen, which reduce the vibration impact level of the project phase and the overall project. In the example project independent of activity modes no vibrations are noticeable at the closest building in the neighbourhood, which is 30 m from the site, as documented by comparing column 6 of Table 7-19, Table 7-20, Table 7-21, Table 7-22 and Table 7-23. Hence, the same activity modes are chosen in the deconstruction project plan so as to minimise the project overall duration (compare column 1 of Table 7-19 and Table 7-23), due to the iterative solution process and Equation 6-10 in section 6.3.1, as mentioned above in section 7.3.2. Furthermore, the average vibration impact level represents an average vibration level over time, based on Equation 4 23 in section 4.5.3.3. Hence, analogous to noise and dust, suggested modes in the deconstruction plan can also have higher activity-related average vibration impact levels than not recommended modes and the relevant above descriptions apply to vibrations as well.

8 Discussion of results, conclusion and outlook

8.1 The deconstruction planning and decision support model TEE-D-Plan

The model TEE-D-Plan for technical, economic and environmental deconstruction planning and decision support has been documented in this thesis. The major objective of the development was the integration of emissions and neighbourhood-dependent local environmental impacts into the deconstruction project planning and decision making process. By depending on the specific deconstruction projects, the model was applied to the identification of those deconstruction techniques which mitigate local environmental impacts from these deconstruction projects the most, while considering economic objectives and the technical feasibility.

As deconstruction projects are potentially the source of high emissions and impacts on the local environment in terms of noise, dust and vibrations, the management and mitigation of emissions and local environment impacts is important. It is significant at present and might become a key aspect in deconstruction project planning and decision making in the course of sustainable development in the future. Local environmental impacts, which are the consequence of noise, dust and vibration emissions of the deconstruction process on site, highly depend on and vary with applied single-activity-related deconstruction techniques and building component characteristics. Furthermore, impact levels and their relevance related to the subject of protection are influenced by and are dependent on the neighbourhood characteristics around the deconstruction site. These influences can be addressed in the planning phase in line with operational deconstruction project planning and decision making, and with environmental assessment. Hence, model-based approaches of operational deconstruction project planning are appropriate for planning and decision making, and environmental impact assessment (EIA) is a suitable method for environmental assessment.

Nevertheless, the analysis of the current state of research in chapter 3 shows that existing model-based operational deconstruction project planning approaches place emphasis on the economic dimension and consider environmental impacts solely in terms of recycling of building materials and related implications on costs. One approach looks at energy demand. Hence, decisions are made on economic objective/s, such as minimum costs and duration of the overall project and a deconstruction plan with respective activity-related deconstruction techniques is provided. Within this context, the approaches often include resource constraints due to varying available resources but constraints due to changing surrounding conditions, and in general surrounding conditions, are not considered.

Even though economic assessment of deconstruction techniques is regularly covered in these approaches, related data is more than 10 years old and different equipment sizes[228] are not considered. The technical feasibility of deconstruction techniques is sometimes examined, but is limited to building component types and materials. Hence, maximal component material thickness and deconstruction heights above ground[229] are not considered in the approaches. Methods for the quantitative assessment of deconstruction techniques due to noise, dust and vibration emissions and impacts are

[228] Different equipment sizes can influence duration and environmental impacts of the single deconstruction activities
[229] The deconstruction heights above ground can influence duration and environmental impacts of the single deconstruction activities.

not at all included in the existing approaches of operational deconstruction planning.

Additionally, existing EIA methods for environmental assessment do not include any quantitative data on the influence of deconstruction techniques, building characteristics and surrounding conditions on specific noise, dust and vibration emissions and impacts. Related appropriate environmental assessment approaches are also not enclosed.

The present research took on these deficits of existing approaches and closed the gaps to the greatest possible extent. Within this context, the model TEE-D-Plan provides the project plan due to the minimisation of local environmental impacts for a specific building to be deconstructed. The plan includes the activity-related deconstruction techniques. In planning and decision making the preferences of the decision maker, economic objectives and the technical feasibility are considered as well. Therefore, in Module 1 of TEE-D-Plan firstly, the technically feasible deconstruction technique modes are selected for each deconstruction project activity. The technical assessment includes new parameters of the technical feasibility of modes. In this context, the maximal building component material thicknesses and deconstruction heights above ground are considered, besides component types and materials.

Secondly, the technically feasible mode-related alternatives of single deconstruction activities are economically and environmentally assessed. For each activity, alternative economic and environmental plan values are calculated in terms of costs of resources for the on-site deconstruction process, durations, average emission levels of dust and average impact levels of noise and vibrations. The economic assessment was advanced to consider typical current costs and durations of deconstruction projects. In this regard, activity-related specific hourly costs of equipment with varying sizes and of labour salaries based on recent literature and adapted and new specific duration values based on literature and on primary data from an expert survey and consultations were used. The economic assessment was also validated within this research by the two test deconstruction projects in section 7.1.

For the first time, average emission/impact levels of noise, dust and vibrations of deconstruction activities can be quantitatively proposed by an EIA-approach, which was newly developed in this thesis. Within this context, primary data was collected by an expert survey and consultations, and experiments to develop specific hourly emission level values of noise, dust and vibrations of different activity parameter configurations.

Based on the alternatives of deconstruction project activities of Module 1, in Module 2 of TEE-D-Plan the deconstruction project plan is generated via the adaption of a multi-mode resource constrained project scheduling problem (MRCPSP) variant.

Primal, within this context, constraints due to changing surrounding conditions in the form of required space on site of different deconstruction technique modes and neighbourhood-usage-type-dependent maximal allowed noise impact levels can be considered to find the solution by adopting the MRCPSP in terms of space- and impact level-dependent constraints. The basis to find the solution was modified due to real situations on deconstruction projects by using the calculated phase-related plan values in terms of phase-related costs and average noise impact levels of Module 1. Thus, it is taken into account that basic units of equipment regularly stay across single deconstruction activity durations on site, independent of whether they are used. Additionally, the non-linear scaled character of noise impacts and time-dependent average impact level values are (partly) considered.

Furthermore, the solution of the overall deconstruction project in line with the sum of deconstruction phase-related solutions approximates the actual top-down, building level-wise deconstruction sequence in conjunction with solvable model calculations. The iterative objective function provides the deconstruction project plan due to the research question in terms of the minimisation of distinct environmental impacts, while considering economic objectives.

The multi-objective solution approach, based on weighted phase-related alternatives, enables the simultaneous consideration of all three environmental objectives in terms of minimising average noise and vibration impact levels and average dust emission levels. Additionally it offers the analysis of potentials of deconstruction plan changes due to different environmental objectives and due to their importance for the decision maker.

In summary, the major original methodical research includes the development of a model for technical, economic and environmental deconstruction planning and decision support. For the quantitative economic and environmental assessment of deconstruction projects, specific duration values of material pre-separation and pre-crushing were newly created based on primary data from an expert survey and consultations. Furthermore, for the environmental assessment by EIA, firstly, deconstruction-activity-related specific hourly emission level values of noise, dust and vibrations were newly generated based on primary data from an expert survey and consultations, and experiments. Secondly, new environmental assessment methods based on structural neighbourhood characteristics and respective defined environmental indicators were established.

8.2 Answers to the research questions

Based on the results documented in chapter 7, in the following the answers to the major research question, which was split into five sub-questions in chapter 1, are summarised. In this regard, firstly the answers to the sub-questions are summarised in section 8.2.1 to 8.2.5. These findings are the basis to answer the major research question in summary in section 8.2.6.

8.2.1 Influence of building characteristics

The results of TEE-D-Plan in section 7.3.2 show that the project phase solution spaces, selected modes and the plan values/the emission/impact levels are influenced by different building characteristics. The component material and the deconstruction height above ground can enlarge or reduce the project phase solution spaces. Furthermore, variation of materials and the height above ground can cause mode changes. For instance, press-cutting is primarily applied to building components out of reinforced concrete to meet the research objective of minimising the noise impact levels of the overall project. Besides the mode change, the material can highly influence the plan values. For example, reinforced concrete instead of masonry materials greatly increases the activity duration, costs and the average noise impact level. Additionally, the dust emission level is increased compared to softer masonry types, such as brick. For deconstruction in heights over 9 m above ground, modes with longfront excavators instead of modes with hydraulic excavators are regularly applied. The application of longfront excavators highly increases the duration and costs of single activities compared to the utilisation of hydraulic excavators. Moreover, deconstruction heights above 15 m above ground can increase the average impact levels of these deconstruction activities.

8.2.2 Influence of surrounding conditions

The results of TEE-D-Plan in section 7.4.2 show that, especially in the short distance between the deconstruction site and the subject of protection, the impact levels of noise and vibration increase with decreasing distance between the deconstruction site and the subject of protection. As expected, the more reflecting walls are around site, the higher are the noise impact levels at the closest building in the neighbourhood

8.2.3 Influence of project constraints

The results of TEE-D-Plan in section 7.5.2 demonstrate that the project phase solution spaces, selected modes and the plan values/the emission/impact levels are influenced by different project constraints. Fewer available basic units, limited available space on site and a distinct urban usage type reduce the project phase solution spaces, which can have an influence on the selected modes and the average impact levels of the deconstruction plan. Additionally, a distinct urban usage type reduces the noise impact level in those deconstruction plans with other objectives than minimising noise by the reduction of project phase solution spaces and related mode changes. Furthermore, the basic unit size has an influence on the plan values of the overall deconstruction project. A larger unit size decreases the duration and increases the costs and the average impact levels.

8.2.4 Conflicts of economic and environmental objectives

The results of TEE-D-Plan in section 7.6.2, based on the base scenario of the case study, show that there are conflicts between all environmental objectives. Furthermore, there is a strong mutual conflict recognisable between the minimisation of the overall project average dust emission levels and both economic objectives, overall project duration and costs. The conflicts of the economic objectives with the minimisation of the overall project average vibration impact levels are limited. The reason is that the average vibration impact levels are not noticeable, independent of the objective function and the selected deconstruction plan by TEE-D-Plan. Consequently, the overall project duration is minimised with the objective to minimise vibrations in the iterative solution process of TEE-D-Plan. The conflicts of the economic objectives with the minimisation of the overall project average noise impact levels are limited as well, with a difference in the overall project costs of 10%. On the other hand, there is a major conflict between the minimisation of the overall project average noise impact levels and both economic objectives. The differences in the noise levels between the minimisation of the overall project average noise impact levels and the minimisation of the duration and the average vibration impact levels of the overall project are the largest.

8.2.5 Objective-dependent plan variations

The results of TEE-D-Plan in section 7.6.3 point out that, firstly, parallelisation of activities is implemented to minimise the overall duration of the deconstruction project. Secondly, deconstruction methods, such as gripping and press-cutting, which are short in duration and have little equipment contingency costs and little operation costs, are suitable for minimising the overall costs of the deconstruction project. Thirdly, on the one hand deconstruction methods/modes, which cause little activity-related average impact levels, are adequate to minimise the respective average impact levels of the overall deconstruction project. On the other hand, whether the deconstruction method/mode is adequate to minimise distinct average impact levels depends on the mitigation effect of the average impact level of this activity on the phase-related/project-related average impact level. This effect is influenced by the difference to the impact levels of the other phase/project activities, the potential mode-dependent lowest impact level of the activity itself and by the activity duration compared to the other activity durations.

8.2.6 Appropriate deconstruction techniques for impact mitigation

To answer, how the distinct emissions and impacts on the local environment caused by deconstruction projects can be mitigated, while considering neighbourhood-dependent conditions, technical parameters and economic objectives, the focus of impact mitigation methods is on deconstruction project planning and decision making due to appropriate deconstruction techniques in this research. In this regard, the results of TEE-D-Plan show in summary that the evaluation of specific deconstruction techniques to minimise emissions and environmental impacts has to be predicated on fixed framework conditions related to the neighbourhood of the deconstruction site and technical parameters.

Firstly, the building characteristics, which are fixed for the specific deconstruction project, influence the project phase solution spaces of feasible deconstruction technique modes and the deconstruction plan in regard to selected modes and economic and environmental plan values. Secondly, surrounding conditions of the deconstruction site, which are also fixed for the specific project, can highly influence the level of impact on the local environment especially in the short distance between the deconstruction site and the subject of protection. Thirdly, project constraints, which are in general fixed for the specific project as well, influence the project phase solution spaces and the deconstruction plan with respect to selected modes and the plan values.

Based on these fixed framework conditions, the possible deconstruction project plans, including single project activities performed in different technique modes, can be evaluated in order to reach the objective of minimising the local environmental impacts. In this regard, the minimisation of environmental impacts can imply the minimisation of a distinct environmental impact/emission in terms of noise, dust or vibrations. Additionally, two or all three environmental impacts can be simultaneously considered in minimisation via Multi-Criteria Decision Analysis (MCDA). The results of TEE-D-Plan demonstrate that all environmental objectives are in some conflict with each other in the deconstruction plan in the form of selected modes and environmental plan values.

In the example project of this research, for instance the deconstruction plans due to minimised overall project average dust emission level and vibration impact level result in partly annoying and partly annoying to annoying average noise impacts and hearing damages when longer exposed. Thereby, the deconstruction plan due to minimised overall project average noise impact levels only effects little annoying average noise impacts at the closest building in the neighbourhood. On the other hand, the deconstruction plan due to minimised overall project average noise levels with medium dust exposures does not meet the objective to minimise the overall project average dust levels of only little to medium dust exposures. The deconstruction plans due to minimised average vibration impact levels result even in medium to high overall project average dust emission levels. Furthermore, in the example the simultaneous consideration of noise, dust and vibrations by MCDA show that even in equal weighting of the environmental objectives, especially the minimisation of dust has a great influence on the project plan. Additionally, minimising the overall project average dust emission levels highly increases the economic plan values overall project duration and costs compared to the other two environmental objectives.

In terms of selected modes, the example provides the following general statements. To minimise the average noise impact levels of the overall project, usually deconstruction with one basic unit rather than with two basic units and the method ripping instead of mortising is applied. In contrast to the suggestions related to the reduction of average noise impact levels, modes of activity parallelisation are usually implemented in the project plans to minimise average dust emission levels and average vibration impact levels. In this regard, modes with on the one hand shortest durations and on the other hand limited differences to the potential lowest dust emission levels are suggested, to minimise the average dust emission levels. Nevertheless, for those activities, which can most influence the reduction of average dust emission levels of the overall project, often deconstruction by hand and modes with longer durations are recommended. In contrast to proposed modes with longer durations of those activities, which can most influence on the reduction of average dust emission levels of the overall project, modes with generally short durations are recommended due to minimising the average vibration impact levels. Within this context, deconstruction modes with on the one hand low vibration levels and on the other hand short durations, such as mortising, gripping and press-cutting and activity parallelisation, are suggested to reach the objective of minimising the average vibration impact levels.

8.3 Critical review of the model

In the following, TEE-D-Plan is critical reviewed partly according to the review structure in Stengel (2014). Additional, constraints/limits of the informative value of the model results are pointed out. The model is critical reviewed due to its granularity (section 8.3.1) and system boundaries (section 8.3.2) with respect to the research questions. Additionally, modelling of activity performance alternatives (section

8.3.3) and of environmental impact assessment (section 8.3.4) are critical reviewed.

8.3.1 Granularity

The characteristics of the building to be deconstructed are modelled based on relevant single vertical and horizontal components of the building shell. Within this context, each building level can encompass up to six different combinations of building component types and materials, which correlate with the project activities. This restricted resolution of TEE-D-Plan is applicable to model the building structure of deconstruction objects, as shown by the test projects in section 7.1, and to keep the model calculations solvable (see section 4.3.2.4). The materials and types of the building components implemented in TEE-D-Plan mainly influence the emissions of noise, vibrations and of dust, independent of the health hazards due to different dust types, to assess the impact on the local environment. Furthermore, the selection of techniques to deconstruct the building structure is dictated by these major materials and types. For technical assessment, building statics can be relevant characteristics due to the building stability during the deconstruction process, which cannot be evaluated by TEE-D-Plan. Within this context, the technical knowledge of the decision maker is essential.

The modelling of the surrounding conditions targets to map the real conditions around the deconstruction site for the evaluation of different technique modes and related environmental impacts. In connection with modelling the surrounding conditions in TEE-D-Plan, noise reflection is modelled as coherent noise levels and independent of further specifications of the surface material, the orientation, the size and the distance to the subject of protection of each reflecting wall. Hence, here the model can overestimate the noise increase by reflections.

The extent of this overestimation depends on the number of reflecting walls. For instance, for two additional reflecting walls the maximal possible overestimation can be 10 dB(A) and can provoke a maximal noise level increase of 12.5%. Vibration impact levels are conservatively assessed. The ground materials, which can reduce the propagation speed of vibrations, are neglected in the calculation of vibration distributions. Nevertheless, in general ground properties are hard to determine, so that this conservative assumption is necessary.

Surrounding conditions in terms of building arrangements and heights, resulting in highly fluctuating wind and turbulence fields, influence the dust distribution. These influences can be modelled by high-resolution dispersion models, which require more detailed maps of the surrounding built environment than implemented in TEE-D-Plan and great computing capacities. But as these influences highly vary over the day inter alia due to fluctuating meteorological conditions, respective dust changes are not considered in planning and decision making of future deconstruction projects in this research.

In the context of project constraints, the resource-dependent restrictions are limited to the availability of basic units in TEE-D-Plan. The availability of attachments and different skills of employees can be relevant for the selection of feasible deconstruction techniques. Nevertheless, usually attachments can be hired. Furthermore, a key expertise of an employee in deconstruction projects is the handling of an excavator. This skill is directly linked to the basic unit and the number of available employees with this expertise can be indicated by the number of unit sizes as well. Hence, it is to be expected that corresponding further project constraints do not enhance the model results.

Related to project-objective-dependent influences on the solution, especially data quality and the calculation of objective variables are relevant in the context of the model granularity. The specific costs related to equipment and employees had been updated in this research, additionally they can be adapted by the decision maker via the user interface of the model.

The specific duration values include global set-up times based on expert knowledge. Hence, there are uncertainties in terms of required times, for instance due to project-specific changes of attachments and lack of works. Moreover, no learning effects due to repetitions of activities are considered in the model by decreasing duration values and resource demands, as respective data is missing. Specific duration values of material pre-separation and pre-crushing are independent of the basic unit size, as more detailed data is missing as well.

The specific hourly emission level values of noise, dust and vibrations are drawn from nine-stage emission level classification numbers. The classification numbers result from expert survey and consultation and encompass the level as well as the annoyance of emissions. Furthermore, the number of respondents in the expert survey was limited to 17. This restricted number of respondents, the nine-stage classification based on averaging of all survey responses and annoyance as a subjective element in the evaluation result in uncertainties in the data of emissions.

The calculation of objective variables includes uncertainties as well. These uncertainties are related to the granularity of objective variables, which determine the quality of the identified deconstruction plan. The environmental assessment in terms of average emission and impact levels is performed on the basis of phase-related average nine-stage percentage emission/impact levels. Firstly, the nine-stage resolution of the evaluation parameters is coarse and evaluation parameters on the interface between two stages can influence the model results. However, more detailed data is missing at present.

Secondly, especially the sum of phase-related average noise impact levels over all project phases can slightly deviate from an overall-project-related average noise impact level, calculated with Equation 4 18 in section 4.5.3.3. Hence, the resulting average noise impact levels of the overall project can differ by one stage (12.5%) of the percentage impact levels. Nevertheless, to keep the model calculations solvable, the phase-related solution process had to be applied in TEE-D-Plan.

Similarly the sum of phase-related costs, calculated with Equation 4 10 in section 4.4.3.2, can deviate from overall-project-related costs, if the contingency costs are related to the overall deconstruction project. For instance, two hydraulic excavators are kept available during the overall deconstruction project, even only one excavator is applied in most phases. Respectively the project costs would increase by the contingency costs of a basic unit for those phases, where only one excavator is required. However, the phase-related solution process is in the line with reality, when they calculate equipment costs related to the top-down, building level-wise deconstruction process. Hence, it is to be expected that the calculation of overall project costs might even increase uncertainties in the economic objective variables.

Finally, an analysis of uncertainties in the economic and environmental plan values could increase the robustness of the identified deconstruction plan. A respective analysis of uncertainties in the plan values is not within the scope of this research.

8.3.2 System boundaries

The system boundaries related to the characteristics of the building to be deconstructed are linked to the deconstruction of the building shell and the actual deconstruction of the building and material handling on site. Especially here emissions of noise, dust and vibrations can occur and these processes are most relevant for the selection of deconstruction techniques and to answer the research question. To evaluate consequences on human health, processes of preliminary work of deconstruction projects, such as the removal of the building core, elimination of interior fittings and the building (thermal) envelop and removal of technical building services, which are not included in this study, would be required to be modelled and assessed as well. Furthermore, these preliminary works and processes related to the disposal of deconstruction waste, which are also outside the system boundaries of this research, would be necessary to be modelled and assessed to estimate the total environmental impacts of the overall deconstruction project.

The system boundaries in connection to the surrounding conditions, such as neglected ground properties and surrounding-structure-related reduction effects on the dust impact level, are discussed related to the model granularity in section 8.3.1.

In the context of project constraints, the impact-level-dependent restrictions are limited to noise impact level-dependent project constraints in TEE-D-Plan. These impact level-dependent project constraints are linked to noise impact guideline values related to day time according to DIN 18005-1:2002-07, AVV (1970) and TA Lärm (1998). Project constraints linked to night-time-related noise impact guideline values should be implemented in the model, when deconstruction projects are performed during night time (between 8 pm and 7 am), which is in practice regularly not the case. Depending on the sensitivity of the neighbourhood, vibration and dust impact level-dependent project constraints can be relevant. Nevertheless, at present respective universal legal impact guideline values due to different neighbourhood usage types do not exist, which could be used in the model. Only technical vibration impact guideline values are available due to different building structures, which could be applied depending on major building structures of the neighbourhood. The resource-dependent restrictions are limited to maximal two available basic units of one type, which are linked to the set of available deconstruction technique modes described in section 8.3.3. Moreover, project constraints in the form of contractual obligations are not included in TEE-D-Plan, as they are not within the current scope of this research.

The system boundaries in the calculation of plan values, which form the objective variables, can influence the solution. Firstly, the calculated costs exclusively include costs of resources of the on-site deconstruction process. Additional costs, such as costs of the unconsidered processes mentioned above, of site facilities and of security installations can vary for the single project, but they do not directly influence the selection of deconstruction techniques and are therefore outside the system boundaries of TEE-D-Plan. Moreover, the inclusion of these processes and costs do not enhance the model results related to the current research focus, which emphasis on decision support to minimise the impacts on the local environment.

Secondly, in the calculation of impact levels variable initial impact levels of noise, dust and vibrations of the specific deconstruction site and its neighbourhood are not considered. In the context of the current research objectives, sole additional emissions and impacts caused by the deconstruction project are evaluated to select appropriate deconstruction techniques.

8.3.3 Activity performance alternatives

Activity parallelisation is restricted to maximal two parallel activities applied to building components of the same type and the same material in TEE-D-Plan. Parallelisation as activity performance alternatives has to be modelled as separate deconstruction activity technique modes, as especially related emissions and environmental impacts cannot be simply added up. Consequently, parallelisation of more than two activities and of activities applied to different building component types and/or materials cannot be modelled. Respectively required data is missing to date. Furthermore, single deconstruction techniques, for example dismantling with a crane and blasting, are not modelled, as the focus is on most widely-used deconstruction methods with hydraulic excavators and data of other techniques is not available in the quantitative form to be implemented in TEE-D-Plan. Additionally, TEE-D-Plan does not include safety measures, which for instance could be modelled in the form of additional alternative activity modes. Therefore, necessary data is absent as well.

Finally, the modelling of the deconstruction process based on single activities targets to map the real conditions on site. In this context, in TEE-D-Plan single activities can be performed in different modes. Disruptions of activities and variations of resources within one activity are not included within the current model.

8.3.4 Environmental impact assessment

The environmental plan values, which form the environmental objective variables, are calculated by environmental assessment. Within this context, average emission/impact level values are calculated, from which average emission/impact levels are derived. The average emission/impact level values represent average emission/impact levels over a period of time according to statutory provisions (see section 4.5.3.3). The effect of an activity-related average emission/impact level on the project-related average emission/impact level increases with increasing differences in the emission/impact level and the duration of this activity compared to the average emission/impact levels and duration of the other project activities. Consequently, depending on emission/impact levels and durations of other project activities, activity modes with long durations can be preferred to those with short durations due to minimising the average emission/impact level of the overall project.

Hence, within the current approach of environmental assessment, an activity-related emission/impact over a long period of time can be positively evaluated in the model, if it reduced the average emission/impact level of the overall project. The minimisation of the project duration, which is equal to the emission/impact exposure time, is only performed in the second step of the iterative solution process of TEE-D-Plan. Thus, limitations in exposure times are secondary. Nevertheless, the present approach of environmental assessment within TEE-D-Plan is based on statutory provisions.

Descriptive indicators[230], in terms of pressure and impact indicators according to EEA (1999), which describe dust emissions and noise and vibration impacts on the environment, are applied for the assessment of local environmental impacts in this research (see section 4.5.3). This approach meets the research objectives by assessing the impacts on the local environment as the 'area of protection' (EC-JRC (2011, p. xii), Guinée et al. (2002, p. 109)). To evaluate consequences on human health, descriptive impact indicators describing 'damage to human health' as the 'area of protection' would be appropriate. Cause-effect-relations in terms of consequences on health have to be assumed due to noise dust and vibrations. Respective data is limited, associated with a relatively high degree of uncertainty and in general many assumptions have to be made as consequences on health can highly differ depending on the situation and the surrounding conditions.

Finally, the environmental assessment focusses on dust emissions and noise and vibration impacts on the local environment due to the research objectives. Nonetheless, the assessment of additional

[230] Furthermore, the indication of the environmental performance, in the form of how the situation should be (so called performance indicators according to EEA), can be included in the environmental assessment by the impact-level-dependent restrictions.

environmental impacts might be interesting within the context of deconstruction projects, for instance freshwater and land ecotoxicity (Guniée at al. (2004, Part 2a, p. 68; Part 3, p. 534)). At present required data is missing.

8.4 Outlook

Based on the critical review of the model, in the following potential future areas of further developments and applications of TEE-D-Plan are outlined.

8.4.1 Model data

In terms of building characteristics, the inclusion of building statics could improve the technical assessment due to the building stability during the deconstruction process within TEE-D-Plan. At the moment this issue is left to the technical knowledge of the decision maker.

In general, a more detailed modelling of the surrounding conditions could enhance the quality of the identified deconstruction plan due to the minimisation of environmental impacts. A more precise mapping of real conditions around site decreases uncertainties in the evaluation of different technique modes and related environmental impacts. A more detailed modelling of noise-reflecting surfaces of the deconstruction site neighbourhood, such as surface material, the orientation, the size and the distance to the subject of protection, would reduce probable overestimations in noise increases by reflections. A link of TEE-D-Plan to high-resolution dispersion models and the availability of more detailed maps of the neighbourhood built environment would facilitate the modelling of dust distributions. This would decrease probable overestimations in dust impact levels at the subject of protection, if TEE-D-Plan is applied for a short-term strategy of deconstruction projects of maximum one day. Nevertheless, to provide this short-term strategy within maximum one day, large computing capacities are essential, as the high-resolution dispersion models usually required several days for their calculations.

Novel information about learning effects on deconstruction durations and size-dependent influences on durations of material pre-separation and pre-crushing could reduce the uncertainties in the deconstruction project duration proposed by TEE-D-Plan.

The future chance of a more detailed classification of the distinct emission levels of different implemented and not yet implemented[231] combinations of deconstruction techniques, materials, basic unit sizes and deconstruction heights above ground could limit uncertainties in emission data.

More specific objective variables could enhance the quality of the identified deconstruction plan, as uncertainties in the evaluation of different technique modes and related environmental impacts are decreased.

Furthermore, the prospect of a more detailed resolution of average emission/impact levels (environmental objective variables) might enhance the quality of the identified deconstruction plan, as uncertainties in the evaluation of different technique modes and related environmental impacts are decreased. Both aspects require the collection and analysis of numerous primary data of distinct emissions and impacts related to deconstruction works. The calculation of overall-project-related average noise impact levels might be possible with the help of large computing capacities, if the

[231] Not yet implemented combinations encompass for instance: parallelisation of more than two activities and of activities applied to different building component types and/or materials; other deconstruction techniques, such as dismantling with a crane and blasting; safety measures.

number of building levels is very small with maximal 2 to 3 levels. Then the current small uncertainties in the calculation of the average noise impact level of the overall deconstruction project could be eliminated.

The explicit consideration of uncertainties in the economic and environmental specific values for the calculation of the project plan values could increase the robustness of the identified deconstruction plan related to unexpected incidents. In general, the consideration of uncertainties in deconstruction projects is important. As there are many uncertain circumstances, for instance on site or due to the deconstruction object.

8.4.2 Model system boundaries

To date, processes of preliminary works of deconstruction projects and related to the disposal of deconstruction waste and the assessment of cause-effect-relations in terms of consequences on human health due to noise dust and vibrations are outside the system boundaries of TEE-D-Plan. The inclusion of these aspects would expand the scope of application of TEE-D-Plan. The modelling of these processes and the implementation of health-related impact indicators would facilitate the assessment of health hazards. Further extensions of the system boundaries within this context are an enhanced apportionment of different building materials, the assessment of other environmental impacts, such as freshwater and land ecotoxicity, and the consideration of initial impact levels of noise, dust and vibrations of the specific deconstruction site and its neighbourhood in the calculation of impact levels. Moreover, the above mentioned processes, to date unconsidered in TEE-D-Plan, cause additional costs, which could be included in the economic assessment.

The scope of application of TEE-D-Plan could be further expanded by additional project constraints. In this regard, firstly, night-time-related noise impact level-dependent project constraints would enable the consideration of noise impact level limits in TEE-D-Plan for deconstruction projects at night time. Secondly, by dust- and vibration-dependent project constraints, limits in dust and vibration impact levels depending on the sensitivity of the neighbourhood could be implemented in the deconstruction technique selection process.

Furthermore, an optional integration of variable initial impact levels of noise, dust and vibrations could additionally expand the scope of application of TEE-D-Plan.

A new environmental assessment approach, independent of statutory provisions, might improve the minimisation of local environmental impacts of the overall project. In TEE-D-Plan to date the average emission/impact levels are minimised, based on current legal critical limits and guideline values and limitations in exposure times are secondary. Within this context, dependent on the other project activities, an activity-related impact over a long period of time can be positively evaluated, if it reduces the average impact level of a project phase. A new environmental assessment approach could provide an alternative deconstruction plan due to the minimisation of environmental impacts. The decision maker could decide between this alternative plan and the current plan of TEE-D-Plan. For such a new approach, future investigations are required to define new evaluation parameters in the form of environmental plan values, which provide the management of trade-offs between exposure times and impact levels.

8.4.3 Model application

Generally, the application of the TEE-D-Plan to different deconstruction projects and the calculation of further deconstruction scenarios would facilitate further tests of the knowledge and conclusions obtained from the model results. Within this context, further combinations of fixed project framework conditions as well as uncertain economic and environmental specific values should be varied systematically and respective consequences should be evaluated. Additionally, further variation of objectives and possible combinations of economic and environmental objectives provide an advanced analysis of interdependences and conflicts.

9 Summary

Especially in cities, limited space and demographic and economic changes require adaptions in the structure of urban development and make deconstruction of buildings increasingly necessary worldwide. Nevertheless, deconstruction usually causes major noise, dust and vibration impacts on the local environment. These impacts can result in health hazards and can harm the surrounding built environment. The required consideration of these specific impacts in deconstruction planning and decision making and suggestions to mitigate these impacts depending on the individual project are part of operational project planning. Within this context, different deconstruction technique modes and constraints and characteristics due to resources, technical parameters and the neighbourhood/surrounding have to be taken into account. Respective planning can be performed by the adaption of a multi-mode resource constrained project planning approach.

The objective of the present research is the development and exemplary application of a novel model-based approach to integrate local environmental impacts into deconstruction project planning and decision making. With the model application, those deconstruction techniques should be identified, which most mitigate local environmental impacts dependent on the specific project and while considering economic objectives and the technical feasibility. In this context, the deficits in existing approaches of deconstruction project planning and decision making and of technical, economic and environmental assessment should be eliminated, which are identified as gaps in existing research.

Firstly, to date emissions and local environmental impacts in terms of noise, dust and vibrations are not considered in existing operational deconstruction project planning approaches. Hence, they do not issue a deconstruction plan with respective activity-related deconstruction techniques that minimise related emissions and local environmental impacts. Secondly, existing EIA methods for environmental assessment do not provide quantitative data of noise, dust and vibration emissions and impacts of deconstruction techniques and appropriate impact assessment approaches, which consider different surrounding conditions of deconstruction sites.

Within this research, a model of operational deconstruction project planning (TEE-D-Plan) is developed, which considers for the first time emissions and local environmental impacts as objectives in decision making, besides technical feasibility and economic objectives. TEE-D-Plan consists of two modules. Module 1 depicts the database-based deconstruction planning for environmental assessment. Module 2 represents resource-, space and impact-constrained deconstruction project planning and decision support due to environmental objectives.

Module 1 firstly provides the model framework of operational deconstruction planning and decision making for the assessment of emissions and local environmental impacts in terms of noise, dust and vibrations. The framework is based on single deconstruction project activities and phases of the on-site deconstruction processes and their sequence. The activities are related to the components of the building shell. Technical options to perform these activities are specified as modes based on current usual combinations of deconstruction methods and equipment in deconstruction projects. Project phases are assigned to the building levels. The deconstruction sequence is defined in reversed order of construction, top-down, building level-wise and activity-based.

Within Module 1, secondly, the technically feasible deconstruction technique modes are selected for each deconstruction project activity. This technical assessment is modelled by relational operators and activity-mode-dependent feasibility parameters. In this regard, for the first time the maximal building component material thicknesses and deconstruction heights above ground are considered as feasibility parameters, besides component types and materials.

Thirdly, the technically feasible mode-related alternatives of single deconstruction activities and of project phases are economically assessed. For each activity and phase, alternative economic plan values are calculated in terms of costs of resources and duration for the on-site deconstruction process. In this context, economic assessment was advanced to usual current costs and durations of deconstruction projects. Activity- and phase-related specific hourly costs of equipment with varying sizes are based on literature. Activity-related hourly labour salaries are drawn from recent literature and adapted and new specific duration values are based on literature and primary data from an expert survey and consultations. The economic assessment is validated by two test deconstruction projects within this research.

Fourthly, the technically feasible mode-related alternatives of single deconstruction activities and of project phases are environmentally assessed. For each activity and phase, alternative environmental plan values are calculated in terms of average emission/impact levels of noise, dust and vibrations. Within this context, for the first time, average emission/impact levels of noise, dust and vibrations of deconstruction activities can be quantitatively proposed by an EIA-approach, which is newly developed in this thesis.

Furthermore, primary data is collected by an expert survey and consultations and experiments to newly develop specific hourly emission level values of noise, dust and vibrations of different activity parameter configurations for environmental assessment. In this context, parameter configurations are defined by the deconstruction technique mode, the basic unit size, the component materials and the deconstruction height above ground. All four parameters influence the emission levels. The difference of these specific hourly emission level values minus surrounding-dependent and neighbourhood-type-dependent emission reduction effects respectively, result in specific hourly impact level values. Via these specific hourly impact level values and the activity phase durations respectively, activity- and phase-related average impact level values are calculated according to legal conditions. The activity- and phase-related average impact level values are converted into activity- and phase-related average nine-stage percentage impact levels, which state the activity- and phase-related environmental plan values.

Finally, the outputs of Module 1 are the technically feasible alternatives of deconstruction project activities and phases and their calculated economic and environmental plan values. All data and information used and calculated in Module 1 are stored in and provided for Module 2 by a newly generated relational database.

Based on the outputs of Module 1, in Module 2 deconstruction project plans are created. In this regard, an adapted variant of the multi-mode resource constrained project scheduling problem (MRCPSP) is used and adopted. The MRCPSP is adapted in terms of space- and impact level-dependent constraints and a predefined deconstruction activity sequence. Thus, primarily constraints due to changing surrounding conditions in the form of required space on site of different deconstruction technique modes and neighbourhood-usage-type-dependent maximal allowed noise impact levels are taken into account in deconstruction project planning to find a solution. Additionally, the basis to find a solution is newly adapted to actual situations in deconstruction projects. This is done by using the calculated phase-related plan values in terms of phase-related costs and average noise impacts levels from Module 1. The outcome is the consideration that basic units regularly remain across single deconstruction activity durations on site, independent of whether they are used. Moreover, the non-linear scaled character of noise impacts and time-dependent average impact level values are (partly) considered. Additionally, the solution of the overall deconstruction project, which is in line with the sum of deconstruction phase-related solutions, approximates the actual top-down, building level-wise deconstruction sequence in conjunction with solvable model calculations. The iterative objective function provides the deconstruction project plan due to the research question in terms of the minimisation of distinct environmental impacts, while considering economic objectives. In addition, the multi-objective solution approach based on weighted phase-related alternatives enables the simultaneous consideration of all three environmental objectives in terms of minimising average noise, dust and vibration emission/impact levels. Moreover, it offers the analysis of potentials of deconstruction plan changes due to different environmental objectives and due to their importance for the decision maker.

In summary, TEE-D-Plan meets the first objective of a novel model-based approach to integrate emissions and neighbourhood-dependent local environmental impacts into the deconstruction project planning and decision making process.

To meet the second objective and to answer the research questions, TEE-D-Plan is applied to an exemplary deconstruction project. To answer the major research question, the results of TEE-D-Plan show in summary, that the evaluation of specific deconstruction techniques to minimise emissions and environmental impacts has to be predicated on fixed framework conditions related to the neighbourhood of the deconstruction site and technical parameters. Firstly, the building characteristics, which are fixed for the specific deconstruction project, influence the project phase solution spaces of feasible deconstruction technique modes and the deconstruction plan in regard to selected modes and economic and environmental plan values (sub-question 1). Secondly, surrounding conditions of the deconstruction site, which are also fixed for the specific project, can highly influence the level of impact on the local environment, especially in the short distance between the deconstruction site and the subject of protection (sub-question 2). Thirdly, project constraints, which are in general fixed for the specific project as well, influence the project phase solution spaces and the deconstruction plan with respect to selected modes and plan values (sub-question 3). Based on these fixed framework conditions, the possible deconstruction project plans, including single project activities performed in different technique modes, can be evaluated to reach the objective of minimising the local environmental impacts. In this regard, the minimisation of environmental impacts can imply the minimisation of a distinct emission/environmental impact in terms of noise, dust or vibrations. To minimise the average noise impact levels of the overall project, usually deconstruction modes with one basic unit rather than two basic units and the method ripping instead of mortising are applied. In contrast to the suggestions related to the reduction of average noise impact levels, modes of activity parallelisation are usually implemented in the project plans to minimise average dust emission levels and vibration impact levels. In this regard, modes with on the one hand shortest durations and on the other hand limited differences to the potential lowest dust emission levels are suggested to minimise the average dust emission levels. Nevertheless, for those activities, which can most influence on the reduction of average dust emission levels of the overall project, often deconstruction by hand and modes with longer durations are recommended. In contrast to proposed modes with longer durations of those activities, which can most influence on the reduction of average dust emission levels of the overall project, modes with generally short durations are recommended due to minimising the average vibration impact levels.

Within this context, deconstruction modes with on the one hand, low vibration levels and on the other hand, short durations, such as mortising, gripping and press-cutting and activity parallelisation, are suggested to reach the objective of minimising the average vibration impact levels (sub-question 4). Additionally, two or all three environmental impacts can be simultaneously minimised via Multi-Criteria Decision Analysis (MCDA). The results of TEE-D-Plan demonstrate that all environmental objectives are in some conflict with each other in the deconstruction plan, in the form of selected modes and environmental plan values (sub-question 5).

Altogether, TEE-D-Plan provides project plans with suggested activity-related deconstruction techniques for a specific building to be deconstructed and due to the preferences of the decision maker related to the minimisation of emissions and local environmental impacts. The realisation of these plans for the planning of real deconstruction projects takes the technical knowledge of the decision maker about building statics for granted. Moreover, the plans are based on several assumptions related to specific economic and environmental values, which lead to conservative calculations of the plan values, and related to the calculation of the overall-project plan values itself. For instance, more detailed classification of the distinct emission levels and further specifications in the surrounding conditions can reduce overestimations of distinct average emission/impact levels. The consideration of learning effects and size-dependent influences due to material pre-separation and pre-crushing can decrease activity durations. All these aspects require the collection and analysis of further primary data. The calculation of overall-project-related economic and environmental plan values instead of the sum of phase-related plan values overall project phases might slightly reduce uncertainties in the values of the plan. Although, the number of building levels is very small with maximal 2 to 3 levels, this approach requires large computing capacities and the phase-related solution process is in the line with reality, the top-down, building level-wise deconstruction process. Further extensions of the system boundaries can increase the scope of application of TEE-D-Plan. For instance, the inclusion of processes of preliminary works and related to the disposal of deconstruction waste, the enhanced apportionment of different building materials, the implementation of health-related indicators due to noise, dust and vibrations and the assessment of other environmental impacts would facilitate the assessment of human health hazards. All these aspects require the collection and analysis of further primary data. Additional alternative impact level-dependent project constraints could enhance neighbourhood-sensitivity-conscious applications of TEE-D-Plan. Furthermore, a new environmental assessment approach, which enables the management of trade-offs between limitations in exposure times and impact levels, could improve the results of TEE-D-Plan in terms of minimisation of local environmental impacts of the overall project. Within this context, future investigations are required to define new evaluation parameters differently from those of the current approach, which are based on statutory provisions. Finally, further project applications of and scenario variations in TEE-D-Plan could facilitate a further validation of the knowledge and conclusions obtained from the model.

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Appendix

A1 Deconstruction activity modes (m)

Activity mode (m) including sorting and crushing of material			Attributes																	
#	Description	Abbreviation	md_m (Tab 2-2)	ad_m (Tab. 4-6)	ab_m (Tab. 4-6)	n^{hy}_m	n^{lt}_m	n^{cw}_m	n^{ha}_m	n^{po}_m	sp_m	hg_m	sty^1_m	sty^2_m	sty^3_m	sty^4_m	sty^5_m	sty^6_m	sty^7_m	sty^8_m
1	Gripping with 1 hydraulic excavator	Grip_HY_1	1	1	1	1	0	0	0	2	2	15	1	0	1	1	0	1	0	0
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	2	2	1	1	0	1	0	2	2	100	1	1	1	1	1	1	1	1
3	Pushing with 1 hydraulic excavator	Push_HY_1	3	3	1	1	0	0	0	2	1	15	1	0	0	1	1	1	1	0
4	Pulling with 1 hydraulic excavator	Pull_HY_1	4	3	1	1	0	0	0	2	2	15	1	0	0	1	1	1	1	0
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	5	3	1	1	0	0	0	2	2	15	0	1	0	0	0	0	0	1
6	Mortising with 1 hydraulic excavator	Mort_HY_1	6	4	1	1	0	0	0	2	1	15	1	1	1	1	1	1	1	1
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	7	5	1	1	0	0	0	2	1	15	1	1	1	1	1	1	1	0
8	Cutting with 1 hydraulic excavator	Cut_HY_1	8	6	1	1	0	0	0	2	1	15	1	1	1	1	1	1	1	0

Activity mode (m) including sorting and crushing of material			Attributes																			
#	Description	Abbreviation	sb^1_m	sb^2_m	sb^3_m	sb^4_m	sb^5_m	sb^6_m	sb^7_m	sb^8_m	sb^9_m	sb^{10}_m	thb^1_m	thb^2_m	thb^3_m	thb^4_m	thb^5_m	thb^6_m	thb^7_m	thb^8_m	thb^9_m	thb^{10}_m
1	Gripping with 1 hydraulic excavator	Grip_HY_1	1	1	1	1	1	0	1	0	1	0	0.5	0.5	0.5	0.5	0.5	0	0.2	0	∞ (1000)	0
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	1	1	1	1	1	1	1	1	0	0	2	2	2	2	2	0.5	1	0.5	0	0
3	Pushing with 1 hydraulic excavator	Push_HY_1	1	1	1	1	1	0	0	1	0	0	0.4	0.4	0.4	0.4	0.4	0	0	0.25	0	0
4	Pulling with 1 hydraulic excavator	Pull_HY_1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	0.75	∞ (1000)	∞ (1000)
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	1	1	1	1	1	1	1	1	0	0	0.5	0.5	0.5	0.5	0.5	0.3	0.5	0.3	0	0
6	Mortising with 1 hydraulic excavator	Mort_HY_1	1	1	1	1	1	1	1	1	0	0	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	3	3	3	0	0
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	1	1	1	1	1	1	1	1	0	0	2.2	2.2	2.2	2.2	2.2	1.6	2.2	1.6	0	0
8	Cutting with 1 hydraulic excavator	Cut_HY_1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	∞ (1000)	0.8

Activity mode (m) including sorting and crushing of material			Attributes																	
#	Description	Abbreviation	md_m (Tab 2-2)	ad_m (Tab. 4-6)	ab_m (Tab. 4-6)	n^{hy}_m	n^{lt}_m	n^{cw}_m	n^{ha}_m	n^{po}_m	sp_m	hg_m	sty^1_m	sty^2_m	sty^3_m	sty^4_m	sty^5_m	sty^6_m	sty^7_m	sty^8_m
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	1	7	7	0	1	0	0	2	2	65	1	0	1	1	0	1	0	0
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 lognfront hydraulic excavator)	Wreck_CW_LT_1	2	2	7	0	1	1	0	2	2	100	1	1	1	1	1	1	1	1
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	3	8	7	0	1	0	0	2	1	15	1	0	0	1	1	1	1	0
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	4	8	7	0	1	0	0	2	2	65	1	0	0	1	1	1	1	0
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	5	8	7	0	1	0	0	2	2	15	0	1	0	0	0	0	0	1
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	6	9	7	0	1	0	0	2	1	65	1	1	1	1	1	1	1	1
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	7	10	7	0	1	0	0	2	1	65	1	1	1	1	1	1	1	0
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	8	11	7	0	1	0	0	2	1	65	1	1	1	1	1	1	1	0
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	19	23	23	0	0	0	2	2	0	∞ (1000)	1	1	1	1	1	1	1	1

Activity mode (m) including sorting and crushing of material			Attributes																			
#	Description	Abbreviation	sb^1_m	sb^2_m	sb^3_m	sb^4_m	sb^5_m	sb^6_m	sb^7_m	sb^8_m	sb^9_m	sb^{10}_m	thb^1_m	thb^2_m	thb^3_m	thb^4_m	thb^5_m	thb^6_m	thb^7_m	thb^8_m	thb^9_m	thb^{10}_m
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	1	1	1	1	1	0	1	0	1	0	0.5	0.5	0.5	0.5	0.5	0	0.2	0	∞ (1000)	0
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 lognfront hydraulic excavator)	Wreck_CW_LT_1	1	1	1	1	1	1	1	1	0	0	2	2	2	2	2	0.5	1	0.5	0	0
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	1	1	1	1	1	0	0	1	0	0	0.4	0.4	0.4	0.4	0.4	0	0	0.25	0	0
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	0.75	∞ (1000)	∞ (1000)
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	1	1	1	1	1	1	1	1	0	0	0.5	0.5	0.5	0.5	0.5	0.3	0.5	0.3	0	0
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	1	1	1	1	1	1	1	1	0	0	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	3	3	3	0	0
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	1	1	1	1	1	1	1	1	0	0	2.2	2.2	2.2	2.2	2.2	1.6	2.2	1.6	0	0
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	∞ (1000)	0.8
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	1	1	1	1	1	1	1	1	1	1	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)

Activity mode (m) including sorting and crushing of material			Attributes																	
#	Description	Abbreviation	md_m (Tab 2-2)	ad_m (Tab. 4-6)	ab_m (Tab. 4-6)	n^{hy}_m	n^{lt}_m	n^{cw}_m	n^{ha}_m	n^{po}_m	sp_m	hg_m	sty^1_m	sty^2_m	sty^3_m	sty^4_m	sty^5_m	sty^6_m	sty^7_m	sty^8_m
18	Gripping with 2 hydraulic excavators	Grip_HY_2	1	12	12	2	0	0	0	4	2	15	1	0	1	1	0	1	0	0
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	2	13	12	2	0	2	0	4	2	100	1	1	1	1	1	1	1	1
20	Pushing with 2 hydraulic excavators	Push_HY_2	3	14	12	2	0	0	0	4	1	15	1	0	0	1	1	1	1	0
21	Pulling with 2 hydraulic excavators	Pull_HY_2	4	14	12	2	0	0	0	4	2	15	1	0	0	1	1	1	1	0
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	5	14	12	2	0	0	0	4	2	15	0	1	0	0	0	0	0	1
23	Mortising with 2 hydraulic excavators	Mort_HY_2	6	15	12	2	0	0	0	4	1	15	1	1	1	1	1	1	1	1
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	7	16	12	2	0	0	0	4	1	15	1	1	1	1	1	1	1	0
25	Cutting with 2 hydraulic excavators	Cut_HY_2	8	17	12	2	0	0	0	4	1	15	1	1	1	1	1	1	1	0

Activity mode (m) including sorting and crushing of material			Attributes																			
#	Description	Abbreviation	sb^1_m	sb^2_m	sb^3_m	sb^4_m	sb^5_m	sb^6_m	sb^7_m	sb^8_m	sb^9_m	sb^{10}_m	thb^1_m	thb^2_m	thb^3_m	thb^4_m	thb^5_m	thb^6_m	thb^7_m	thb^8_m	thb^9_m	thb^{10}_m
18	Gripping with 2 hydraulic excavators	Grip_HY_2	1	1	1	1	1	0	1	0	1	0	0.5	0.5	0.5	0.5	0.5	0	0.2	0	∞ (1000)	0
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	1	1	1	1	1	1	1	1	0	0	2	2	2	2	2	0.5	1	0.5	0	0
20	Pushing with 2 hydraulic excavators	Push_HY_2	1	1	1	1	1	0	0	1	0	0	0.4	0.4	0.4	0.4	0.4	0	0	0.25	0	0
21	Pulling with 2 hydraulic excavators	Pull_HY_2	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	0.75	∞ (1000)	∞ (1000)
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	1	1	1	1	1	1	1	1	0	0	0.5	0.5	0.5	0.5	0.5	0.3	0.5	0.3	0	0
23	Mortising with 2 hydraulic excavators	Mort_HY_2	1	1	1	1	1	1	1	1	0	0	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	3	3	3	0	0
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	1	1	1	1	1	1	1	1	0	0	2.2	2.2	2.2	2.2	2.2	1.6	2.2	1.6	0	0
25	Cutting with 2 hydraulic excavators	Cut_HY_2	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	∞ (1000)	0.8

Activity mode (m) including sorting and crushing of material			Attributes																	
#	Description	Abbreviation	md_m (Tab 2-2)	ad_m (Tab. 4-6)	ab_m (Tab. 4-6)	n^{hy}_m	n^{lt}_m	n^{cw}_m	n^{ha}_m	n^{po}_m	sp_m	hg_m	sty^1_m	sty^2_m	sty^3_m	sty^4_m	sty^5_m	sty^6_m	sty^7_m	sty^8_m
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	1	18	18	0	2	0	0	4	2	65	1	0	1	1	0	1	0	0
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	2	13	18	0	2	2	0	4	2	100	1	1	1	1	1	1	1	1
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	3	19	18	0	2	0	0	4	1	15	1	0	0	1	1	1	1	0
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	4	19	18	0	2	0	0	4	2	65	1	0	0	1	1	1	1	0
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	5	19	18	0	2	0	0	4	2	15	0	1	0	0	0	0	0	1
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	6	20	18	0	2	0	0	4	1	65	1	1	1	1	1	1	1	1
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	7	21	18	0	2	0	0	4	1	65	1	1	1	1	1	1	1	0
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	8	22	18	0	2	0	0	4	1	65	1	1	1	1	1	1	1	0
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	19	23	18	0	0	0	4	4	0	∞ (1000)	1	1	1	1	1	1	1	1

Activity mode (m) including sorting and crushing of material			Attributes																			
#	Description	Abbreviation	sb^1_m	sb^2_m	sb^3_m	sb^4_m	sb^5_m	sb^6_m	sb^7_m	sb^8_m	sb^9_m	sb^{10}_m	thb^1_m	thb^2_m	thb^3_m	thb^4_m	thb^5_m	thb^6_m	thb^7_m	thb^8_m	thb^9_m	thb^{10}_m
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	1	1	1	1	1	0	1	0	1	0	0.5	0.5	0.5	0.5	0.5	0	0.2	0	∞ (1000)	0
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	1	1	1	1	1	1	1	1	0	0	2	2	2	2	2	0.5	1	0.5	0	0
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	1	1	1	1	1	0	0	1	0	0	0.4	0.4	0.4	0.4	0.4	0	0	0.25	0	0
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	0.75	∞ (1000)	∞ (1000)
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	1	1	1	1	1	1	1	1	0	0	0.5	0.5	0.5	0.5	0.5	0.3	0.5	0.3	0	0
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	1	1	1	1	1	1	1	1	0	0	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	3	3	3	0	0
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	1	1	1	1	1	1	1	1	0	0	2.2	2.2	2.2	2.2	2.2	1.6	2.2	1.6	0	0
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	∞ (1000)	0.8
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	1	1	1	1	1	1	1	1	1	1	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)	∞ (1000)

A2 Specific duration values

Functions of/specific duration values of the single activity segments of each mode applied to different building materials.[232]

Explanations:

Dark grey cells with x: not suitable/not relevant for the material

*Assumtion of a volumic mass of steel of 7.6 t/m^3

[232] Sources of the specific duration values of the deconstruction activity segment (δ_d(m,b,sz)): Weimann et al. (2013); DA (2015); Seemann (2003); Rentz et al. (2002); Schultmann (1998); Rentz (1993); Willkomm (1990), expert evaluation. Sources of the specific duration values of the pre-separation (δ_o(m,b)) and pre-crushing (δ_q(m,b)) activity segments: expert survey and consultation.

			Functions of/specific duration values of the single activity segments [h/m^3material]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)
1	Gripping with 1 hydraulic excavator	Grip_HY_1	2.0632*sz^{hy}^(-0.772)	0.02	0.03	1.5474*sz^{hy}^(-0.772)	0.02	0.02	2.0632*szhy^(-0.772)	0.02	0.03
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	0.05	0.04	0.03	0.05	0.04	0.02	0.05	0.04	0.03
3	Pushing with 1 hydraulic excavator	Push_HY_1	2.0632*sz^{hy}^(-0.772)	0.04	0.04	1.5474*sz^{hy}^(-0.772)	0.04	0.03	2.0632*szhy^(-0.772)	0.04	0.04
4	Pulling with 1 hydraulic excavator	Pull_HY_1	3.6105*sz^{hy}^(-0.772)	0.04	0.04	3.6105*sz^{hy}^(-0.772)	0.04	0.03	3.6105*szhy^(-0.772)	0.04	0.04
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	2.0632*sz^{hy}^(-0.772)	0.04	0.03	2.0632*sz^{hy}^(-0.772)	0.04	0.02	2.0632*szhy^(-0.772)	0.04	0.03
6	Mortising with 1 hydraulic excavator	Mort_HY_1	2.0632*sz^{hy}^(-0.772)	0.02	0.03	1.5474*szhy^(-0.772)	0.02	0.02	2.0632*szhy^(-0.772)	0.02	0.03
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	2.0632*sz^{hy}^(-0.772)	0.02	0.01	1.5474*szhy^(-0.772)	0.02	0	2.0632*szhy^(-0.772)	0.02	0.01
8	Cutting with 1 hydraulic excavator	Cut_HY_1	x			x			x		

			Functions of/specific duration values of the single activity segments [h/m3material]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)
1	Gripping with 1 hydraulic excavator	Grip_HY_1	1.5474*szhy^(-0.772)	0.02	0.02	2.0632*szhy^(-0.772)	0.02	0.03
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	0.05	0.04	0.02	0.05	0.04	0.03
3	Pushing with 1 hydraulic excavator	Push_HY_1	1.5474*szhy^(-0.772)	0.04	0.03	2.0632*szhy^(-0.772)	0.04	0.04
4	Pulling with 1 hydraulic excavator	Pull_HY_1	3.6105*szhy^(-0.772)	0.04	0.03	3.6105*szhy^(-0.772)	0.04	0.04
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	2.0632*szhy^(-0.772)	0.04	0.02	2.0632*szhy^(-0.772)	0.04	0.03
6	Mortising with 1 hydraulic excavator	Mort_HY_1	1.5474*szhy^(-0.772)	0.02	0.02	2.0632*szhy^(-0.772)	0.02	0.03
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	1.5474*szhy^(-0.772)	0.02	0	2.0632*szhy^(-0.772)	0.02	0.01
8	Cutting with 1 hydraulic excavator	Cut_HY_1	x			x		

			Functions of/specific duration values of the single activity segments [h/m3material]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)
1	Gripping with 1 hydraulic excavator	Grip_HY_1	x			2.0632*szhy^(-0.772)	0.02	0.03	x		
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	0.07	0.04	0.04	0.05	0.04	0.03	0.07	0.04	0.04
3	Pushing with 1 hydraulic excavator	Push_HY_1	x			x			4.1263*szhy^(-0.772)	0.04	0.05
4	Pulling with 1 hydraulic excavator	Pull_HY_1	x			x			3.6105*szhy^(-0.772)	0.04	0.05
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	4.1263*szhy^(-0.772)	0.04	0.04	4.1263*szhy^(-0.772)	0.04	0.03	4.1263*szhy^(-0.772)	0.04	0.04
6	Mortising with 1 hydraulic excavator	Mort_HY_1	3.0947*szhy^(-0.772)	0.02	0.04	2.0632*szhy^(-0.772)	0.02	0.03	3.0947*szhy^(-0.772)	0.02	0.04
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	3.0947*szhy^(-0.772)	0.02	0.01	2.0632*szhy^(-0.772)	0.02	0.01	3.0947*szhy^(-0.772)	0.02	0.01
8	Cutting with 1 hydraulic excavator	Cut_HY_1	x			x			x		

			Functions of/specific duration values of the single activity segments [h/m3material]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\delta_d(m,b,sz)$	$\delta_o(m,b)$	$\delta_q(m,b)$	$\delta_d(m,b,sz)$	$\delta_o(m,b)$	$\delta_q(m,b)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	1.5474*szhy^(-0.772)	0.02	0.02	x		
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	x			x		
3	Pushing with 1 hydraulic excavator	Push_HY_1	3.6105*szhy^(-0.772)	0.04	0.03	x		
4	Pulling with 1 hydraulic excavator	Pull_HY_1	3.6105*szhy^(-0.772)	0.04	0.03	48.484*szhy^(-0.772)	0.03	0.05
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	x			x		
6	Mortising with 1 hydraulic excavator	Mort_HY_1	x			x		
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	x			x		
8	Cutting with 1 hydraulic excavator	Cut_HY_1	4.1263*szhy^(-0.772)	0.02	0	80.463*szhy^(-0.772)	0.02	0.02

			Functions of/specific duration values of the single activity segments [h/m^3material]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	6.7053*sz^{lt}^(-0.772)	0.02	0.03	5.1579*sz^{lt}^(-0.772)	0.02	0.02	6.7053*sz^{lt}^(-0.772)	0.02	0.03
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	0.05	0.04	0.03	0.05	0.04	0.02	0.05	0.04	0.03
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	6.7053*sz^{lt}^(-0.772)	0.04	0.04	5.1579*sz^{lt}^(-0.772)	0.04	0.03	6.7053*sz^{lt}^(-0.772)	0.04	0.04
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	11.863*sz^{lt}^(-0.772)	0.04	0.04	11.863*sz^{lt}^(-0.772)	0.04	0.03	11.863*sz^{lt}^(-0.772)	0.04	0.04
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	6.7053*sz^{lt}^(-0.772)	0.04	0.03	6.7053*sz^{lt}^(-0.772)	0.04	0.02	6.7053*sz^{lt}^(-0.772)	0.04	0.03
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	6.7053*sz^{lt}^(-0.772)	0.02	0.03	5.1579*sz^{lt}^(-0.772)	0.02	0.02	6.7053*sz^{lt}^(-0.772)	0.02	0.03
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	6.7053*sz^{lt}^(-0.772)	0.02	0.01	5.1579*sz^{lt}^(-0.772)	0.02	0	6.7053*sz^{lt}^(-0.772)	0.02	0.01
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	x			x			x		
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	2	0	0	2	0	0	2	0	0

			Functions of/specific duration values of the single activity segments [h/m3material]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	$5.1579*sz^{lt}$^(-0.772)	0.02	0.02	$6.7053*sz^{lt}$^(-0.772)	0.02	0.03
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	0.05	0.04	0.02	0.05	0.04	0.03
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	$5.1579*sz^{lt}$^(-0.772)	0.04	0.03	$6.7053*sz^{lt}$^(-0.772)	0.04	0.04
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	$11.863*sz^{lt}$^(-0.772)	0.04	0.03	$11.863*sz^{lt}$^(-0.772)	0.04	0.04
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	$6.7053*sz^{lt}$^(-0.772)	0.04	0.02	$6.7053*sz^{lt}$^(-0.772)	0.04	0.03
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	$5.1579*sz^{lt}$^(-0.772)	0.02	0.02	$6.7053*sz^{lt}$^(-0.772)	0.02	0.03
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	$5.1579*sz^{lt}$^(-0.772)	0.02	0	$6.7053*sz^{lt}$^(-0.772)	0.02	0.01
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	x			x		
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	2	0	0	2	0	0

			Functions of/specific duration values of the single activity segments [h/m3material]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\delta_d(m,b,sz)$	$\delta_o(m,b)$	$\delta_q(m,b)$	$\delta_d(m,b,sz)$	$\delta_o(m,b)$	$\delta_q(m,b)$	$\delta_d(m,b,sz)$	$\delta_o(m,b)$	$\delta_q(m,b)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	x			$6.7053*sz^{lt}$^(-0.772)	0.02	0.03	x		
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	0.07	0.04	0.04	0.05	0.04	0.03	0.07	0.04	0.04
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	x			x			$13.411*sz^{lt}$^(-0.772)	0.04	0.05
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	x			x			$11.863*sz^{lt}$^(-0.772)	0.04	0.05
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	$13.411*sz^{lt}$^(-0.772)	0.04	0.04	$13.411*sz^{lt}$^(-0.772)	0.04	0.03	$13.411*sz^{lt}$^(-0.772)	0.04	0.04
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	$9.8*sz^{lt}$^(-0.772)	0.02	0.04	$6.7053*sz^{lt}$^(-0.772)	0.02	0.03	$9.8*sz^{lt}$^(-0.772)	0.02	0.04
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	$9.8*sz^{lt}$^(-0.772)	0.02	0.01	$6.7053*sz^{lt}$^(-0.772)	0.02	0.01	$9.8*sz^{lt}$^(-0.772)	0.02	0.01
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	x			x			x		
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	3.2	0	0	2	0	0	3.2	0	0

			Functions of/specific duration values of the single activity segments [h/m3material]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	5.1579*sz^{lt}^(-0.772)	0.02	0.02	x		
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	x			x		
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	11.863*sz^{lt}^(-0.772)	0.04	0.03	x		
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	11.863*sz^{lt}^(-0.772)	0.04	0.03	154.74*sz^{lt}^(-0.772)	0.03	0.05
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	x			x		
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	x			x		
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	x			x		
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	13.411*sz^{lt}^(-0.772)	0.02	0	257.89*sz^{lt}^(-0.772)	0.02	0.02
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	1.2	0	0	19.5	0	0

			Functions of/specific duration values of the single activity segments [h/m^{3}material]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\delta_d(m,b,sz)$	$\delta_o(m,b)$	$\delta_q(m,b)$	$\delta_d(m,b,sz)$	$\delta_o(m,b)$	$\delta_q(m,b)$	$\delta_d(m,b,sz)$	$\delta_o(m,b)$	$\delta_q(m,b)$
18	Gripping with 2 hydraulic excavators	Grip_HY_2	$(2.0632*sz^{hy}\wedge(-0.772))/2$	0.01	0.015	$(1.5474*sz^{hy}\wedge(-0.772))/2$	0.01	0.01	$(2.0632*sz^{hy}\wedge(-0.772))/2$	0.01	0.015
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	0.03	0.02	0.015	0.03	0.02	0.01	0.03	0.02	0.015
20	Pushing with 2 hydraulic excavators	Push_HY_2	$(2.0632*sz^{hy}\wedge(-0.772))/2$	0.02	0.02	$(1.5474*sz^{hy}\wedge(-0.772))/2$	0.02	0.015	$(2.0632*sz^{hy}\wedge(-0.772))/2$	0.02	0.02
21	Pulling with 2 hydraulic excavators	Pull_HY_2	$(3.6105*sz^{hy}\wedge(-0.772))/2$	0.02	0.02	$(3.6105*sz^{hy}\wedge(-0.772))/2$	0.02	0.015	$(3.6105*sz^{hy}\wedge(-0.772))/2$	0.02	0.02
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	$(2.0632*sz^{hy}\wedge(-0.772))/2$	0.02	0.015	$(2.0632*sz^{hy}\wedge(-0.772))/2$	0.02	0.01	$(2.0632*sz^{hy}\wedge(-0.772))/2$	0.02	0.015
23	Mortising with 2 hydraulic excavators	Mort_HY_2	$(2.0632*sz^{hy}\wedge(-0.772))/2$	0.01	0.015	$(1.5474*sz^{hy}\wedge(-0.772))/2$	0.01	0.01	$(2.0632*sz^{hy}\wedge(-0.772))/2$	0.01	0.015
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	$(2.0632*sz^{hy}\wedge(-0.772))/2$	0.01	0.005	$(1.5474*sz^{hy}\wedge(-0.772))/2$	0.01	0	$(2.0632*sz^{hy}\wedge(-0.772))/2$	0.01	0.005
25	Cutting with 2 hydraulic excavators	Cut_HY_2	x			x			x		

			Functions of/specific duration values of the single activity segments [h/m3material]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\delta_d(m,b,sz)$	$\delta_o(m,b)$	$\delta_q(m,b)$	$\delta_d(m,b,sz)$	$\delta_o(m,b)$	$\delta_q(m,b)$
18	Gripping with 2 hydraulic excavators	Grip_HY_2	$(1.5474*sz^{hy}$^(-0.772))/2	0.01	0.01	$(2.0632*sz^{hy}$^(-0.772))/2	0.01	0.015
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	0.03	0.02	0.01	0.03	0.02	0.015
20	Pushing with 2 hydraulic excavators	Push_HY_2	$(1.5474*sz^{hy}$^(-0.772))/2	0.02	0.015	$(2.0632*sz^{hy}$^(-0.772))/2	0.02	0.02
21	Pulling with 2 hydraulic excavators	Pull_HY_2	$(3.6105*sz^{hy}$^(-0.772))/2	0.02	0.015	$(3.6105*sz^{hy}$^(-0.772))/2	0.02	0.02
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	$(2.0632*sz^{hy}$^(-0.772))/2	0.02	0.01	$(2.0632*sz^{hy}$^(-0.772))/2	0.02	0.015
23	Mortising with 2 hydraulic excavators	Mort_HY_2	$(1.5474*sz^{hy}$^(-0.772))/2	0.01	0.01	$(2.0632*sz^{hy}$^(-0.772))/2	0.01	0.015
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	$(1.5474*sz^{hy}$^(-0.772))/2	0.01	0	$(2.0632*sz^{hy}$^(-0.772))/2	0.01	0.005
25	Cutting with 2 hydraulic excavators	Cut_HY_2	x			x		

			Functions of/specific duration values of the single activity segments [h/m3material]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)
18	Gripping with 2 hydraulic excavators	Grip_HY_2	x			(2.0632*sz^{hy}^(-0.772))/2	0.01	0.015	x		
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	0.04	0.02	0.02	0.03	0.02	0.015	0.04	0.02	0.02
20	Pushing with 2 hydraulic excavators	Push_HY_2	x			x			(4.1263*sz^{hy}^(-0.772))/2	0.02	0.025
21	Pulling with 2 hydraulic excavators	Pull_HY_2	x			x			(3.6105*sz^{hy}^(-0.772))/2	0.02	0.025
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	(4.1263*sz^{hy}^(-0.772))/2	0.02	0.02	(4.1263*sz^{hy}^(-0.772))/2	0.02	0.015	(4.1263*sz^{hy}^(-0.772))/2	0.02	0.02
23	Mortising with 2 hydraulic excavators	Mort_HY_2	(3.0947*sz^{hy}^(-0.772))/2	0.01	0.02	(2.0632*sz^{hy}^(-0.772))/2	0.01	0.015	(3.0947*sz^{hy}^(-0.772))/2	0.01	0.02
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	(3.0947*sz^{hy}^(-0.772))/2	0.01	0.005	(2.0632*sz^{hy}^(-0.772))/2	0.01	0.005	(3.0947*sz^{hy}^(-0.772))/2	0.01	0.005
25	Cutting with 2 hydraulic excavators	Cut_HY_2	x			x			x		

			Functions of/specific duration values of the single activity segments [h/m3material]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)
18	Gripping with 2 hydraulic excavators	Grip_HY_2	(1.5474*sz^{hy}^(-0.772))/2	0.01	0.01	x		
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	x			x		
20	Pushing with 2 hydraulic excavators	Push_HY_2	(3.6105*sz^{hy}^(-0.772))/2	0.02	0.015	x		
21	Pulling with 2 hydraulic excavators	Pull_HY_2	(3.6105*sz^{hy}^(-0.772))/2	0.02	0.015	(48.484*sz^{hy}^(-0.772))/2	0.015	0.025
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	x			x		
23	Mortising with 2 hydraulic excavators	Mort_HY_2	x			x		
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	x			x		
25	Cutting with 2 hydraulic excavators	Cut_HY_2	(4.1263*sz^{hy}^(-0.772))/2	0.01	0	(80.463*sz^{hy}^(-0.772))/2	0.01	0.01

			Functions of/specific duration values of the single activity segments [h/m^{3}material]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	(6.7053*sz^{lt}^(-0.772))/2	0.01	0.015	(5.1579*sz^{lt}^(-0.772))/2	0.01	0.01	(6.7053*s^{lt}^(-0.772))/2	0.01	0.015
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	0.05	0.02	0.015	0.05	0.02	0.01	0.05	0.02	0.015
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	(6.7053*sz^{lt}^(-0.772))/2	0.02	0.02	(5.1579*sz^{lt}^(-0.772))/2	0.02	0.015	(6.7053*sz^{lt}^(-0.772))/2	0.02	0.02
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	(11.863*sz^{lt}^(-0.772))/2	0.02	0.02	(11.863*sz^{lt}^(-0.772))/2	0.02	0.015	(11.863*sz^{lt}^(-0.772))/2	0.02	0.02
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	(6.7053*sz^{lt}^(-0.772))/2	0.02	0.015	(6.7053*sz^{lt}^(-0.772))/2	0.02	0.01	(6.7053*sz^{lt}^(-0.772))/2	0.02	0.015
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	(6.7053*szlt^(-0.772))/2	0.01	0.015	(5.1579*sz^{lt}^(-0.772))/2	0.01	0.01	(6.7053*sz^{lt}^(-0.772))/2	0.01	0.015
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	(6.7053*szlt^(-0.772))/2	0.01	0.005	(5.1579*sz^{lt}^(-0.772))/2	0.01	0	(6.7053*sz^{lt}^(-0.772))/2	0.01	0.005
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	x			x			x		
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	1	0	0	1	0	0	1	0	0

			Functions of/specific duration values of the single activity segments [h/m3material]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	(5.1579*sz^{lt}^(-0.772))/2	0.01	0.01	(6.7053*sz^{lt}^(-0.772))/2	0.01	0.015
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	0.05	0.02	0.01	0.05	0.02	0.015
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	(5.1579*sz^{lt}^(-0.772))/2	0.02	0.015	(6.7053*sz^{lt}^(-0.772))/2	0.02	0.02
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	(11.863*sz^{lt}^(-0.772))/2	0.02	0.015	(11.863*sz^{lt}^(-0.772))/2	0.02	0.02
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	(6.7053*sz^{lt}^(-0.772))/2	0.02	0.01	(6.7053*sz^{lt}^(-0.772))/2	0.02	0.015
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	(5.1579*sz^{lt}^(-0.772))/2	0.01	0.01	(6.7053*sz^{lt}^(-0.772))/2	0.01	0.015
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	(5.1579*sz^{lt}^(-0.772))/2	0.01	0	(6.7053*sz^{lt}^(-0.772))/2	0.01	0.005
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	x			x		
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	1	0	0	1	0	0

			Functions of/specific duration values of the single activity segments [h/m3material]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	x			(6.7053*s^{lt}^(-0.772))/2	0.01	0.015	x		
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	0.04	0.02	0.02	0.03	0.02	0.015	0.04	0.02	0.02
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	x			x			(13.411*sz^{lt}^(-0.772))/2	0.02	0.025
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	x			x			(11.863*sz^{lt}^(-0.772))/2	0.02	0.025
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	(13.411*sz^{lt}^(-0.772))/2	0.02	0.02	(13.411*sz^{lt}^(-0.772))/2	0.02	0.015	(13.411*sz^{lt}^(-0.772))/2	0.02	0.02
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	(9.8*sz^{lt}^(-0.772))/2	0.01	0.02	(6.7053*sz^{lt}^(-0.772))/2	0.01	0.015	(9.8*sz^{lt}^(-0.772))/2	0.01	0.02
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	(9.8*sz^{lt}^(-0.772))/2	0.01	0.005	(6.7053*sz^{lt}^(-0.772))2	0.01	0.005	(9.8*sz^{lt}^(-0.772))/2	0.01	0.005
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	x			x			x		
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	1.6	0	0	1	0	0	1.6	0	0

			Functions of/specific duration values of the single activity segments [h/m3material]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)	δ_d(m,b,sz)	δ_o(m,b)	δ_q(m,b)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	(5.1579*sz^{lt}^(-0.772))/2	0.01	0.01	x		
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	x			x		
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	(11.863*sz^{lt}^(-0.772))/2	0.02	0.015	x		
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	(11.863*sz^{lt}^(-0.772))/2	0.02	0.015	(154.74*sz^{lt}^(-0.772))/2	0.015	0.025
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	x			x		
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	x			x		
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	x			x		
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	(13.411*sz^{lt}^(-0.772))/2	0.01	0	(257.89*sz^{lt}^(-0.772))/2	0.01	0.01
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	0.6	0	0	9.75	0	0

A3 Equipment contingency cost functions

Functions of/specific hourly contingency costs of basic units and attachments of each mode of the investment report-year (yr) 2014 (based on BGL (2015))

Activity mode (m) including sorting and crushing of material			Functions of/specific hourly contingency costs							
			of the basic units				of attachament/s			
			of the deconstruction activity segment		of the pre-separation and pre-crushing activity segment		of the deconstruction activity segment		of the pre-separation and pre-crushing activity segment	
#	Description	Abbreviation	$\kappa^{ex(hy)}(sz^{hy},yr)$/ $\kappa^{ex(lt)}(sz^{lt},yr)$/ $\kappa^{ex(cw)}(sz^{cw},yr)$/ $\kappa^{ex(ha)}(sz^{ha},yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(hy)}(sz^{hy},yr)$/ $\kappa^{ex(lt)}(sz^{lt},yr)$/ $\kappa^{ex(cw)}(sz^{cw},yr)$/ $\kappa^{ex(ha)}(sz^{ha},yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(ad)}(m,sz,yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(ab)}(m,sz,yr)$ **[€/h]**	included positions of BGL 2015
1	Gripping with 1 hydraulic excavator	Grip_HY_1	$0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$0.1399*sz^{HY}$	D.1.82	$0.1399*sz^{HY}$	D.1.82
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	$0.3168sz^{CW}$	C.2.21 C.2.22 C.2.23 C.2.24	$0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	0.75	D.0.52	$0.1399*sz^{HY}$	D.1.82
3	Pushing with 1 hydraulic excavator	Push_HY_1	$0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$0.0211*sz^{HY}$	D.1.83	$0.1399*sz^{HY}$	D.1.82
4	Pulling with 1 hydraulic excavator	Pull_HY_1	$0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$0.0211*sz^{HY}$	D.1.83	$0.1399*sz^{HY}$	D.1.82

Activity mode (m) including sorting and crushing of material			Functions of/specific hourly contingency costs							
			of the basic units				of attachament/s			
			of the deconstruction activity segment		of the pre-separation and pre-crushing activity segment		of the deconstruction activity segment		of the pre-separation and pre-crushing activity segment	
#	Description	Abbreviation	$\kappa^{ex(hy)}(sz^{hy},yr)$/ $\kappa^{ex(lt)}(sz^{lt},yr)$/ $\kappa^{ex(cw)}(sz^{cw},yr)$/ $\kappa^{ex(ha)}(sz^{ha},yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(hy)}(sz^{hy},yr)$/ $\kappa^{ex(lt)}(sz^{lt},yr)$/ $\kappa^{ex(cw)}(sz^{cw},yr)$/ $\kappa^{ex(ha)}(sz^{ha},yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(ad)}(m,sz,yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(ab)}(m,sz,yr)$ **[€/h]**	included positions of BGL 2015
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	$0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$0.0211*sz^{HY}$	D.1.83	$0.1399*sz^{HY}$	D.1.82
6	Mortising with 1 hydraulic excavator	Mort_HY_1	$0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$0.2264*s^{HY}$	J.5.00	$0.1399*sz^{HY}$	D.1.82
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	$0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$0.1399*s^{HY}$	D.1.85 (cost calculation based on D.1.82 due to technical similarities)	$0.1399*sz^{HY}$	D.1.82
8	Cutting with 1 hydraulic excavator	Cut_HY_1	$0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$0.1399*sz^{HY}$	D.1.87 (cost calculation based on D.1.82 due to technical similarities)	$0.1399*sz^{HY}$	D.1.82

Activity mode (m) including sorting and crushing of material			Functions of/specific hourly contingency costs							
			of the basic units				of attachament/s			
			of the deconstruction activity segment		of the pre-separation and pre-crushing activity segment		of the deconstruction activity segment		of the pre-separation and pre-crushing activity segment	
#	Description	Abbreviation	$\kappa^{ex(hy)}(sz^{hy},yr)$/ $\kappa^{ex(lt)}(sz^{lt},yr)$/ $\kappa^{ex(cw)}(sz^{cw},yr)$/ $\kappa^{ex(ha)}(sz^{ha},yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(hy)}(sz^{hy},yr)$/ $\kappa^{ex(lt)}(sz^{lt},yr)$/ $\kappa^{ex(cw)}(sz^{cw},yr)$/ $\kappa^{ex(ha)}(sz^{ha},yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(ad)}(m,sz,yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(ab)}(m,sz,yr)$ **[€/h]**	included positions of BGL 2015
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	$0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$0.1399*sz^{LT}$	D.1.82	$0.1399*sz^{LT}$	D.1.82
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 lognfront hydraulic excavator)	Wreck_CW_LT_1	$0.3168sz^{CW}$	C.2.21 C.2.22 C.2.23 C.2.24	$0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	0.75	D.0.52	$0.1399*sz^{LT}$	D.1.82
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	$0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$0.0211*sz^{LT}$	D.1.83	$0.1399*sz^{LT}$	D.1.82
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	$0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$0.0211*sz^{LT}$	D.1.83	$0.1399*sz^{LT}$	D.1.82

Activity mode (m) including sorting and crushing of material			Functions of/specific hourly contingency costs							
			of the basic units				of attachament/s			
			of the deconstruction activity segment		of the pre-separation and pre-crushing activity segment		of the deconstruction activity segment		of the pre-separation and pre-crushing activity segment	
#	Description	Abbreviation	$\kappa^{ex(hy)}(sz^{hy},yr)$/ $\kappa^{ex(lt)}(sz^{lt},yr)$/ $\kappa^{ex(cw)}(sz^{cw},yr)$/ $\kappa^{ex(ha)}(sz^{ha},yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(hy)}(sz^{hy},yr)$/ $\kappa^{ex(lt)}(sz^{lt},yr)$/ $\kappa^{ex(cw)}(sz^{cw},yr)$/ $\kappa^{ex(ha)}(sz^{ha},yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(ad)}(m,sz,yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(ab)}(m,sz,yr)$ **[€/h]**	included positions of BGL 2015
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	$0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$0.0211*sz^{LT}$	D.1.83	$0.1399*sz^{LT}$	D.1.82
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	$0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$0.2264*sz^{LT}$	J.5.00	$0.1399*sz^{LT}$	D.1.82
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	$0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$0.1399*sz^{LT}$	D.1.85 (cost calculation based on D.1.82 due to technical similarities)	$0.1399*sz^{LT}$	D.1.82
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	$0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$0.1399*sz^{LT}$	D.1.87 (cost calculation based on D.1.82 due to technical similarities)	$0.1399*sz^{LT}$	D.1.82
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	7.7	W.7.02 Q.0.00	7.7	W.7.02 Q.0.00	-/-	-/-	-/-	-/-

Activity mode (m) including sorting and crushing of material			Functions of/specific hourly contingency costs							
			of the basic units				of attachament/s			
			of the deconstruction activity segment		of the pre-separation and pre-crushing activity segment		of the deconstruction activity segment		of the pre-separation and pre-crushing activity segment	
#	Description	Abbreviation	$\kappa^{ex(hy)}(sz^{hy},yr)$/ $\kappa^{ex(lt)}(sz^{lt},yr)$/ $\kappa^{ex(cw)}(sz^{cw},yr)$/ $\kappa^{ex(ha)}(sz^{ha},yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(hy)}(sz^{hy},yr)$/ $\kappa^{ex(lt)}(sz^{lt},yr)$/ $\kappa^{ex(cw)}(sz^{cw},yr)$/ $\kappa^{ex(ha)}(sz^{ha},yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(ad)}(m,sz,yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(ab)}(m,sz,yr)$ **[€/h]**	included positions of BGL 2015
18	Gripping with 2 hydraulic excavators	Grip_HY_2	$2*0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$2*0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$2*0.1399*sz^{HY}$	D.1.82	$2*0.1399*sz^{HY}$	D.1.82
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	$2*0.3168*sz^{CW}$	C.2.21 C.2.22 C.2.23 C.2.24	$2*0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	2*0.75	D.0.52	$2*0.1399*sz^{HY}$	D.1.82
20	Pushing with 2 hydraulic excavators	Push_HY_2	$2*0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$2*0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$2*0.0211*s^{HY}$	D.1.83	$2*0.1399*sz^{HY}$	D.1.82
21	Pulling with 2 hydraulic excavators	Pull_HY_2	$2*0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$2*0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$2*0.0211*sz^{HY}$	D.1.83	$2*0.1399*sz^{HY}$	D.1.82

Activity mode (m) including sorting and crushing of material			Functions of/specific hourly contingency costs							
			of the basic units				of attachament/s			
			of the deconstruction activity segment		of the pre-separation and pre-crushing activity segment		of the deconstruction activity segment		of the pre-separation and pre-crushing activity segment	
#	Description	Abbreviation	$\kappa^{ex(hy)}(sz^{hy},yr)$/ $\kappa^{ex(lt)}(sz^{lt},yr)$/ $\kappa^{ex(cw)}(sz^{cw},yr)$/ $\kappa^{ex(ha)}(sz^{ha},yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(hy)}(sz^{hy},yr)$/ $\kappa^{ex(lt)}(sz^{lt},yr)$/ $\kappa^{ex(cw)}(sz^{cw},yr)$/ $\kappa^{ex(ha)}(sz^{ha},yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(ad)}(m,sz,yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(ab)}(m,sz,yr)$ **[€/h]**	included positions of BGL 2015
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	$2*0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$2*0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$2*0.0211*sz^{HY}$	D.1.83	$2*0.1399*sz^{HY}$	D.1.82
23	Mortising with 2 hydraulic excavators	Mort_HY_2	$2*0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$2*0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$2*0.2264*s^{HY}$	J.5.00	$2*0.1399*sz^{HY}$	D.1.82
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	$2*0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$2*0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$2*0.1399*sz^{HY}$	D.1.85 (cost calculation based on D.1.82 due to technical similarities)	$2*0.1399*sz^{HY}$	D.1.82
25	Cutting with 2 hydraulic excavators	Cut_HY_2	$2*0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$2*0.6043*sz^{HY}$	D.1.00 D.1.40 D.1.43 D.1.43*.***-AC	$2*0.1399*sz^{HY}$	D.1.87 (cost calculation based on D.1.82 due to technical similarities)	$2*0.1399*sz^{HY}$	D.1.82

Activity mode (m) including sorting and crushing of material			Functions of/specific hourly contingency costs							
			of the basic units				of attachament/s			
			of the deconstruction activity segment		of the pre-separation and pre-crushing activity segment		of the deconstruction activity segment		of the pre-separation and pre-crushing activity segment	
#	Description	Abbreviation	$\kappa^{ex(hy)}(sz^{hy},yr)$/ $\kappa^{ex(lt)}(sz^{lt},yr)$/ $\kappa^{ex(cw)}(sz^{cw},yr)$/ $\kappa^{ex(ha)}(sz^{ha},yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(hy)}(sz^{hy},yr)$/ $\kappa^{ex(lt)}(sz^{lt},yr)$/ $\kappa^{ex(cw)}(sz^{cw},yr)$/ $\kappa^{ex(ha)}(sz^{ha},yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(ad)}(m,sz,yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(ab)}(m,sz,yr)$ **[€/h]**	included positions of BGL 2015
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	$2*0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$2*0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$2*0.1399*sz^{LT}$	D.1.82	$2*0.1399*sz^{LT}$	D.1.82
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	$2*0.3168sz^{CW}$	C.2.21 C.2.22 C.2.23 C.2.24	$2*0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	2*0.75	D.0.52	$2*0.1399*sz^{LT}$	D.1.82
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	$2*0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$2*0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$2*0.0211*sz^{LT}$	D.1.83	$2*0.1399*sz^{LT}$	D.1.82
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	$2*0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$2*0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$2*0.0211*sz^{LT}$	D.1.83	$2*0.1399*sz^{LT}$	D.1.82

Activity mode (m) including sorting and crushing of material			Functions of/specific hourly contingency costs							
			of the basic units				of attachament/s			
			of the deconstruction activity		of the pre-separation and pre-		of the deconstruction activity		of the pre-separation and	
#	Description	Abbreviation	$\kappa^{ex(hy)}(sz^{hy},yr)$/ $\kappa^{ex(lt)}(sz^{lt},yr)$/ $\kappa^{ex(cw)}(sz^{cw},yr)$/ $\kappa^{ex(ha)}(sz^{ha},yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(hy)}(sz^{hy},yr)$/ $\kappa^{ex(lt)}(sz^{lt},yr)$/ $\kappa^{ex(cw)}(sz^{cw},yr)$/ $\kappa^{ex(ha)}(sz^{ha},yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(ad)}(m,sz,yr)$ **[€/h]**	included positions of BGL 2015	$\kappa^{ex(ab)}(m,sz,yr)$ **[€/h]**	included positions of BGL 2015
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	$2*0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$2*0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$2*0.0211*sz^{LT}$	D.1.83	$2*0.1399*sz^{LT}$	D.1.82
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	$2*0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$2*0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$2*0.2264*sz^{LT}$	J.5.00	$2*0.1399*sz^{LT}$	D.1.82
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	$2*0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$2*0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$2*0.1399*sz^{LT}$	D.1.85 (cost calculation based on D.1.82 due to technical similarities)	$2*0.1399*sz^{LT}$	D.1.82
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	$2*0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$2*0.692*sz^{LT}$	D.1.00 D.1.81 D.1.43*.***-AC	$2*0.1399*sz^{LT}$	D.1.87 (cost calculation based on D.1.82 due to technical similarities)	$2*0.1399*sz^{LT}$	D.1.82
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	2*7.7	W.7.02 Q.0.00	2*7.7	W.7.02 Q.0.00	-/-	-/-	-/-	-/-

A4 Basic data for EIA - specific emission level values

Explanations:

Dark grey cells with x: not suitable/not relevant for the material

*Assumtion of a volumic mass of steel of 7.6 t/m^3

A4-1 Specific hourly average noise emission level values

($\lambda^e_d(m,b,sz,hg)$, $\lambda^e_o(m,b,sz,hg)$, $\lambda^e_q(m,b,sz,hg)$)

Specific hourly noise emission level values of the single activity segments of each mode applied to different building materials, performed with basic unit/s of sizes sz <=160 kW/40 t and in deconstruction heights above ground hg <=15 m

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	80	70	80	80	70	80	80	70	80
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	100	70	80	100	70	80	100	70	80
3	Pushing with 1 hydraulic excavator	Push_HY_1	80	70	80	80	70	80	80	70	80
4	Pulling with 1 hydraulic excavator	Pull_HY_1	70	70	80	70	70	80	70	70	80
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	80	70	80	80	70	80	80	70	80
6	Mortising with 1 hydraulic excavator	Mort_HY_1	90	70	80	90	70	80	90	70	80
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	80	70	80	80	70	80	80	70	80
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x			x	

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	80	60	80	80	70	90
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	100	60	80	100	70	90
3	Pushing with 1 hydraulic excavator	Push_HY_1	80	60	80	80	70	90
4	Pulling with 1 hydraulic excavator	Pull_HY_1	70	60	80	70	70	90
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	80	60	80	80	70	90
6	Mortising with 1 hydraulic excavator	Mort_HY_1	90	60	80	90	70	90
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	80	60	80	80	70	90
8	Cutting with 1 hydraulic excavator	Cut_HY_1	x			x		

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b		6			7			8	
		Name		Reinforced concrete			Concrete			Precast reinforced concrete unit	
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1		x		80	70	90		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	110	80	100	100	70	90	110	80	100
3	Pushing with 1 hydraulic excavator	Push_HY_1		x			x		90	80	100
4	Pulling with 1 hydraulic excavator	Pull_HY_1		x			x		80	80	100
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	90	80	100	80	70	90	90	80	100
6	Mortising with 1 hydraulic excavator	Mort_HY_1	110	80	100	100	70	90	110	80	100
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	90	80	100	80	70	90	90	80	100
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x			x	

#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
1	Gripping with 1 hydraulic excavator	Grip_HY_1	60	60	70		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1		x			x	
3	Pushing with 1 hydraulic excavator	Push_HY_1	70	60	70			
4	Pulling with 1 hydraulic excavator	Pull_HY_1	70	60	70	90	70	90
5	Ripping with 1 hydraulic excavator	Ripp_HY_1		x			x	
6	Mortising with 1 hydraulic excavator	Mort_HY_1		x			x	
7	Press-cutting with 1 hydraulic excavator	Press_HY_1		x			x	
8	Cutting with 1 hydraulic excavator	Cut_HY_1	70	60	70	90	70	90

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	80	70	80	80	70	80	80	70	80
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	100	70	80	100	70	80	100	70	80
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	80	70	80	80	70	80	80	70	80
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	70	70	80	70	70	80	70	70	80
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	80	70	80	80	70	80	80	70	80
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	90	70	80	90	70	80	90	70	80
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	80	70	80	80	70	80	80	70	80
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	x			x			x		
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	90	70	80	90	70	80	90	70	80

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^{e}_{d}(m,b,sz,hg)$	$\lambda^{e}_{o}(m,b,sz,hg)$	$\lambda^{e}_{q}(m,b,sz,hg)$	$\lambda^{e}_{d}(m,b,sz,hg)$	$\lambda^{e}_{o}(m,b,sz,hg)$	$\lambda^{e}_{q}(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	80	60	80	80	70	90
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	100	60	80	100	70	90
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	80	60	80	80	70	90
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	70	60	80	70	70	90
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	80	60	80	80	70	90
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	90	60	80	90	70	90
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	80	60	80	80	70	90
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	80	60	80	90	70	90

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1		x		80	70	90		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	110	80	100	100	70	90	110	80	100
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1		x			x		90	80	100
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1		x			x		80	80	100
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	90	80	100	80	70	90	90	80	100
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	110	80	100	100	70	90	110	80	100
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	90	80	100	80	70	90	90	80	100
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	110	80	100	100	70	90	110	80	100

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	60	60	70		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1		x			x	
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	70	60	70		x	
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	70	60	70	90	70	90
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1		x			x	
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1		x			x	
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1		x			x	
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	70	60	70	90	70	90
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	80	60	70	110	70	90

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
18	Gripping with 2 hydraulic excavators	Grip_HY_2	90	80	90	90	80	90	90	80	90
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic	Wreck_CW_HY_2	110	80	90	110	80	90	110	80	90
20	Pushing with 2 hydraulic excavators	Push_HY_2	90	80	90	90	80	90	90	80	90
21	Pulling with 2 hydraulic excavators	Pull_HY_2	80	80	90	80	80	90	80	80	90
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	90	80	90	90	80	90	90	80	90
23	Mortising with 2 hydraulic excavators	Mort_HY_2	100	80	90	100	80	90	100	80	90
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	90	80	90	90	80	90	90	80	90
25	Cutting with 2 hydraulic excavators	Cut_HY_2		x			x			x	

Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation						
18	Gripping with 2 hydraulic excavators	Grip_HY_2	90	70	90	90	80	100
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	110	70	90	110	80	100
20	Pushing with 2 hydraulic excavators	Push_HY_2	90	70	90	90	80	100
21	Pulling with 2 hydraulic excavators	Pull_HY_2	80	70	90	80	80	100
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	90	70	90	90	80	100
23	Mortising with 2 hydraulic excavators	Mort_HY_2	100	70	90	100	80	100
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	90	70	90	90	80	100
25	Cutting with 2 hydraulic excavators	Cut_HY_2		x			x	

Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation									
18	Gripping with 2 hydraulic excavators	Grip_HY_2				90	80	100			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	120	90	110	110	80	100	120	90	110
20	Pushing with 2 hydraulic excavators	Push_HY_2							100	90	110
21	Pulling with 2 hydraulic excavators	Pull_HY_2							90	90	110
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	100	90	110	90	80	100	100	90	110
23	Mortising with 2 hydraulic excavators	Mort_HY_2	120	90	110	110	80	100	120	90	110
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	100	90	110	90	80	100	100	90	110
25	Cutting with 2 hydraulic excavators	Cut_HY_2									

Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation						
18	Gripping with 2 hydraulic excavators	Grip_HY_2	70	70	80			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic	Wreck_CW_HY_2						
20	Pushing with 2 hydraulic excavators	Push_HY_2	80	70	80			
21	Pulling with 2 hydraulic excavators	Pull_HY_2	80	70	80	100	80	100
22	Ripping with 2 hydraulic excavators	Ripp_HY_2						
23	Mortising with 2 hydraulic excavators	Mort_HY_2						
24	Press-cutting with 2 hydraulic excavators	Press_HY_2						
25	Cutting with 2 hydraulic excavators	Cut_HY_2	80	70	80	100	80	100

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	90	80	90	90	80	90	90	80	90
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	110	80	90	110	80	90	110	80	90
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	90	80	90	90	80	90	90	80	90
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	80	80	90	80	80	90	80	80	90
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	90	80	90	90	80	90	90	80	90
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	100	80	90	100	80	90	100	80	90
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	90	80	90	90	80	90	90	80	90
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	x			x			x		
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	100	80	90	100	80	90	100	80	90

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	90	70	90	90	80	100
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	110	70	90	110	80	100
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	90	70	90	90	80	100
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	80	70	90	80	80	100
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	90	70	90	90	80	100
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	100	70	90	100	80	100
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	90	70	90	90	80	100
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2		x			x	
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	90	70	90	100	80	100

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2				90	80	100			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	120	90	110	110	80	100	120	90	110
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2							100	90	110
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2							90	90	110
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	100	90	110	90	80	100	100	90	110
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	120	90	110	110	80	100	120	90	110
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	100	90	110	90	80	100	100	90	110
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2									
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	120	90	110	110	80	100	120	90	110

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	70	70	80			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2						
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	80	70	80			
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	80	70	80	100	80	100
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2						
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2						
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2						
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	80	70	80	100	80	100
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	90	70	80	120	80	100

Specific hourly noise emission level values of the single activity segments of each mode applied to different building materials, performed with basic unit/s of sizes sz <=160 kW/40 t and in deconstruction heights above ground hg >15 m

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	90	70	80	90	70	80	90	70	80
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	110	70	80	110	70	80	110	70	80
3	Pushing with 1 hydraulic excavator	Push_HY_1	90	70	80	90	70	80	90	70	80
4	Pulling with 1 hydraulic excavator	Pull_HY_1	80	70	80	80	70	80	80	70	80
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	90	70	80	90	70	80	90	70	80
6	Mortising with 1 hydraulic excavator	Mort_HY_1	100	70	80	100	70	80	100	70	80
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	80	70	80	80	70	80	80	70	80
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x			x	

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	90	60	80	90	70	90
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	110	60	80	110	70	90
3	Pushing with 1 hydraulic excavator	Push_HY_1	90	60	80	90	70	90
4	Pulling with 1 hydraulic excavator	Pull_HY_1	80	60	80	80	70	90
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	90	60	80	90	70	90
6	Mortising with 1 hydraulic excavator	Mort_HY_1	100	60	80	100	70	90
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	80	60	80	80	70	90
8	Cutting with 1 hydraulic excavator	Cut_HY_1	x			x		

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1		x		90	70	90		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	120	80	100	110	70	90	120	80	100
3	Pushing with 1 hydraulic excavator	Push_HY_1		x			x		100	80	100
4	Pulling with 1 hydraulic excavator	Pull_HY_1		x			x		90	80	100
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	100	80	100	90	70	90	100	80	100
6	Mortising with 1 hydraulic excavator	Mort_HY_1	120	80	100	110	70	90	120	80	100
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	90	80	100	80	70	90	90	80	100
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x			x	

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	λ^e_d(m,b,sz,hg)	λ^e_o(m,b,sz,hg)	λ^e_q(m,b,sz,hg)	λ^e_d(m,b,sz,hg)	λ^e_o(m,b,sz,hg)	λ^e_q(m,b,sz,hg)
1	Gripping with 1 hydraulic excavator	Grip_HY_1	70	60	70		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1		x			x	
3	Pushing with 1 hydraulic excavator	Push_HY_1	80	60	70			
4	Pulling with 1 hydraulic excavator	Pull_HY_1	80	60	70	100	70	90
5	Ripping with 1 hydraulic excavator	Ripp_HY_1		x			x	
6	Mortising with 1 hydraulic excavator	Mort_HY_1		x			x	
7	Press-cutting with 1 hydraulic excavator	Press_HY_1		x			x	
8	Cutting with 1 hydraulic excavator	Cut_HY_1	70	60	70	90	70	90

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	λ^e_d(m,b,sz,hg)	λ^e_o(m,b,sz,hg)	λ^e_q(m,b,sz,hg)	λ^e_d(m,b,sz,hg)	λ^e_o(m,b,sz,hg)	λ^e_q(m,b,sz,hg)	λ^e_d(m,b,sz,hg)	λ^e_o(m,b,sz,hg)	λ^e_q(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	90	70	80	90	70	80	90	70	80
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	110	70	80	110	70	80	110	70	80
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	90	70	80	90	70	80	90	70	80
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	80	70	80	80	70	80	80	70	80
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	90	70	80	90	70	80	90	70	80
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	100	70	80	100	70	80	100	70	80
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	80	70	80	80	70	80	80	70	80
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	100	70	80	100	70	80	100	70	80

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	90	60	80	90	70	90
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	110	60	80	110	70	90
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	90	60	80	90	70	90
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	80	60	80	80	70	90
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	90	60	80	90	70	90
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	100	60	80	100	70	90
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	80	60	80	80	70	90
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	90	60	80	100	70	90

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1		x		90	70	90		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	120	80	100	110	70	90	120	80	100
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1		x			x		100	80	100
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1		x			x		90	80	100
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	100	80	100	90	70	90	100	80	100
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	120	80	100	110	70	90	120	80	100
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	90	80	100	80	70	90	90	80	100
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	120	80	100	110	70	90	120	80	100

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	70	60	70		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1		x			x	
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	80	60	70		x	
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	80	60	70	100	70	90
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1		x			x	
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1		x			x	
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1		x			x	
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	70	60	70	90	70	90
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	90	60	70	120	70	90

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
18	Gripping with 2 hydraulic excavators	Grip_HY_2	100	80	90	100	80	90	100	80	90
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	120	80	90	120	80	90	120	80	90
20	Pushing with 2 hydraulic excavators	Push_HY_2	100	80	90	100	80	90	100	80	90
21	Pulling with 2 hydraulic excavators	Pull_HY_2	90	80	90	90	80	90	90	80	90
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	100	80	90	100	80	90	100	80	90
23	Mortising with 2 hydraulic excavators	Mort_HY_2	110	80	90	110	80	90	110	80	90
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	90	80	90	90	80	90	90	80	90
25	Cutting with 2 hydraulic excavators	Cut_HY_2		x			x			x	

Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation						
18	Gripping with 2 hydraulic excavators	Grip_HY_2	100	70	90	100	80	100
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	120	70	90	120	80	100
20	Pushing with 2 hydraulic excavators	Push_HY_2	100	70	90	100	80	100
21	Pulling with 2 hydraulic excavators	Pull_HY_2	90	70	90	90	80	100
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	100	70	90	100	80	100
23	Mortising with 2 hydraulic excavators	Mort_HY_2	110	70	90	110	80	100
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	90	70	90	90	80	100
25	Cutting with 2 hydraulic excavators	Cut_HY_2	x			x		

Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation									
18	Gripping with 2 hydraulic excavators	Grip_HY_2				100	80	100			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	120	90	110	120	80	100	120	90	110
20	Pushing with 2 hydraulic excavators	Push_HY_2							110	90	110
21	Pulling with 2 hydraulic excavators	Pull_HY_2							100	90	110
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	110	90	110	100	80	100	110	90	110
23	Mortising with 2 hydraulic excavators	Mort_HY_2	120	90	110	120	80	100	120	90	110
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	100	90	110	90	80	100	100	90	110
25	Cutting with 2 hydraulic excavators	Cut_HY_2									

Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation						
18	Gripping with 2 hydraulic excavators	Grip_HY_2	80	70	80			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2						
20	Pushing with 2 hydraulic excavators	Push_HY_2	90	70	80			
21	Pulling with 2 hydraulic excavators	Pull_HY_2	90	70	80	110	80	100
22	Ripping with 2 hydraulic excavators	Ripp_HY_2						
23	Mortising with 2 hydraulic excavators	Mort_HY_2						
24	Press-cutting with 2 hydraulic excavators	Press_HY_2						
25	Cutting with 2 hydraulic excavators	Cut_HY_2	80	70	80	100	80	100

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	100	80	90	100	80	90	100	80	90
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	120	80	90	120	80	90	120	80	90
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	100	80	90	100	80	90	100	80	90
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	90	80	90	90	80	90	90	80	90
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	100	80	90	100	80	90	100	80	90
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	110	80	90	110	80	90	110	80	90
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	90	80	90	90	80	90	90	80	90
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2		x			x			x	
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	110	80	90	110	80	90	110	80	90

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	100	70	90	100	80	100
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	120	70	90	120	80	100
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	100	70	90	100	80	100
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	90	70	90	90	80	100
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	100	70	90	100	80	100
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	110	70	90	110	80	100
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	90	70	90	90	80	100
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2		x			x	
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	100	70	90	110	80	100

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	λ^e_d(m,b,sz,hg)	λ^e_o(m,b,sz,hg)	λ^e_q(m,b,sz,hg)	λ^e_d(m,b,sz,hg)	λ^e_o(m,b,sz,hg)	λ^e_q(m,b,sz,hg)	λ^e_d(m,b,sz,hg)	λ^e_o(m,b,sz,hg)	λ^e_q(m,b,sz,hg)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2				100	80	100			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	120	90	110	120	80	100	120	90	110
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2							110	90	110
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2							100	90	110
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	110	90	110	100	80	100	110	90	110
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	120	90	110	120	80	100	120	90	110
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	100	90	110	90	80	100	100	90	110
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2									
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	120	90	110	120	80	100	120	90	110

Materials (b)		ID_b	Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	80	70	80			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2						
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	90	70	80			
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	90	70	80	110	80	100
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2						
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2						
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2						
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	80	70	80	100	80	100
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	100	70	80	120	80	100

Specific hourly noise emission level values of the single activity segments of each mode applied to different building materials, performed with basic unit/s of sizes sz >160 kW/40 t and in deconstruction heights above ground hg <=15 m

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	80	70	90	80	70	90	80	70	90
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	100	70	90	100	70	90	100	70	90
3	Pushing with 1 hydraulic excavator	Push_HY_1	90	70	90	90	70	90	90	70	90
4	Pulling with 1 hydraulic excavator	Pull_HY_1	70	70	90	70	70	90	70	70	90
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	80	70	90	80	70	90	80	70	90
6	Mortising with 1 hydraulic excavator	Mort_HY_1	100	70	90	100	70	90	100	70	90
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	80	70	90	80	70	90	80	70	90
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x			x	

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	80	60	90	80	70	100
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	100	60	90	100	70	100
3	Pushing with 1 hydraulic excavator	Push_HY_1	90	60	90	90	70	100
4	Pulling with 1 hydraulic excavator	Pull_HY_1	70	60	90	70	70	100
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	80	60	90	80	70	100
6	Mortising with 1 hydraulic excavator	Mort_HY_1	100	60	90	100	70	100
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	80	60	90	80	70	100
8	Cutting with 1 hydraulic excavator	Cut_HY_1	x			x		

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	x			80	70	100	x		
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	110	80	110	100	70	100	110	80	110
3	Pushing with 1 hydraulic excavator	Push_HY_1	x			x			100	80	110
4	Pulling with 1 hydraulic excavator	Pull_HY_1	x			x			80	80	110
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	90	80	110	80	70	100	90	80	110
6	Mortising with 1 hydraulic excavator	Mort_HY_1	120	80	110	110	70	100	120	80	110
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	90	80	110	80	70	100	90	80	110
8	Cutting with 1 hydraulic excavator	Cut_HY_1	x			x			x		

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	60	60	80		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1		x			x	
3	Pushing with 1 hydraulic excavator	Push_HY_1	80	60	80			
4	Pulling with 1 hydraulic excavator	Pull_HY_1	70	60	80	90	70	100
5	Ripping with 1 hydraulic excavator	Ripp_HY_1		x			x	
6	Mortising with 1 hydraulic excavator	Mort_HY_1		x			x	
7	Press-cutting with 1 hydraulic excavator	Press_HY_1		x			x	
8	Cutting with 1 hydraulic excavator	Cut_HY_1	70	60	80	90	70	100

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	80	70	90	80	70	90	80	70	90
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	100	70	90	100	70	90	100	70	90
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	90	70	90	90	70	90	90	70	90
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	70	70	90	70	70	90	70	70	90
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	80	70	90	80	70	90	80	70	90
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	100	70	90	100	70	90	100	70	90
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	80	70	90	80	70	90	80	70	90
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	100	70	90	100	70	90	100	70	90

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	80	60	90	80	70	100
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	100	60	90	100	70	100
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	90	60	90	90	70	100
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	70	60	90	70	70	100
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	80	60	90	80	70	100
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	100	60	90	100	70	100
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	80	60	90	80	70	100
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	90	60	90	100	70	100

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1		x		80	70	100		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	110	80	110	100	70	100	110	80	110
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1		x			x		100	80	110
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1		x			x		80	80	110
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	90	80	110	80	70	100	90	80	110
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	120	80	110	110	70	100	120	80	110
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	90	80	110	80	70	100	90	80	110
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	120	80	110	110	70	100	120	80	110

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	60	60	80		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1		x			x	
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	80	60	80		x	
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	70	60	80	90	70	100
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1		x			x	
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1		x			x	
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1		x			x	
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	70	60	80	90	70	100
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	90	60	80	120	70	100

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
18	Gripping with 2 hydraulic excavators	Grip_HY_2	90	80	100	90	80	100	90	80	100
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	110	80	100	110	80	100	110	80	100
20	Pushing with 2 hydraulic excavators	Push_HY_2	100	80	100	100	80	100	100	80	100
21	Pulling with 2 hydraulic excavators	Pull_HY_2	80	80	100	80	80	100	80	80	100
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	90	80	100	90	80	100	90	80	100
23	Mortising with 2 hydraulic excavators	Mort_HY_2	110	80	100	110	80	100	110	80	100
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	90	80	100	90	80	100	90	80	100
25	Cutting with 2 hydraulic excavators	Cut_HY_2		x			x			x	

Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation						
18	Gripping with 2 hydraulic excavators	Grip_HY_2	90	70	100	90	80	110
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	110	70	100	110	80	110
20	Pushing with 2 hydraulic excavators	Push_HY_2	100	70	100	100	80	110
21	Pulling with 2 hydraulic excavators	Pull_HY_2	80	70	100	80	80	110
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	90	70	100	90	80	110
23	Mortising with 2 hydraulic excavators	Mort_HY_2	110	70	100	110	80	110
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	90	70	100	90	80	110
25	Cutting with 2 hydraulic excavators	Cut_HY_2	x			x		

Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation									
18	Gripping with 2 hydraulic excavators	Grip_HY_2				90	80	110			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	120	90	120	110	80	110	120	90	120
20	Pushing with 2 hydraulic excavators	Push_HY_2							110	90	120
21	Pulling with 2 hydraulic excavators	Pull_HY_2							90	90	120
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	100	90	120	90	80	110	100	90	120
23	Mortising with 2 hydraulic excavators	Mort_HY_2	120	90	120	120	80	110	120	90	120
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	100	90	120	90	80	110	100	90	120
25	Cutting with 2 hydraulic excavators	Cut_HY_2									

Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation						
18	Gripping with 2 hydraulic excavators	Grip_HY_2	70	70	90			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2						
20	Pushing with 2 hydraulic excavators	Push_HY_2	90	70	90			
21	Pulling with 2 hydraulic excavators	Pull_HY_2	80	70	90	100	80	110
22	Ripping with 2 hydraulic excavators	Ripp_HY_2						
23	Mortising with 2 hydraulic excavators	Mort_HY_2						
24	Press-cutting with 2 hydraulic excavators	Press_HY_2						
25	Cutting with 2 hydraulic excavators	Cut_HY_2	80	70	90	100	80	110

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	90	80	100	90	80	100	90	80	100
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	110	80	100	110	80	100	110	80	100
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	100	80	100	100	80	100	100	80	100
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	80	80	100	80	80	100	80	80	100
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	90	80	100	90	80	100	90	80	100
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	110	80	100	110	80	100	110	80	100
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	90	80	100	90	80	100	90	80	100
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2		x			x			x	
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	110	80	100	110	80	100	110	80	100

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	90	70	100	90	80	110
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	110	70	100	110	80	110
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	100	70	100	100	80	110
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	80	70	100	80	80	110
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	90	70	100	90	80	110
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	110	70	100	110	80	110
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	90	70	100	90	80	110
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2		x			x	
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	100	70	100	110	80	110

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2				90	80	110			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	120	90	120	110	80	110	120	90	120
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2							110	90	120
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2							90	90	120
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	100	90	120	90	80	110	100	90	120
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	120	90	120	120	80	110	120	90	120
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	100	90	120	90	80	110	100	90	120
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2									
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	120	90	120	120	80	110	120	90	120

#	Materials (b)	ID_b	9			10		
		Name	Wood			Steel*		
	Activity mode (m)		Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	70	70	90			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2						
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	90	70	90			
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	80	70	90	100	80	110
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2						
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2						
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2						
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	80	70	90	100	80	110
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	100	70	90	120	80	110

Specific hourly noise emission level values of the single activity segments of each mode applied to different building materials, performed with basic unit/s of sizes sz >160 kW/40 t and in deconstruction heights above ground hg >15 m

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	90	70	90	90	70	90	90	70	90
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	110	70	90	110	70	90	110	70	90
3	Pushing with 1 hydraulic excavator	Push_HY_1	90	70	90	90	70	90	90	70	90
4	Pulling with 1 hydraulic excavator	Pull_HY_1	80	70	90	80	70	90	80	70	90
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	90	70	90	90	70	90	90	70	90
6	Mortising with 1 hydraulic excavator	Mort_HY_1	110	70	90	110	70	90	110	70	90
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	80	70	90	80	70	90	80	70	90
8	Cutting with 1 hydraulic excavator	Cut_HY_1	x			x			x		

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	90	60	90	90	70	100
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	110	60	90	110	70	100
3	Pushing with 1 hydraulic excavator	Push_HY_1	90	60	90	90	70	100
4	Pulling with 1 hydraulic excavator	Pull_HY_1	80	60	90	80	70	100
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	90	60	90	90	70	100
6	Mortising with 1 hydraulic excavator	Mort_HY_1	110	60	90	110	70	100
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	80	60	90	80	70	100
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x	

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1		x		90	70	100		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	120	80	110	110	70	100	120	80	110
3	Pushing with 1 hydraulic excavator	Push_HY_1		x			x		100	80	110
4	Pulling with 1 hydraulic excavator	Pull_HY_1		x			x		90	80	110
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	100	80	110	90	70	100	100	80	110
6	Mortising with 1 hydraulic excavator	Mort_HY_1	120	80	110	120	70	100	120	80	110
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	90	80	110	80	70	100	90	80	110
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x			x	

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	70	60	80		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1		x			x	
3	Pushing with 1 hydraulic excavator	Push_HY_1	80	60	80			
4	Pulling with 1 hydraulic excavator	Pull_HY_1	80	60	80	100	70	100
5	Ripping with 1 hydraulic excavator	Ripp_HY_1		x			x	
6	Mortising with 1 hydraulic excavator	Mort_HY_1		x			x	
7	Press-cutting with 1 hydraulic excavator	Press_HY_1		x			x	
8	Cutting with 1 hydraulic excavator	Cut_HY_1	80	60	80	100	70	100

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	90	70	90	90	70	90	90	70	90
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	110	70	90	110	70	90	110	70	90
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	90	70	90	90	70	90	90	70	90
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	80	70	90	80	70	90	80	70	90
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	90	70	90	90	70	90	90	70	90
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	110	70	90	110	70	90	110	70	90
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	80	70	90	80	70	90	80	70	90
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	x			x			x		
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	100	70	90	100	70	90	100	70	90

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	λ^e_d(m,b,sz,hg)	λ^e_o(m,b,sz,hg)	λ^e_q(m,b,sz,hg)	λ^e_d(m,b,sz,hg)	λ^e_o(m,b,sz,hg)	λ^e_q(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	90	60	90	90	70	100
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	110	60	90	110	70	100
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	90	60	90	90	70	100
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	80	60	90	80	70	100
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	90	60	90	90	70	100
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	110	60	90	110	70	100
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	80	60	90	80	70	100
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	90	60	90	100	70	100

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1		x		90	70	100		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	120	80	110	110	70	100	120	80	110
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1		x			x		100	80	110
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1		x			x		90	80	110
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	100	80	110	90	70	100	100	80	110
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	120	80	110	120	70	100	120	80	110
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	90	80	110	80	70	100	90	80	110
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	120	80	110	110	70	100	120	80	110

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	70	60	80		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1		x			x	
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	80	60	80		x	
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	80	60	80	100	70	100
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1		x			x	
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1		x			x	
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1		x			x	
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	80	60	80	100	70	100
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	90	60	80	120	70	100

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
18	Gripping with 2 hydraulic excavators	Grip_HY_2	100	80	100	100	80	100	100	80	100
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	120	80	100	120	80	100	120	80	100
20	Pushing with 2 hydraulic excavators	Push_HY_2	100	80	100	100	80	100	100	80	100
21	Pulling with 2 hydraulic excavators	Pull_HY_2	90	80	100	90	80	100	90	80	100
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	100	80	100	100	80	100	100	80	100
23	Mortising with 2 hydraulic excavators	Mort_HY_2	120	80	100	120	80	100	120	80	100
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	90	80	100	90	80	100	90	80	100
25	Cutting with 2 hydraulic excavators	Cut_HY_2		x			x			x	

Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation						
18	Gripping with 2 hydraulic excavators	Grip_HY_2	100	70	100	100	80	110
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	120	70	100	120	80	110
20	Pushing with 2 hydraulic excavators	Push_HY_2	100	70	100	100	80	110
21	Pulling with 2 hydraulic excavators	Pull_HY_2	90	70	100	90	80	110
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	100	70	100	100	80	110
23	Mortising with 2 hydraulic excavators	Mort_HY_2	120	70	100	120	80	110
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	90	70	100	90	80	110
25	Cutting with 2 hydraulic excavators	Cut_HY_2		x			x	

Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation									
18	Gripping with 2 hydraulic excavators	Grip_HY_2				100	80	110			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	120	90	120	120	80	110	120	90	120
20	Pushing with 2 hydraulic excavators	Push_HY_2							110	90	120
21	Pulling with 2 hydraulic excavators	Pull_HY_2							100	90	120
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	110	90	120	100	80	110	110	90	120
23	Mortising with 2 hydraulic excavators	Mort_HY_2	120	90	120	120	80	110	120	90	120
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	100	90	120	90	80	110	100	90	120
25	Cutting with 2 hydraulic excavators	Cut_HY_2									

Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation						
18	Gripping with 2 hydraulic excavators	Grip_HY_2	80	70	90			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2						
20	Pushing with 2 hydraulic excavators	Push_HY_2	90	70	90			
21	Pulling with 2 hydraulic excavators	Pull_HY_2	90	70	90	110	80	110
22	Ripping with 2 hydraulic excavators	Ripp_HY_2						
23	Mortising with 2 hydraulic excavators	Mort_HY_2						
24	Press-cutting with 2 hydraulic excavators	Press_HY_2						
25	Cutting with 2 hydraulic excavators	Cut_HY_2	90	70	90	110	80	110

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	100	80	100	100	80	100	100	80	100
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	120	80	100	120	80	100	120	80	100
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	100	80	100	100	80	100	100	80	100
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	90	80	100	90	80	100	90	80	100
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	100	80	100	100	80	100	100	80	100
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	120	80	100	120	80	100	120	80	100
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	90	80	100	90	80	100	90	80	100
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2		x			x			x	
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	110	80	100	110	80	100	110	80	100

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	100	70	100	100	80	110
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	120	70	100	120	80	110
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	100	70	100	100	80	110
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	90	70	100	90	80	110
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	100	70	100	100	80	110
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	120	70	100	120	80	110
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	90	70	100	90	80	110
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2		x			x	
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	100	70	100	110	80	110

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2				100	80	110			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	120	90	120	120	80	110	120	90	120
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2							110	90	120
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2							100	90	120
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	110	90	120	100	80	110	110	90	120
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	120	90	120	120	80	110	120	90	120
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	100	90	120	90	80	110	100	90	120
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2									
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	120	90	120	120	80	110	120	90	120

			Specific hourly values of average noise emission levels of the single activity segments [dB(A)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$	$\lambda^e_d(m,b,sz,hg)$	$\lambda^e_o(m,b,sz,hg)$	$\lambda^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	80	70	90			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2						
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	90	70	90			
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	90	70	90	110	80	110
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2						
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2						
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2						
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	90	70	90	110	80	110
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	100	70	90	120	80	110

A4-2 Specific hourly average dust emission level values

(σ^e_d(m,b,sz,hg), σ^e_o(m,b,sz,hg), σ^e_q(m,b,sz,hg))

Specific hourly dust emission level values of the single activity segments of each mode applied to different building materials, performed with basic unit/s of sizes sz <=160 kW/40 t and in deconstruction heights above ground hg <=15 m

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	40	25	25	40	25	25	70	25	25
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	70	25	25	70	25	25	70	25	25
3	Pushing with 1 hydraulic excavator	Push_HY_1	40	25	25	40	25	25	40	25	25
4	Pulling with 1 hydraulic excavator	Pull_HY_1	40	25	25	40	25	25	40	25	25
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	70	25	25	70	25	25	70	25	25
6	Mortising with 1 hydraulic excavator	Mort_HY_1	100	25	25	100	25	25	100	25	25
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	40	25	25	40	25	25	70	25	25
8	Cutting with 1 hydraulic excavator	Cut_HY_1	x			x			x		

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
1	Gripping with 1 hydraulic excavator	Grip_HY_1	70	25	25	40	25	25
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	70	25	25	70	25	25
3	Pushing with 1 hydraulic excavator	Push_HY_1	40	25	25	40	25	25
4	Pulling with 1 hydraulic excavator	Pull_HY_1	40	25	25	40	25	25
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	100	25	25	70	25	25
6	Mortising with 1 hydraulic excavator	Mort_HY_1	100	25	25	70	25	25
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	70	25	25	40	25	25
8	Cutting with 1 hydraulic excavator	Cut_HY_1	x			x		

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	x			40	25	25	x		
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	40	25	25	70	25	25	40	25	25
3	Pushing with 1 hydraulic excavator	Push_HY_1	x			x			40	25	25
4	Pulling with 1 hydraulic excavator	Pull_HY_1	x			x			40	25	25
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	40	25	25	70	25	25	40	25	25
6	Mortising with 1 hydraulic excavator	Mort_HY_1	70	25	25	70	25	25	70	25	25
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	70	25	25	40	25	25	70	25	25
8	Cutting with 1 hydraulic excavator	Cut_HY_1	x			x			x		

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	5,5	5,5	5,5		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1		x			x	
3	Pushing with 1 hydraulic excavator	Push_HY_1	5,5	5,5	5,5			
4	Pulling with 1 hydraulic excavator	Pull_HY_1	5,5	5,5	5,5	1	1	1
5	Ripping with 1 hydraulic excavator	Ripp_HY_1		x			x	
6	Mortising with 1 hydraulic excavator	Mort_HY_1		x			x	
7	Press-cutting with 1 hydraulic excavator	Press_HY_1		x			x	
8	Cutting with 1 hydraulic excavator	Cut_HY_1	1	5,5	5,5	1	1	1

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	40	25	25	40	25	25	70	25	25
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	70	25	25	70	25	25	70	25	25
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	40	25	25	40	25	25	40	25	25
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	40	25	25	40	25	25	40	25	25
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	70	25	25	70	25	25	70	25	25
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	100	25	25	100	25	25	100	25	25
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	40	25	25	40	25	25	70	25	25
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	40	25	25	40	25	25	40	25	25

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	70	25	25	40	25	25
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	70	25	25	70	25	25
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	40	25	25	40	25	25
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	40	25	25	40	25	25
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	100	25	25	70	25	25
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	100	25	25	70	25	25
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	70	25	25	40	25	25
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	x			x		
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	70	25	25	40	25	25

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1		x		40	25	25		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	40	25	25	70	25	25	40	25	25
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1		x			x		40	25	25
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1		x			x		40	25	25
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	40	25	25	70	25	25	40	25	25
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	70	25	25	70	25	25	70	25	25
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	70	25	25	40	25	25	70	25	25
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	40	25	25	40	25	25	40	25	25

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	5,5	5,5	5,5		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1		x			x	
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	5,5	5,5	5,5		x	
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	5,5	5,5	5,5	1	1	1
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1		x			x	
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1		x			x	
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1		x			x	
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	1	5,5	5,5	1	1	1
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	10	5,5	5,5	5,5	1	1

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2	70	40	40	70	40	40	100	40	40
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	100	40	40	100	40	40	100	40	40
20	Pushing with 2 hydraulic excavators	Push_HY_2	70	40	40	70	40	40	70	40	40
21	Pulling with 2 hydraulic excavators	Pull_HY_2	70	40	40	70	40	40	70	40	40
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	100	40	40	100	40	40	100	40	40
23	Mortising with 2 hydraulic excavators	Mort_HY_2	200	40	40	200	40	40	200	40	40
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	70	40	40	70	40	40	100	40	40
25	Cutting with 2 hydraulic excavators	Cut_HY_2		x			x			x	

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m^3)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2	100	40	40	70	40	40
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	100	40	40	100	40	40
20	Pushing with 2 hydraulic excavators	Push_HY_2	70	40	40	70	40	40
21	Pulling with 2 hydraulic excavators	Pull_HY_2	70	40	40	70	40	40
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	200	40	40	100	40	40
23	Mortising with 2 hydraulic excavators	Mort_HY_2	200	40	40	100	40	40
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	100	40	40	70	40	40
25	Cutting with 2 hydraulic excavators	Cut_HY_2	x			x		

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2				70	40	40			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	70	40	40	100	40	40	70	40	40
20	Pushing with 2 hydraulic excavators	Push_HY_2							70	40	40
21	Pulling with 2 hydraulic excavators	Pull_HY_2							70	40	40
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	70	40	40	100	40	40	70	40	40
23	Mortising with 2 hydraulic excavators	Mort_HY_2	100	40	40	100	40	40	100	40	40
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	100	40	40	70	40	40	100	40	40
25	Cutting with 2 hydraulic excavators	Cut_HY_2									

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2	10	10	10			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2						
20	Pushing with 2 hydraulic excavators	Push_HY_2	10	10	10			
21	Pulling with 2 hydraulic excavators	Pull_HY_2	10	10	10	1	1	1
22	Ripping with 2 hydraulic excavators	Ripp_HY_2						
23	Mortising with 2 hydraulic excavators	Mort_HY_2						
24	Press-cutting with 2 hydraulic excavators	Press_HY_2						
25	Cutting with 2 hydraulic excavators	Cut_HY_2	1	10	10	1	1	1

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	70	40	40	70	40	40	100	40	40
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	100	40	40	100	40	40	100	40	40
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	70	40	40	70	40	40	70	40	40
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	70	40	40	70	40	40	70	40	40
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	100	40	40	100	40	40	100	40	40
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	200	40	40	200	40	40	200	40	40
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	70	40	40	70	40	40	100	40	40
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2		x			x			x	
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	70	40	40	70	40	40	70	40	40

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	100	40	40	70	40	40
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	100	40	40	100	40	40
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	70	40	40	70	40	40
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	70	40	40	70	40	40
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	200	40	40	100	40	40
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	200	40	40	100	40	40
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	100	40	40	70	40	40
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2		x			x	
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	100	40	40	70	40	40

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2				70	40	40			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	70	40	40	100	40	40	70	40	40
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2							70	40	40
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2							70	40	40
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	70	40	40	100	40	40	70	40	40
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	100	40	40	100	40	40	100	40	40
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	100	40	40	70	40	40	100	40	40
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2									
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	70	40	40	70	40	40	70	40	40

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	10	10	10			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2						
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	10	10	10			
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	10	10	10	1	1	1
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2						
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2						
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2						
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	1	10	10	1	1	1
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	25	10	10	10	1	1

Specific hourly dust emission level values of the single activity segments of each mode applied to different building materials, performed with basic unit/s of sizes sz <=160 kW/40 t and in deconstruction heights above ground hg >15 m

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	70	25	25	70	25	25	100	25	25
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	200	25	25	200	25	25	200	25	25
3	Pushing with 1 hydraulic excavator	Push_HY_1	100	25	25	100	25	25	100	25	25
4	Pulling with 1 hydraulic excavator	Pull_HY_1	100	25	25	100	25	25	100	25	25
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	200	25	25	200	25	25	200	25	25
6	Mortising with 1 hydraulic excavator	Mort_HY_1	200	25	25	200	25	25	200	25	25
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	100	25	25	100	25	25	200	25	25
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x			x	

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m^3)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	100	25	25	70	25	25
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	200	25	25	200	25	25
3	Pushing with 1 hydraulic excavator	Push_HY_1	100	25	25	100	25	25
4	Pulling with 1 hydraulic excavator	Pull_HY_1	100	25	25	100	25	25
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	200	25	25	200	25	25
6	Mortising with 1 hydraulic excavator	Mort_HY_1	200	25	25	200	25	25
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	200	25	25	100	25	25
8	Cutting with 1 hydraulic excavator	Cut_HY_1	x			x		

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
1	Gripping with 1 hydraulic excavator	Grip_HY_1		x		70	25	25		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	100	25	25	200	25	25	100	25	25
3	Pushing with 1 hydraulic excavator	Push_HY_1		x			x		100	25	25
4	Pulling with 1 hydraulic excavator	Pull_HY_1		x			x		100	25	25
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	100	25	25	200	25	25	100	25	25
6	Mortising with 1 hydraulic excavator	Mort_HY_1	200	25	25	200	25	25	200	25	25
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	200	25	25	100	25	25	200	25	25
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x			x	

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
1	Gripping with 1 hydraulic excavator	Grip_HY_1	10	5,5	5,5		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1		x			x	
3	Pushing with 1 hydraulic excavator	Push_HY_1	10	5,5	5,5			
4	Pulling with 1 hydraulic excavator	Pull_HY_1	10	5,5	5,5	1	1	1
5	Ripping with 1 hydraulic excavator	Ripp_HY_1		x			x	
6	Mortising with 1 hydraulic excavator	Mort_HY_1		x			x	
7	Press-cutting with 1 hydraulic excavator	Press_HY_1		x			x	
8	Cutting with 1 hydraulic excavator	Cut_HY_1	1	5,5	5,5	1	1	1

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m^3)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	70	25	25	70	25	25	100	25	25
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	200	25	25	200	25	25	200	25	25
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	100	25	25	100	25	25	100	25	25
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	100	25	25	100	25	25	100	25	25
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	200	25	25	200	25	25	200	25	25
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	200	25	25	200	25	25	200	25	25
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	100	25	25	100	25	25	200	25	25
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	70	25	25	70	25	25	70	25	25

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m^3)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	100	25	25	70	25	25
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	200	25	25	200	25	25
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	100	25	25	100	25	25
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	100	25	25	100	25	25
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	200	25	25	200	25	25
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	200	25	25	200	25	25
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	200	25	25	100	25	25
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	100	25	25	70	25	25

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1		x		70	25	25		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	100	25	25	200	25	25	100	25	25
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1		x			x		100	25	25
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1		x			x		100	25	25
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	100	25	25	200	25	25	100	25	25
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	200	25	25	200	25	25	200	25	25
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	200	25	25	100	25	25	200	25	25
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	70	25	25	70	25	25	70	25	25

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	10	5,5	5,5		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1		x			x	
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	10	5,5	5,5		x	
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	10	5,5	5,5	1	1	1
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1		x			x	
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1		x			x	
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1		x			x	
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	1	5,5	5,5	1	1	1
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	10	5,5	5,5	10	1	1

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2	100	40	40	100	40	40	200	40	40
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	200	40	40	200	40	40	200	40	40
20	Pushing with 2 hydraulic excavators	Push_HY_2	200	40	40	200	40	40	200	40	40
21	Pulling with 2 hydraulic excavators	Pull_HY_2	200	40	40	200	40	40	200	40	40
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	200	40	40	200	40	40	200	40	40
23	Mortising with 2 hydraulic excavators	Mort_HY_2	200	40	40	200	40	40	200	40	40
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	200	40	40	200	40	40	200	40	40
25	Cutting with 2 hydraulic excavators	Cut_HY_2		x			x			x	

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2	200	40	40	100	40	40
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	200	40	40	200	40	40
20	Pushing with 2 hydraulic excavators	Push_HY_2	200	40	40	200	40	40
21	Pulling with 2 hydraulic excavators	Pull_HY_2	200	40	40	200	40	40
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	200	40	40	200	40	40
23	Mortising with 2 hydraulic excavators	Mort_HY_2	200	40	40	200	40	40
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	200	40	40	200	40	40
25	Cutting with 2 hydraulic excavators	Cut_HY_2	x			x		

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m^3)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
18	Gripping with 2 hydraulic excavators	Grip_HY_2				100	40	40			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	200	40	40	200	40	40	200	40	40
20	Pushing with 2 hydraulic excavators	Push_HY_2							200	40	40
21	Pulling with 2 hydraulic excavators	Pull_HY_2							200	40	40
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	200	40	40	200	40	40	200	40	40
23	Mortising with 2 hydraulic excavators	Mort_HY_2	200	40	40	200	40	40	200	40	40
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	200	40	40	200	40	40	200	40	40
25	Cutting with 2 hydraulic excavators	Cut_HY_2									

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2	25	10	10			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2						
20	Pushing with 2 hydraulic excavators	Push_HY_2	25	10	10			
21	Pulling with 2 hydraulic excavators	Pull_HY_2	25	10	10	1	1	1
22	Ripping with 2 hydraulic excavators	Ripp_HY_2						
23	Mortising with 2 hydraulic excavators	Mort_HY_2						
24	Press-cutting with 2 hydraulic excavators	Press_HY_2						
25	Cutting with 2 hydraulic excavators	Cut_HY_2	1	10	10	1	1	1

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m^3)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	100	40	40	100	40	40	200	40	40
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	200	40	40	200	40	40	200	40	40
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	200	40	40	200	40	40	200	40	40
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	200	40	40	200	40	40	200	40	40
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	200	40	40	200	40	40	200	40	40
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	200	40	40	200	40	40	200	40	40
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	200	40	40	200	40	40	200	40	40
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2		x			x			x	
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	100	40	40	100	40	40	100	40	40

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m^3)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	200	40	40	100	40	40
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	200	40	40	200	40	40
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	200	40	40	200	40	40
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	200	40	40	200	40	40
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	200	40	40	200	40	40
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	200	40	40	200	40	40
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	200	40	40	200	40	40
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	x			x		
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	200	40	40	100	40	40

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m^3)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2				100	40	40			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	200	40	40	200	40	40	200	40	40
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2							200	40	40
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2							200	40	40
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	200	40	40	200	40	40	200	40	40
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	200	40	40	200	40	40	200	40	40
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	200	40	40	200	40	40	200	40	40
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2									
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	100	40	40	100	40	40	100	40	40

#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	25	10	10			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2						
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	25	10	10			
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	25	10	10	1	1	1
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2						
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2						
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2						
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	1	10	10	1	1	1
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	25	10	10	25	1	1

Specific hourly dust emission level values of the single activity segments of each mode applied to different building materials, performed with basic unit/s of sizes sz >160 kW/40 t and in deconstruction heights above ground hg <=15 m

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
1	Gripping with 1 hydraulic excavator	Grip_HY_1	40	25	25	40	25	25	100	25	25
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	70	25	25	70	25	25	70	25	25
3	Pushing with 1 hydraulic excavator	Push_HY_1	40	25	25	40	25	25	40	25	25
4	Pulling with 1 hydraulic excavator	Pull_HY_1	40	25	25	40	25	25	40	25	25
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	70	25	25	70	25	25	70	25	25
6	Mortising with 1 hydraulic excavator	Mort_HY_1	100	25	25	100	25	25	100	25	25
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	40	25	25	40	25	25	70	25	25
8	Cutting with 1 hydraulic excavator	Cut_HY_1	x			x			x		

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
1	Gripping with 1 hydraulic excavator	Grip_HY_1	100	25	25	40	25	25
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	70	25	25	70	25	25
3	Pushing with 1 hydraulic excavator	Push_HY_1	40	25	25	40	25	25
4	Pulling with 1 hydraulic excavator	Pull_HY_1	40	25	25	40	25	25
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	100	25	25	70	25	25
6	Mortising with 1 hydraulic excavator	Mort_HY_1	100	25	25	100	25	25
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	70	25	25	40	25	25
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x	

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
1	Gripping with 1 hydraulic excavator	Grip_HY_1		x		40	25	25		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	40	25	25	70	25	25	40	25	25
3	Pushing with 1 hydraulic excavator	Push_HY_1		x			x		40	25	25
4	Pulling with 1 hydraulic excavator	Pull_HY_1		x			x		40	25	25
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	40	25	25	70	25	25	40	25	25
6	Mortising with 1 hydraulic excavator	Mort_HY_1	100	25	25	100	25	25	100	25	25
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	70	25	25	40	25	25	70	25	25
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x			x	

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
1	Gripping with 1 hydraulic excavator	Grip_HY_1	5,5	5,5	5,5		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1		x			x	
3	Pushing with 1 hydraulic excavator	Push_HY_1	5,5	5,5	5,5			
4	Pulling with 1 hydraulic excavator	Pull_HY_1	5,5	5,5	5,5	1	1	1
5	Ripping with 1 hydraulic excavator	Ripp_HY_1		x			x	
6	Mortising with 1 hydraulic excavator	Mort_HY_1		x			x	
7	Press-cutting with 1 hydraulic excavator	Press_HY_1		x			x	
8	Cutting with 1 hydraulic excavator	Cut_HY_1	1	5,5	5,5	1	1	1

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m^3)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	40	25	25	40	25	25	100	25	25
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	70	25	25	70	25	25	70	25	25
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	40	25	25	40	25	25	40	25	25
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	40	25	25	40	25	25	40	25	25
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	70	25	25	70	25	25	70	25	25
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	100	25	25	100	25	25	100	25	25
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	40	25	25	40	25	25	70	25	25
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	x			x			x		
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	70	25	25	70	25	25	70	25	25

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m^3)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	100	25	25	40	25	25
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	70	25	25	70	25	25
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	40	25	25	40	25	25
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	40	25	25	40	25	25
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	100	25	25	70	25	25
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	100	25	25	100	25	25
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	70	25	25	40	25	25
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	x			x		
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	100	25	25	70	25	25

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1		x		40	25	25		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	40	25	25	70	25	25	40	25	25
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1		x			x		40	25	25
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1		x			x		40	25	25
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	40	25	25	70	25	25	40	25	25
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	100	25	25	100	25	25	100	25	25
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	70	25	25	40	25	25	70	25	25
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	70	25	25	70	25	25	70	25	25

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	5,5	5,5	5,5		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1		x			x	
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	5,5	5,5	5,5		x	
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	5,5	5,5	5,5	1	1	1
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1		x			x	
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1		x			x	
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1		x			x	
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	1	5,5	5,5	1	1	1
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	10	5,5	5,5	5,5	1	1

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2	70	40	40	70	40	40	200	40	40
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	100	40	40	100	40	40	100	40	40
20	Pushing with 2 hydraulic excavators	Push_HY_2	70	40	40	70	40	40	70	40	40
21	Pulling with 2 hydraulic excavators	Pull_HY_2	70	40	40	70	40	40	70	40	40
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	100	40	40	100	40	40	100	40	40
23	Mortising with 2 hydraulic excavators	Mort_HY_2	200	40	40	200	40	40	200	40	40
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	70	40	40	70	40	40	100	40	40
25	Cutting with 2 hydraulic excavators	Cut_HY_2		x			x			x	

			Specific hourly values of average dust emission levels of the single activity segments [$(mg/m^3)/h$]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2	200	40	40	70	40	40
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	100	40	40	100	40	40
20	Pushing with 2 hydraulic excavators	Push_HY_2	70	40	40	70	40	40
21	Pulling with 2 hydraulic excavators	Pull_HY_2	70	40	40	70	40	40
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	200	40	40	100	40	40
23	Mortising with 2 hydraulic excavators	Mort_HY_2	200	40	40	200	40	40
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	100	40	40	70	40	40
25	Cutting with 2 hydraulic excavators	Cut_HY_2	x			x		

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2				70	40	40			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	70	40	40	100	40	40	70	40	40
20	Pushing with 2 hydraulic excavators	Push_HY_2							70	40	40
21	Pulling with 2 hydraulic excavators	Pull_HY_2							70	40	40
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	70	40	40	100	40	40	70	40	40
23	Mortising with 2 hydraulic excavators	Mort_HY_2	200	40	40	200	40	40	200	40	40
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	100	40	40	70	40	40	100	40	40
25	Cutting with 2 hydraulic excavators	Cut_HY_2									

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2	10	10	10			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2						
20	Pushing with 2 hydraulic excavators	Push_HY_2	10	10	10			
21	Pulling with 2 hydraulic excavators	Pull_HY_2	10	10	10	1	1	1
22	Ripping with 2 hydraulic excavators	Ripp_HY_2						
23	Mortising with 2 hydraulic excavators	Mort_HY_2						
24	Press-cutting with 2 hydraulic excavators	Press_HY_2						
25	Cutting with 2 hydraulic excavators	Cut_HY_2	1	10	10	1	1	1

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m^3)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	70	40	40	70	40	40	200	40	40
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	100	40	40	100	40	40	100	40	40
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	70	40	40	70	40	40	70	40	40
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	70	40	40	70	40	40	70	40	40
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	100	40	40	100	40	40	100	40	40
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	200	40	40	200	40	40	200	40	40
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	70	40	40	70	40	40	100	40	40
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2		x			x			x	
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	100	40	40	100	40	40	100	40	40

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m^3)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	200	40	40	70	40	40
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	100	40	40	100	40	40
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	70	40	40	70	40	40
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	70	40	40	70	40	40
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	200	40	40	100	40	40
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	200	40	40	200	40	40
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	100	40	40	70	40	40
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	x			x		
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	200	40	40	100	40	40

			Specific hourly values of average dust emission levels of the single activity segments [$(mg/m^3)/h$]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2				70	40	40			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	70	40	40	100	40	40	70	40	40
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2							70	40	40
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2							70	40	40
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	70	40	40	100	40	40	70	40	40
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	200	40	40	200	40	40	200	40	40
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	100	40	40	70	40	40	100	40	40
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2									
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	100	40	40	100	40	40	100	40	40

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	10	10	10			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2						
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	10	10	10			
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	10	10	10	1	1	1
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2						
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2						
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2						
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	1	10	10	1	1	1
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	25	10	10	10	1	1

Specific hourly dust emission level values of the single activity segments of each mode applied to different building materials, performed with basic unit/s of sizes sz >160 kW/40 t and in deconstruction heights above ground hg >15 m

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	100	25	25	100	25	25	200	25	25
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	200	25	25	200	25	25	200	25	25
3	Pushing with 1 hydraulic excavator	Push_HY_1	100	25	25	100	25	25	100	25	25
4	Pulling with 1 hydraulic excavator	Pull_HY_1	100	25	25	100	25	25	100	25	25
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	200	25	25	200	25	25	200	25	25
6	Mortising with 1 hydraulic excavator	Mort_HY_1	200	25	25	200	25	25	200	25	25
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	100	25	25	100	25	25	200	25	25
8	Cutting with 1 hydraulic excavator	Cut_HY_1	x			x			x		

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	200	25	25	100	25	25
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	200	25	25	200	25	25
3	Pushing with 1 hydraulic excavator	Push_HY_1	100	25	25	100	25	25
4	Pulling with 1 hydraulic excavator	Pull_HY_1	100	25	25	100	25	25
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	200	25	25	200	25	25
6	Mortising with 1 hydraulic excavator	Mort_HY_1	200	25	25	200	25	25
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	200	25	25	100	25	25
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x	

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
1	Gripping with 1 hydraulic excavator	Grip_HY_1		x		100	25	25		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	100	25	25	200	25	25	100	25	25
3	Pushing with 1 hydraulic excavator	Push_HY_1		x			x		100	25	25
4	Pulling with 1 hydraulic excavator	Pull_HY_1		x			x		100	25	25
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	100	25	25	200	25	25	100	25	25
6	Mortising with 1 hydraulic excavator	Mort_HY_1	200	25	25	200	25	25	200	25	25
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	200	25	25	100	25	25	200	25	25
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x			x	

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m^3)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
1	Gripping with 1 hydraulic excavator	Grip_HY_1	10	5,5	5,5		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1		x			x	
3	Pushing with 1 hydraulic excavator	Push_HY_1	25	5,5	5,5			
4	Pulling with 1 hydraulic excavator	Pull_HY_1	10	5,5	5,5	1	1	1
5	Ripping with 1 hydraulic excavator	Ripp_HY_1		x			x	
6	Mortising with 1 hydraulic excavator	Mort_HY_1		x			x	
7	Press-cutting with 1 hydraulic excavator	Press_HY_1		x			x	
8	Cutting with 1 hydraulic excavator	Cut_HY_1	1	5,5	5,5	1	1	1

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	100	25	25	100	25	25	200	25	25
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	200	25	25	200	25	25	200	25	25
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	100	25	25	100	25	25	100	25	25
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	100	25	25	100	25	25	100	25	25
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	200	25	25	200	25	25	200	25	25
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	200	25	25	200	25	25	200	25	25
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	100	25	25	100	25	25	200	25	25
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	100	25	25	100	25	25	100	25	25

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	200	25	25	100	25	25
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	200	25	25	200	25	25
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	100	25	25	100	25	25
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	100	25	25	100	25	25
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	200	25	25	200	25	25
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	200	25	25	200	25	25
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	200	25	25	100	25	25
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	x			x		
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	200	25	25	100	25	25

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1		x		100	25	25		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	100	25	25	200	25	25	100	25	25
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1		x			x		100	25	25
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1		x			x		100	25	25
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	100	25	25	200	25	25	100	25	25
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	200	25	25	200	25	25	200	25	25
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	200	25	25	100	25	25	200	25	25
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	100	25	25	100	25	25	100	25	25

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m^3)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	10	5,5	5,5		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1		x			x	
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	25	5,5	5,5		x	
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	10	5,5	5,5	1	1	1
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1		x			x	
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1		x			x	
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1		x			x	
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	1	5,5	5,5	1	1	1
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	25	5,5	5,5	10	1	1

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m^3)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2	200	40	40	200	40	40	200	40	40
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	200	40	40	200	40	40	200	40	40
20	Pushing with 2 hydraulic excavators	Push_HY_2	200	40	40	200	40	40	200	40	40
21	Pulling with 2 hydraulic excavators	Pull_HY_2	200	40	40	200	40	40	200	40	40
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	200	40	40	200	40	40	200	40	40
23	Mortising with 2 hydraulic excavators	Mort_HY_2	200	40	40	200	40	40	200	40	40
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	200	40	40	200	40	40	200	40	40
25	Cutting with 2 hydraulic excavators	Cut_HY_2		x			x			x	

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
18	Gripping with 2 hydraulic excavators	Grip_HY_2	200	40	40	200	40	40
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	200	40	40	200	40	40
20	Pushing with 2 hydraulic excavators	Push_HY_2	200	40	40	200	40	40
21	Pulling with 2 hydraulic excavators	Pull_HY_2	200	40	40	200	40	40
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	200	40	40	200	40	40
23	Mortising with 2 hydraulic excavators	Mort_HY_2	200	40	40	200	40	40
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	200	40	40	200	40	40
25	Cutting with 2 hydraulic excavators	Cut_HY_2	x			x		

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m^3)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2				200	40	40			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	200	40	40	200	40	40	200	40	40
20	Pushing with 2 hydraulic excavators	Push_HY_2							200	40	40
21	Pulling with 2 hydraulic excavators	Pull_HY_2							200	40	40
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	200	40	40	200	40	40	200	40	40
23	Mortising with 2 hydraulic excavators	Mort_HY_2	200	40	40	200	40	40	200	40	40
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	200	40	40	200	40	40	200	40	40
25	Cutting with 2 hydraulic excavators	Cut_HY_2									

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
18	Gripping with 2 hydraulic excavators	Grip_HY_2	25	10	10			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2						
20	Pushing with 2 hydraulic excavators	Push_HY_2	40	10	10			
21	Pulling with 2 hydraulic excavators	Pull_HY_2	25	10	10	1	1	1
22	Ripping with 2 hydraulic excavators	Ripp_HY_2						
23	Mortising with 2 hydraulic excavators	Mort_HY_2						
24	Press-cutting with 2 hydraulic excavators	Press_HY_2						
25	Cutting with 2 hydraulic excavators	Cut_HY_2	1	10	10	1	1	1

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m^3)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	200	40	40	200	40	40	200	40	40
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	200	40	40	200	40	40	200	40	40
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	200	40	40	200	40	40	200	40	40
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	200	40	40	200	40	40	200	40	40
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	200	40	40	200	40	40	200	40	40
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	200	40	40	200	40	40	200	40	40
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	200	40	40	200	40	40	200	40	40
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2		x			x			x	
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	200	40	40	200	40	40	200	40	40

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	200	40	40	200	40	40
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	200	40	40	200	40	40
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	200	40	40	200	40	40
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	200	40	40	200	40	40
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	200	40	40	200	40	40
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	200	40	40	200	40	40
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	200	40	40	200	40	40
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2		x			x	
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	200	40	40	200	40	40

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m^3)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)	σ^e_d(m,b,sz,hg)	σ^e_o(m,b,sz,hg)	σ^e_q(m,b,sz,hg)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2				200	40	40			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	200	40	40	200	40	40	200	40	40
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2							200	40	40
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2							200	40	40
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	200	40	40	200	40	40	200	40	40
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	200	40	40	200	40	40	200	40	40
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	200	40	40	200	40	40	200	40	40
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2									
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	200	40	40	200	40	40	200	40	40

			Specific hourly values of average dust emission levels of the single activity segments [(mg/m³)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$	$\sigma^e_d(m,b,sz,hg)$	$\sigma^e_o(m,b,sz,hg)$	$\sigma^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	25	10	10			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2						
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	40	10	10			
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	25	10	10	1	1	1
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2						
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2						
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2						
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	1	10	10	1	1	1
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	40	10	10	25	1	1

A4-3 Specific hourly average vibration emission level values

($\psi^{e}_{d}(m,b,sz,hg)$, $\psi^{e}_{o}(m,b,sz,hg)$, $\psi^{e}_{q}(m,b,sz,hg)$)

Specific hourly vibration emission level values of the single activity segments of each mode applied to different building materials, performed with basic unit/s of sizes sz <=160 kW/40 t and in deconstruction heights above ground hg <=15 m

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	1,6	0,3	0,3	1,6	0,3	0,3	1,6	0,3	0,3
3	Pushing with 1 hydraulic excavator	Push_HY_1	1	0,3	0,3	1	0,3	0,3	1	0,3	0,3
4	Pulling with 1 hydraulic excavator	Pull_HY_1	1	0,3	0,3	1	0,3	0,3	1	0,3	0,3
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	1	0,3	0,3	1	0,3	0,3	1	0,3	0,3
6	Mortising with 1 hydraulic excavator	Mort_HY_1	1	0,3	0,3	1	0,3	0,3	1	0,3	0,3
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	0,4	0,3	0,3	0,4	0,3	0,3	0,4	0,3	0,3
8	Cutting with 1 hydraulic excavator	Cut_HY_1	x			x			x		

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	0,3	0,3	0,3	0,3	0,3	0,3
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	1,6	0,3	0,3	1,6	0,3	0,3
3	Pushing with 1 hydraulic excavator	Push_HY_1	1	0,3	0,3	1	0,3	0,3
4	Pulling with 1 hydraulic excavator	Pull_HY_1	1	0,3	0,3	1	0,3	0,3
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	1	0,3	0,3	1	0,3	0,3
6	Mortising with 1 hydraulic excavator	Mort_HY_1	1	0,3	0,3	1	0,3	0,3
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	0,4	0,3	0,3	0,4	0,3	0,3
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x	

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
1	Gripping with 1 hydraulic excavator	Grip_HY_1		x		0,3	0,3	0,3		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	6,3	0,3	0,4	1,6	0,3	0,3	6,3	0,3	0,4
3	Pushing with 1 hydraulic excavator	Push_HY_1		x			x		1	0,3	0,4
4	Pulling with 1 hydraulic excavator	Pull_HY_1		x			x		1	0,3	0,4
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	1,6	0,3	0,4	1	0,3	0,3	1,6	0,3	0,4
6	Mortising with 1 hydraulic excavator	Mort_HY_1	6,3	0,3	0,4	1,6	0,3	0,3	6,3	0,3	0,4
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	1	0,3	0,4	0,4	0,3	0,3	1	0,3	0,4
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x			x	

Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	0,2	0,2	0,2		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1		x			x	
3	Pushing with 1 hydraulic excavator	Push_HY_1	0,2	0,2	0,2			
4	Pulling with 1 hydraulic excavator	Pull_HY_1	0,2	0,2	0,2	1	0,3	0,3
5	Ripping with 1 hydraulic excavator	Ripp_HY_1		x			x	
6	Mortising with 1 hydraulic excavator	Mort_HY_1		x			x	
7	Press-cutting with 1 hydraulic excavator	Press_HY_1		x			x	
8	Cutting with 1 hydraulic excavator	Cut_HY_1	0,2	0,2	0,2	0,3	0,3	0,3

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	1,6	0,3	0,3	1,6	0,3	0,3	1,6	0,3	0,3
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	1	0,3	0,3	1	0,3	0,3	1	0,3	0,3
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	1	0,3	0,3	1	0,3	0,3	1	0,3	0,3
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	1	0,3	0,3	1	0,3	0,3	1	0,3	0,3
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	1	0,3	0,3	1	0,3	0,3	1	0,3	0,3
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	0,4	0,3	0,3	0,4	0,3	0,3	0,4	0,3	0,3
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	x			x			x		
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	0,4	0,3	0,3	0,4	0,3	0,3	0,4	0,3	0,3

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	0,3	0,3	0,3	0,3	0,3	0,3
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	1,6	0,3	0,3	1,6	0,3	0,3
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	1	0,3	0,3	1	0,3	0,3
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	1	0,3	0,3	1	0,3	0,3
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	1	0,3	0,3	1	0,3	0,3
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	1	0,3	0,3	1	0,3	0,3
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	0,4	0,3	0,3	0,4	0,3	0,3
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	0,4	0,3	0,3	0,4	0,3	0,3

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1		x		0,3	0,3	0,3		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	6,3	0,3	0,4	1,6	0,3	0,3	6,3	0,3	0,4
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1		x			x		1	0,3	0,4
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1		x			x		1	0,3	0,4
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	1,6	0,3	0,4	1	0,3	0,3	1,6	0,3	0,4
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	6,3	0,3	0,4	1,6	0,3	0,3	6,3	0,3	0,4
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	1	0,3	0,4	0,4	0,3	0,3	1	0,3	0,4
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	1	0,3	0,4	0,4	0,3	0,3	1	0,3	0,4

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\psi^{e}_{d}(m,b,sz,hg)$	$\psi^{e}_{o}(m,b,sz,hg)$	$\psi^{e}_{q}(m,b,sz,hg)$	$\psi^{e}_{d}(m,b,sz,hg)$	$\psi^{e}_{o}(m,b,sz,hg)$	$\psi^{e}_{q}(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	0,2	0,2	0,2	x		
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	x			x		
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	0,2	0,2	0,2	x		
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	0,2	0,2	0,2	1	0,3	0,3
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	x			x		
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	x			x		
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	x			x		
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	0,2	0,2	0,2	0,3	0,3	0,3
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	0,4	0,2	0,2	1	0,3	0,3

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
18	Gripping with 2 hydraulic excavators	Grip_HY_2	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	4	0,4	0,4	4	0,4	0,4	4	0,4	0,4
20	Pushing with 2 hydraulic excavators	Push_HY_2	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
21	Pulling with 2 hydraulic excavators	Pull_HY_2	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
23	Mortising with 2 hydraulic excavators	Mort_HY_2	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	1	0,4	0,4	1	0,4	0,4	1	0,4	0,4
25	Cutting with 2 hydraulic excavators	Cut_HY_2	x			x			x		

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2	0,4	0,4	0,4	0,4	0,4	0,4
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	4	0,4	0,4	4	0,4	0,4
20	Pushing with 2 hydraulic excavators	Push_HY_2	1,6	0,4	0,4	1,6	0,4	0,4
21	Pulling with 2 hydraulic excavators	Pull_HY_2	1,6	0,4	0,4	1,6	0,4	0,4
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	1,6	0,4	0,4	1,6	0,4	0,4
23	Mortising with 2 hydraulic excavators	Mort_HY_2	1,6	0,4	0,4	1,6	0,4	0,4
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	1	0,4	0,4	1	0,4	0,4
25	Cutting with 2 hydraulic excavators	Cut_HY_2		x			x	

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2				0,4	0,4	0,4			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	15,7	0,4	1	4	0,4	0,4	15,7	0,4	1
20	Pushing with 2 hydraulic excavators	Push_HY_2							1,6	0,4	1
21	Pulling with 2 hydraulic excavators	Pull_HY_2							1,6	0,4	1
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	4	0,4	1	1,6	0,4	0,4	4	0,4	1
23	Mortising with 2 hydraulic excavators	Mort_HY_2	15,7	0,4	1	4	0,4	0,4	15,7	0,4	1
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	1,6	0,4	1	1	0,4	0,4	1,6	0,4	1
25	Cutting with 2 hydraulic excavators	Cut_HY_2									

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
18	Gripping with 2 hydraulic excavators	Grip_HY_2	0,4	0,4	0,4			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2						
20	Pushing with 2 hydraulic excavators	Push_HY_2	0,4	0,4	0,4			
21	Pulling with 2 hydraulic excavators	Pull_HY_2	0,4	0,4	0,4	1,6	0,4	0,4
22	Ripping with 2 hydraulic excavators	Ripp_HY_2						
23	Mortising with 2 hydraulic excavators	Mort_HY_2						
24	Press-cutting with 2 hydraulic excavators	Press_HY_2						
25	Cutting with 2 hydraulic excavators	Cut_HY_2	0,4	0,4	0,4	0,4	0,4	0,4

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	4	0,4	0,4	4	0,4	0,4	4	0,4	0,4
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	1	0,4	0,4	1	0,4	0,4	1	0,4	0,4
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2		x			x			x	
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	1	0,4	0,4	1	0,4	0,4	1	0,4	0,4

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	0,4	0,4	0,4	0,4	0,4	0,4
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	4	0,4	0,4	4	0,4	0,4
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	1,6	0,4	0,4	1,6	0,4	0,4
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	1,6	0,4	0,4	1,6	0,4	0,4
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	1,6	0,4	0,4	1,6	0,4	0,4
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	1,6	0,4	0,4	1,6	0,4	0,4
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	1	0,4	0,4	1	0,4	0,4
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2		x			x	
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	1	0,4	0,4	1	0,4	0,4

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2				0,4	0,4	0,4			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	15,7	0,4	1	4	0,4	0,4	15,7	0,4	1
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2							1,6	0,4	1
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2							1,6	0,4	1
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	4	0,4	1	1,6	0,4	0,4	4	0,4	1
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	15,7	0,4	1	4	0,4	0,4	15,7	0,4	1
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	1,6	0,4	1	1	0,4	0,4	1,6	0,4	1
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2									
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	1,6	0,4	1	1	0,4	0,4	1,6	0,4	1

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	ψ^{e}_{d}(m,b,sz,hg)	ψ^{e}_{o}(m,b,sz,hg)	ψ^{e}_{q}(m,b,sz,hg)	ψ^{e}_{d}(m,b,sz,hg)	ψ^{e}_{o}(m,b,sz,hg)	ψ^{e}_{q}(m,b,sz,hg)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	0,4	0,4	0,4			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2						
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	0,4	0,4	0,4			
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	0,4	0,4	0,4	1,6	0,4	0,4
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2						
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2						
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2						
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	0,4	0,4	0,4	0,4	0,4	0,4
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	1	0,4	0,4	1,6	0,4	0,4

Specific hourly vibration emission level values of the single activity segments of each mode applied to different building materials, performed with basic unit/s of sizes sz <=160 kW/40 t and in deconstruction heights above ground hg >15 m

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	0,4	0,3	0,3	0,4	0,3	0,3	0,4	0,3	0,3
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	4	0,3	0,3	4	0,3	0,3	4	0,3	0,3
3	Pushing with 1 hydraulic excavator	Push_HY_1	1,6	0,3	0,3	1,6	0,3	0,3	1,6	0,3	0,3
4	Pulling with 1 hydraulic excavator	Pull_HY_1	1,6	0,3	0,3	1,6	0,3	0,3	1,6	0,3	0,3
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	4	0,3	0,3	4	0,3	0,3	4	0,3	0,3
6	Mortising with 1 hydraulic excavator	Mort_HY_1	1,6	0,3	0,3	1,6	0,3	0,3	1,6	0,3	0,3
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	1	0,3	0,3	1	0,3	0,3	1	0,3	0,3
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x			x	

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
1	Gripping with 1 hydraulic excavator	Grip_HY_1	0,4	0,3	0,3	0,4	0,3	0,3
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	4	0,3	0,3	4	0,3	0,3
3	Pushing with 1 hydraulic excavator	Push_HY_1	1,6	0,3	0,3	1,6	0,3	0,3
4	Pulling with 1 hydraulic excavator	Pull_HY_1	1,6	0,3	0,3	1,6	0,3	0,3
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	4	0,3	0,3	4	0,3	0,3
6	Mortising with 1 hydraulic excavator	Mort_HY_1	1,6	0,3	0,3	1,6	0,3	0,3
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	1	0,3	0,3	1	0,3	0,3
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x	

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	ψ^{e}_{d}(m,b,sz,hg)	ψ^{e}_{o}(m,b,sz,hg)	ψ^{e}_{q}(m,b,sz,hg)	ψ^{e}_{d}(m,b,sz,hg)	ψ^{e}_{o}(m,b,sz,hg)	ψ^{e}_{q}(m,b,sz,hg)	ψ^{e}_{d}(m,b,sz,hg)	ψ^{e}_{o}(m,b,sz,hg)	ψ^{e}_{q}(m,b,sz,hg)
1	Gripping with 1 hydraulic excavator	Grip_HY_1		x		0,4	0,3	0,3		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	15,7	0,3	0,4	4	0,3	0,3	15,7	0,3	0,4
3	Pushing with 1 hydraulic excavator	Push_HY_1		x			x		1,6	0,3	0,4
4	Pulling with 1 hydraulic excavator	Pull_HY_1		x			x		1,6	0,3	0,4
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	4	0,3	0,4	4	0,3	0,3	4	0,3	0,4
6	Mortising with 1 hydraulic excavator	Mort_HY_1	15,7	0,3	0,4	4	0,3	0,3	15,7	0,3	0,4
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	1,6	0,3	0,4	1	0,3	0,3	1,6	0,3	0,4
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x			x	

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
1	Gripping with 1 hydraulic excavator	Grip_HY_1	0,3	0,2	0,2		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1		x			x	
3	Pushing with 1 hydraulic excavator	Push_HY_1	0,4	0,2	0,2			
4	Pulling with 1 hydraulic excavator	Pull_HY_1	0,4	0,2	0,2	1,6	0,3	0,3
5	Ripping with 1 hydraulic excavator	Ripp_HY_1		x			x	
6	Mortising with 1 hydraulic excavator	Mort_HY_1		x			x	
7	Press-cutting with 1 hydraulic excavator	Press_HY_1		x			x	
8	Cutting with 1 hydraulic excavator	Cut_HY_1	0,3	0,2	0,2	0,4	0,3	0,3

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	ψ^{e}_{d}(m,b,sz,hg)	ψ^{e}_{o}(m,b,sz,hg)	ψ^{e}_{q}(m,b,sz,hg)	ψ^{e}_{d}(m,b,sz,hg)	ψ^{e}_{o}(m,b,sz,hg)	ψ^{e}_{q}(m,b,sz,hg)	ψ^{e}_{d}(m,b,sz,hg)	ψ^{e}_{o}(m,b,sz,hg)	ψ^{e}_{q}(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	0,4	0,3	0,3	0,4	0,3	0,3	0,4	0,3	0,3
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	4	0,3	0,3	4	0,3	0,3	4	0,3	0,3
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	1,6	0,3	0,3	1,6	0,3	0,3	1,6	0,3	0,3
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	1,6	0,3	0,3	1,6	0,3	0,3	1,6	0,3	0,3
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	4	0,3	0,3	4	0,3	0,3	4	0,3	0,3
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	1,6	0,3	0,3	1,6	0,3	0,3	1,6	0,3	0,3
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	1	0,3	0,3	1	0,3	0,3	1	0,3	0,3
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	0,4	0,3	0,3	0,4	0,3	0,3	0,4	0,3	0,3

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	0,4	0,3	0,3	0,4	0,3	0,3
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	4	0,3	0,3	4	0,3	0,3
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	1,6	0,3	0,3	1,6	0,3	0,3
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	1,6	0,3	0,3	1,6	0,3	0,3
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	4	0,3	0,3	4	0,3	0,3
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	1,6	0,3	0,3	1,6	0,3	0,3
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	1	0,3	0,3	1	0,3	0,3
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	0,4	0,3	0,3	0,4	0,3	0,3

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1		x		0,4	0,3	0,3		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	15,7	0,3	0,4	4	0,3	0,3	15,7	0,3	0,4
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1		x			x		1,6	0,3	0,4
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1		x			x		1,6	0,3	0,4
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	4	0,3	0,4	4	0,3	0,3	4	0,3	0,4
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	15,7	0,3	0,4	4	0,3	0,3	15,7	0,3	0,4
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	1,6	0,3	0,4	1	0,3	0,3	1,6	0,3	0,4
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	1,6	0,3	0,4	0,4	0,3	0,3	1,6	0,3	0,4

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	0,3	0,2	0,2	x		
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	x			x		
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	0,4	0,2	0,2	x		
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	0,4	0,2	0,2	1,6	0,3	0,3
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	x			x		
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	x			x		
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	x			x		
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	0,3	0,2	0,2	0,4	0,3	0,3
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	0,4	0,2	0,2	1,6	0,3	0,3

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2	1	0,4	0,4	1	0,4	0,4	1	0,4	0,4
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	6,3	0,4	0,4	6,3	0,4	0,4	6,3	0,4	0,4
20	Pushing with 2 hydraulic excavators	Push_HY_2	4	0,4	0,4	4	0,4	0,4	4	0,4	0,4
21	Pulling with 2 hydraulic excavators	Pull_HY_2	4	0,4	0,4	4	0,4	0,4	4	0,4	0,4
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	6,3	0,4	0,4	6,3	0,4	0,4	6,3	0,4	0,4
23	Mortising with 2 hydraulic excavators	Mort_HY_2	4	0,4	0,4	4	0,4	0,4	4	0,4	0,4
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
25	Cutting with 2 hydraulic excavators	Cut_HY_2		x			x			x	

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
18	Gripping with 2 hydraulic excavators	Grip_HY_2	1	0,4	0,4	1	0,4	0,4
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	6,3	0,4	0,4	6,3	0,4	0,4
20	Pushing with 2 hydraulic excavators	Push_HY_2	4	0,4	0,4	4	0,4	0,4
21	Pulling with 2 hydraulic excavators	Pull_HY_2	4	0,4	0,4	4	0,4	0,4
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	6,3	0,4	0,4	6,3	0,4	0,4
23	Mortising with 2 hydraulic excavators	Mort_HY_2	4	0,4	0,4	4	0,4	0,4
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	1,6	0,4	0,4	1,6	0,4	0,4
25	Cutting with 2 hydraulic excavators	Cut_HY_2	x			x		

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2				1	0,4	0,4			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	15,7	0,4	1	6,3	0,4	0,4	15,7	0,4	1
20	Pushing with 2 hydraulic excavators	Push_HY_2							4	0,4	1
21	Pulling with 2 hydraulic excavators	Pull_HY_2							4	0,4	1
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	6,3	0,4	1	6,3	0,4	0,4	6,3	0,4	1
23	Mortising with 2 hydraulic excavators	Mort_HY_2	15,7	0,4	1	6,3	0,4	0,4	15,7	0,4	1
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	4	0,4	1	1,6	0,4	0,4	4	0,4	1
25	Cutting with 2 hydraulic excavators	Cut_HY_2									

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
18	Gripping with 2 hydraulic excavators	Grip_HY_2	0,4	0,4	0,4			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2						
20	Pushing with 2 hydraulic excavators	Push_HY_2	1	0,4	0,4			
21	Pulling with 2 hydraulic excavators	Pull_HY_2	1	0,4	0,4	4	0,4	0,4
22	Ripping with 2 hydraulic excavators	Ripp_HY_2						
23	Mortising with 2 hydraulic excavators	Mort_HY_2						
24	Press-cutting with 2 hydraulic excavators	Press_HY_2						
25	Cutting with 2 hydraulic excavators	Cut_HY_2	0,4	0,4	0,4	1	0,4	0,4

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	1	0,4	0,4	1	0,4	0,4	1	0,4	0,4
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	6,3	0,4	0,4	6,3	0,4	0,4	6,3	0,4	0,4
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	4	0,4	0,4	4	0,4	0,4	4	0,4	0,4
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	4	0,4	0,4	4	0,4	0,4	4	0,4	0,4
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	6,3	0,4	0,4	6,3	0,4	0,4	6,3	0,4	0,4
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	4	0,4	0,4	4	0,4	0,4	4	0,4	0,4
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2		x			x			x	
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	1	0,4	0,4	1	0,4	0,4	1	0,4	0,4

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	1	0,4	0,4	1	0,4	0,4
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	6,3	0,4	0,4	6,3	0,4	0,4
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	4	0,4	0,4	4	0,4	0,4
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	4	0,4	0,4	4	0,4	0,4
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	6,3	0,4	0,4	6,3	0,4	0,4
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	4	0,4	0,4	4	0,4	0,4
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	1,6	0,4	0,4	1,6	0,4	0,4
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	x			x		
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	1	0,4	0,4	1	0,4	0,4

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2				1	0,4	0,4			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	15,7	0,4	1	6,3	0,4	0,4	15,7	0,4	1
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2							4	0,4	1
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2							4	0,4	1
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	6,3	0,4	1	6,3	0,4	0,4	6,3	0,4	1
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	15,7	0,4	1	6,3	0,4	0,4	15,7	0,4	1
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	4	0,4	1	1,6	0,4	0,4	4	0,4	1
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2									
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	4	0,4	1	1	0,4	0,4	4	0,4	1

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	0,4	0,4	0,4			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2						
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	1	0,4	0,4			
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	1	0,4	0,4	4	0,4	0,4
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2						
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2						
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2						
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	0,4	0,4	0,4	1	0,4	0,4
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	1	0,4	0,4	4	0,4	0,4

Specific hourly vibration emission level values of the single activity segments of each mode applied to different building materials, performed with basic unit/s of sizes sz >160 kW/40 t and in deconstruction heights above ground hg <=15 m

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	4	0,4	0,4	4	0,4	0,4	4	0,4	0,4
3	Pushing with 1 hydraulic excavator	Push_HY_1	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
4	Pulling with 1 hydraulic excavator	Pull_HY_1	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
6	Mortising with 1 hydraulic excavator	Mort_HY_1	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x			x	

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
1	Gripping with 1 hydraulic excavator	Grip_HY_1	0,4	0,4	0,4	0,4	0,4	0,4
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	4	0,4	0,4	4	0,4	0,4
3	Pushing with 1 hydraulic excavator	Push_HY_1	1,6	0,4	0,4	1,6	0,4	0,4
4	Pulling with 1 hydraulic excavator	Pull_HY_1	1,6	0,4	0,4	1,6	0,4	0,4
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	1,6	0,4	0,4	1,6	0,4	0,4
6	Mortising with 1 hydraulic excavator	Mort_HY_1	1,6	0,4	0,4	1,6	0,4	0,4
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	0,4	0,4	0,4	0,4	0,4	0,4
8	Cutting with 1 hydraulic excavator	Cut_HY_1	x			x		

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
1	Gripping with 1 hydraulic excavator	Grip_HY_1		x		0,4	0,4	0,4		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	15,7	0,4	0,4	4	0,4	0,4	15,7	0,4	0,4
3	Pushing with 1 hydraulic excavator	Push_HY_1		x			x		1,6	0,4	0,4
4	Pulling with 1 hydraulic excavator	Pull_HY_1		x			x		1,6	0,4	0,4
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
6	Mortising with 1 hydraulic excavator	Mort_HY_1	15,7	0,4	0,4	4	0,4	0,4	15,7	0,4	0,4
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	1,6	0,4	0,4	0,4	0,4	0,4	1,6	0,4	0,4
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x			x	

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	0,3	0,3	0,3		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1		x			x	
3	Pushing with 1 hydraulic excavator	Push_HY_1	0,3	0,3	0,3			
4	Pulling with 1 hydraulic excavator	Pull_HY_1	0,3	0,3	0,3	1,6	0,4	0,4
5	Ripping with 1 hydraulic excavator	Ripp_HY_1		x			x	
6	Mortising with 1 hydraulic excavator	Mort_HY_1		x			x	
7	Press-cutting with 1 hydraulic excavator	Press_HY_1		x			x	
8	Cutting with 1 hydraulic excavator	Cut_HY_1	0,3	0,3	0,3	0,4	0,4	0,4

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	4	0,4	0,4	4	0,4	0,4	4	0,4	0,4
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	x			x			x		
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	1	0,4	0,4	1	0,4	0,4	1	0,4	0,4

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	0,4	0,4	0,4	0,4	0,4	0,4
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	4	0,4	0,4	4	0,4	0,4
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	1,6	0,4	0,4	1,6	0,4	0,4
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	1,6	0,4	0,4	1,6	0,4	0,4
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	1,6	0,4	0,4	1,6	0,4	0,4
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	1,6	0,4	0,4	1,6	0,4	0,4
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	0,4	0,4	0,4	0,4	0,4	0,4
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	1	0,4	0,4	1	0,4	0,4

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1		x		0,4	0,4	0,4		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	15,7	0,4	0,4	4	0,4	0,4	15,7	0,4	0,4
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1		x			x		1,6	0,4	0,4
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1		x			x		1,6	0,4	0,4
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	1,6	0,4	0,4	1,6	0,4	0,4	1,6	0,4	0,4
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	15,7	0,4	0,4	4	0,4	0,4	15,7	0,4	0,4
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	1,6	0,4	0,4	0,4	0,4	0,4	1,6	0,4	0,4
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	1,6	0,4	0,4	1	0,4	0,4	1,6	0,4	0,4

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	0,3	0,3	0,3	x		
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	x			x		
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	0,3	0,3	0,3	x		
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	0,3	0,3	0,3	1,6	0,4	0,4
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	x			x		
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	x			x		
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	x			x		
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	0,3	0,3	0,3	0,4	0,4	0,4
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	1	0,3	0,3	1,6	0,4	0,4

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
18	Gripping with 2 hydraulic excavators	Grip_HY_2	1	1	1	1	1	1	1	1	1
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	6,3	1	1	6,3	1	1	6,3	1	1
20	Pushing with 2 hydraulic excavators	Push_HY_2	4	1	1	4	1	1	4	1	1
21	Pulling with 2 hydraulic excavators	Pull_HY_2	4	1	1	4	1	1	4	1	1
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	4	1	1	4	1	1	4	1	1
23	Mortising with 2 hydraulic excavators	Mort_HY_2	4	1	1	4	1	1	4	1	1
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	1	1	1	1	1	1	1	1	1
25	Cutting with 2 hydraulic excavators	Cut_HY_2	x			x			x		

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2	1	1	1	1	1	1
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	6,3	1	1	6,3	1	1
20	Pushing with 2 hydraulic excavators	Push_HY_2	4	1	1	4	1	1
21	Pulling with 2 hydraulic excavators	Pull_HY_2	4	1	1	4	1	1
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	4	1	1	4	1	1
23	Mortising with 2 hydraulic excavators	Mort_HY_2	4	1	1	4	1	1
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	1	1	1	1	1	1
25	Cutting with 2 hydraulic excavators	Cut_HY_2	x			x		

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2				1	1	1			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	15,7	1	1	6,3	1	1	15,7	1	1
20	Pushing with 2 hydraulic excavators	Push_HY_2							4	1	1
21	Pulling with 2 hydraulic excavators	Pull_HY_2							4	1	1
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	4	1	1	4	1	1	4	1	1
23	Mortising with 2 hydraulic excavators	Mort_HY_2	15,7	1	1	6,3	1	1	15,7	1	1
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	4	1	1	1	1	1	4	1	1
25	Cutting with 2 hydraulic excavators	Cut_HY_2									

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
18	Gripping with 2 hydraulic excavators	Grip_HY_2	0,4	0,4	0,4			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2						
20	Pushing with 2 hydraulic excavators	Push_HY_2	0,4	0,4	0,4			
21	Pulling with 2 hydraulic excavators	Pull_HY_2	0,4	0,4	0,4	4	1	1
22	Ripping with 2 hydraulic excavators	Ripp_HY_2						
23	Mortising with 2 hydraulic excavators	Mort_HY_2						
24	Press-cutting with 2 hydraulic excavators	Press_HY_2						
25	Cutting with 2 hydraulic excavators	Cut_HY_2	0,4	0,4	0,4	1	1	1

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	1	1	1	1	1	1	1	1	1
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	6,3	1	1	6,3	1	1	6,3	1	1
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	4	1	1	4	1	1	4	1	1
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	4	1	1	4	1	1	4	1	1
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	4	1	1	4	1	1	4	1	1
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	4	1	1	4	1	1	4	1	1
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	1	1	1	1	1	1	1	1	1
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2		x			x			x	
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	1,6	1	1	1,6	1	1	1,6	1	1

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	1	1	1	1	1	1
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	6,3	1	1	6,3	1	1
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	4	1	1	4	1	1
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	4	1	1	4	1	1
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	4	1	1	4	1	1
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	4	1	1	4	1	1
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	1	1	1	1	1	1
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	x			x		
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	1,6	1	1	1,6	1	1

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2				1	1	1			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	15,7	1	1	6,3	1	1	15,7	1	1
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2							4	1	1
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2							4	1	1
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	4	1	1	4	1	1	4	1	1
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	15,7	1	1	6,3	1	1	15,7	1	1
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	4	1	1	1	1	1	4	1	1
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2									
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	4	1	1	1,6	1	1	4	1	1

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	0,4	0,4	0,4			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2						
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	0,4	0,4	0,4			
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	0,4	0,4	0,4	4	1	1
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2						
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2						
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2						
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	0,4	0,4	0,4	1	1	1
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	1,6	0,4	0,4	4	1	1

Specific hourly vibration emission level values of the single activity segments of each mode applied to different building materials, performed with basic unit/s of sizes sz >160 kW/40 t and in deconstruction heights above ground hg >15 m

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	6,3	0,4	0,4	6,3	0,4	0,4	6,3	0,4	0,4
3	Pushing with 1 hydraulic excavator	Push_HY_1	4	0,4	0,4	4	0,4	0,4	4	0,4	0,4
4	Pulling with 1 hydraulic excavator	Pull_HY_1	4	0,4	0,4	4	0,4	0,4	4	0,4	0,4
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	4	0,4	0,4	4	0,4	0,4	4	0,4	0,4
6	Mortising with 1 hydraulic excavator	Mort_HY_1	4	0,4	0,4	4	0,4	0,4	4	0,4	0,4
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	1	0,4	0,4	1	0,4	0,4	1	0,4	0,4
8	Cutting with 1 hydraulic excavator	Cut_HY_1	x			x			x		

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	0,4	0,4	0,4	0,4	0,4	0,4
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	6,3	0,4	0,4	6,3	0,4	0,4
3	Pushing with 1 hydraulic excavator	Push_HY_1	4	0,4	0,4	4	0,4	0,4
4	Pulling with 1 hydraulic excavator	Pull_HY_1	4	0,4	0,4	4	0,4	0,4
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	4	0,4	0,4	4	0,4	0,4
6	Mortising with 1 hydraulic excavator	Mort_HY_1	4	0,4	0,4	4	0,4	0,4
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	1	0,4	0,4	1	0,4	0,4
8	Cutting with 1 hydraulic excavator	Cut_HY_1	x			x		

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1		x		0,4	0,4	0,4		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1	15,7	0,4	0,4	6,3	0,4	0,4	15,7	0,4	0,4
3	Pushing with 1 hydraulic excavator	Push_HY_1		x			x		4	0,4	0,4
4	Pulling with 1 hydraulic excavator	Pull_HY_1		x			x		4	0,4	0,4
5	Ripping with 1 hydraulic excavator	Ripp_HY_1	6,3	0,4	0,4	4	0,4	0,4	6,3	0,4	0,4
6	Mortising with 1 hydraulic excavator	Mort_HY_1	15,7	0,4	0,4	6,3	0,4	0,4	15,7	0,4	0,4
7	Press-cutting with 1 hydraulic excavator	Press_HY_1	1,6	0,4	0,4	1	0,4	0,4	1,6	0,4	0,4
8	Cutting with 1 hydraulic excavator	Cut_HY_1		x			x			x	

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
1	Gripping with 1 hydraulic excavator	Grip_HY_1	0,4	0,3	0,3		x	
2	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 hydraulic excavator)	Wreck_CW_HY_1		x			x	
3	Pushing with 1 hydraulic excavator	Push_HY_1	1	0,3	0,3			
4	Pulling with 1 hydraulic excavator	Pull_HY_1	0,4	0,3	0,3	4	0,4	0,4
5	Ripping with 1 hydraulic excavator	Ripp_HY_1		x			x	
6	Mortising with 1 hydraulic excavator	Mort_HY_1		x			x	
7	Press-cutting with 1 hydraulic excavator	Press_HY_1		x			x	
8	Cutting with 1 hydraulic excavator	Cut_HY_1	0,4	0,3	0,3	0,4	0,4	0,4

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	6,3	0,4	0,4	6,3	0,4	0,4	6,3	0,4	0,4
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	4	0,4	0,4	4	0,4	0,4	4	0,4	0,4
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	4	0,4	0,4	4	0,4	0,4	4	0,4	0,4
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	4	0,4	0,4	4	0,4	0,4	4	0,4	0,4
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	4	0,4	0,4	4	0,4	0,4	4	0,4	0,4
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	1	0,4	0,4	1	0,4	0,4	1	0,4	0,4
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	x			x			x		
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	1	0,4	0,4	1	0,4	0,4	1	0,4	0,4

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	ψ^{e}_{d}(m,b,sz,hg)	ψ^{e}_{o}(m,b,sz,hg)	ψ^{e}_{q}(m,b,sz,hg)	ψ^{e}_{d}(m,b,sz,hg)	ψ^{e}_{o}(m,b,sz,hg)	ψ^{e}_{q}(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	0,4	0,4	0,4	0,4	0,4	0,4
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	6,3	0,4	0,4	6,3	0,4	0,4
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	4	0,4	0,4	4	0,4	0,4
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	4	0,4	0,4	4	0,4	0,4
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	4	0,4	0,4	4	0,4	0,4
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	4	0,4	0,4	4	0,4	0,4
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	1	0,4	0,4	1	0,4	0,4
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	1	0,4	0,4	1	0,4	0,4

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1		x		0,4	0,4	0,4		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1	15,7	0,4	0,4	6,3	0,4	0,4	15,7	0,4	0,4
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1		x			x		4	0,4	0,4
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1		x			x		4	0,4	0,4
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1	6,3	0,4	0,4	4	0,4	0,4	6,3	0,4	0,4
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1	15,7	0,4	0,4	6,3	0,4	0,4	15,7	0,4	0,4
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1	1,6	0,4	0,4	1	0,4	0,4	1,6	0,4	0,4
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1		x			x			x	
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	1,6	0,4	0,4	1	0,4	0,4	1,6	0,4	0,4

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
9	Gripping with 1 longfront hydraulic excavator	Grip_LT_1	0,4	0,3	0,3		x	
10	Wrecking with 1 cable-operated excavator (material sorting and crushing with 1 longfront hydraulic excavator)	Wreck_CW_LT_1		x			x	
11	Pushing with 1 longfront hydraulic excavator	Push_LT_1	1	0,3	0,3		x	
12	Pulling with 1 longfront hydraulic excavator	Pull_LT_1	0,4	0,3	0,3	4	0,4	0,4
13	Ripping with 1 longfront hydraulic excavator	Ripp_LT_1		x			x	
14	Mortising with 1 longfront hydraulic excavator	Mort_LT_1		x			x	
15	Press-cutting with 1 longfront hydraulic excavator	Press_LT_1		x			x	
16	Cutting with 1 longfront hydraulic excavator	Cut_LT_1	0,4	0,3	0,3	0,4	0,4	0,4
17	Deconstruction by hand with 2 hand tools and 1 compressor	Dec_HA_1	1	0,3	0,3	1,6	0,4	0,4

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
18	Gripping with 2 hydraulic excavators	Grip_HY_2	1	1	1	1	1	1	1	1	1
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	15,7	1	1	15,7	1	1	15,7	1	1
20	Pushing with 2 hydraulic excavators	Push_HY_2	6,3	1	1	6,3	1	1	6,3	1	1
21	Pulling with 2 hydraulic excavators	Pull_HY_2	6,3	1	1	6,3	1	1	6,3	1	1
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	6,3	1	1	6,3	1	1	6,3	1	1
23	Mortising with 2 hydraulic excavators	Mort_HY_2	6,3	1	1	6,3	1	1	6,3	1	1
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	1,6	1	1	1,6	1	1	1,6	1	1
25	Cutting with 2 hydraulic excavators	Cut_HY_2	x			x			x		

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
18	Gripping with 2 hydraulic excavators	Grip_HY_2	1	1	1	1	1	1
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	15,7	1	1	15,7	1	1
20	Pushing with 2 hydraulic excavators	Push_HY_2	6,3	1	1	6,3	1	1
21	Pulling with 2 hydraulic excavators	Pull_HY_2	6,3	1	1	6,3	1	1
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	6,3	1	1	6,3	1	1
23	Mortising with 2 hydraulic excavators	Mort_HY_2	6,3	1	1	6,3	1	1
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	1,6	1	1	1,6	1	1
25	Cutting with 2 hydraulic excavators	Cut_HY_2	x			x		

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\psi^{e}_{d}(m,b,sz,hg)$	$\psi^{e}_{o}(m,b,sz,hg)$	$\psi^{e}_{q}(m,b,sz,hg)$	$\psi^{e}_{d}(m,b,sz,hg)$	$\psi^{e}_{o}(m,b,sz,hg)$	$\psi^{e}_{q}(m,b,sz,hg)$	$\psi^{e}_{d}(m,b,sz,hg)$	$\psi^{e}_{o}(m,b,sz,hg)$	$\psi^{e}_{q}(m,b,sz,hg)$
18	Gripping with 2 hydraulic excavators	Grip_HY_2				1	1	1			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2	15,7	1	1	15,7	1	1	15,7	1	1
20	Pushing with 2 hydraulic excavators	Push_HY_2							6,3	1	1
21	Pulling with 2 hydraulic excavators	Pull_HY_2							6,3	1	1
22	Ripping with 2 hydraulic excavators	Ripp_HY_2	15,7	1	1	6,3	1	1	15,7	1	1
23	Mortising with 2 hydraulic excavators	Mort_HY_2	15,7	1	1	15,7	1	1	15,7	1	1
24	Press-cutting with 2 hydraulic excavators	Press_HY_2	4	1	1	1,6	1	1	4	1	1
25	Cutting with 2 hydraulic excavators	Cut_HY_2									

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
18	Gripping with 2 hydraulic excavators	Grip_HY_2	1	0,4	0,4			
19	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 hydraulic excavators)	Wreck_CW_HY_2						
20	Pushing with 2 hydraulic excavators	Push_HY_2	1,6	0,4	0,4			
21	Pulling with 2 hydraulic excavators	Pull_HY_2	1	0,4	0,4	6,3	1	1
22	Ripping with 2 hydraulic excavators	Ripp_HY_2						
23	Mortising with 2 hydraulic excavators	Mort_HY_2						
24	Press-cutting with 2 hydraulic excavators	Press_HY_2						
25	Cutting with 2 hydraulic excavators	Cut_HY_2	1	0,4	0,4	1	1	1

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	1			2			3		
		Name	Natural stone			Brick			Sand lime brick		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	1	1	1	1	1	1	1	1	1
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	15,7	1	1	15,7	1	1	15,7	1	1
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	6,3	1	1	6,3	1	1	6,3	1	1
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	6,3	1	1	6,3	1	1	6,3	1	1
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	6,3	1	1	6,3	1	1	6,3	1	1
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	6,3	1	1	6,3	1	1	6,3	1	1
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	1,6	1	1	1,6	1	1	1,6	1	1
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2		x			x			x	
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	1,6	1	1	1,6	1	1	1,6	1	1

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	4			5		
		Name	Aerated concrete			Precast concrete block		
Activity mode (m)								
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	1	1	1	1	1	1
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	15,7	1	1	15,7	1	1
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	6,3	1	1	6,3	1	1
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	6,3	1	1	6,3	1	1
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	6,3	1	1	6,3	1	1
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	6,3	1	1	6,3	1	1
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	1,6	1	1	1,6	1	1
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	x			x		
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	1,6	1	1	1,6	1	1

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]								
Materials (b)		ID_b	6			7			8		
		Name	Reinforced concrete			Concrete			Precast reinforced concrete unit		
Activity mode (m)											
#	Description	Abbreviation	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$	$\psi^e_d(m,b,sz,hg)$	$\psi^e_o(m,b,sz,hg)$	$\psi^e_q(m,b,sz,hg)$
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2				1	1	1			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2	15,7	1	1	15,7	1	1	15,7	1	1
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2							6,3	1	1
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2							6,3	1	1
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2	15,7	1	1	6,3	1	1	15,7	1	1
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2	15,7	1	1	15,7	1	1	15,7	1	1
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2	4	1	1	1,6	1	1	4	1	1
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2									
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	4	1	1	1,6	1	1	4	1	1

			Specific hourly values of average vibration emission levels of the single activity segments [(mm/s)/h]					
Materials (b)		ID_b	9			10		
		Name	Wood			Steel*		
Activity mode (m)								
#	Description	Abbreviation	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)	ψ^e_d(m,b,sz,hg)	ψ^e_o(m,b,sz,hg)	ψ^e_q(m,b,sz,hg)
26	Gripping with 2 longfront hydraulic excavators	Grip_LT_2	1	0,4	0,4			
27	Wrecking with 2 cable-operated excavators (material sorting and crushing with 2 longfront hydraulic excavators)	Wreck_CW_LT_2						
28	Pushing with 2 longfront hydraulic excavators	Push_LT_2	1,6	0,4	0,4			
29	Pulling with 2 longfront hydraulic excavators	Pull_LT_2	1	0,4	0,4	6,3	1	1
30	Ripping with 2 longfront hydraulic excavators	Ripp_LT_2						
31	Mortising with 2 longfront hydraulic excavators	Mort_LT_2						
32	Press-cutting with 2 longfront hydraulic excavators	Press_LT_2						
33	Cutting with 2 longfront hydraulic excavators	Cut_LT_2	1	0,4	0,4	1	1	1
34	Deconstruction by hand with 4 hand tools and 2 compressors	Dec_HA_2	1,6	0,4	0,4	4	1	1

A5: Further (selected) results of the expert consultation/expert survey

Explanations:

Dark grey cells: not suitable/not relevant for the material

A5-1 Response analysis due to the evaluation categories of average pre-separation and pre-crushing time expenditures of deconstruction-method- and building-material-type-combinations

Response analysis with **arithmetic means and the standard deviations** of the evaluation categories of average pre-separation and pre-crushing time expenditures for $1m^3$ material (1, 2, 3, 4) of all questions/of each combination of deconstruction method and building material type

Arithmetic means and the standard deviations of the evaluation categories of average pre-separation time expenditures for 1m3 material (1, 2, 3, 4) of each combination of deconstruction method and building material type

Material/ Method	ID_b (see Table 4-3		1	2	3	4	5	6	7	8	9	10
# (see Table 2-2)	Name		Natural stone	Brick	Sand lime brick	Aerated concrete	Precast concrete block	Reinforced concrete	Concrete	Precast reinforced concrete unit	Wood	Steel
1	Gripping	Arithmethic mean	1.9	2	2	2.3	2		2		2.1	
		Standard deviation	0.5	0.6	0.6	0.9	0.6		0.6		0.7	
2	Wrecking	Arithmethic mean	2	2	2.5	2.5	2	2	2	2		
		Standard deviation	1.4	1.4	2.1	2.1	1.4	1.4	1.4	1.4		
3	Pushing	Arithmethic mean	2.8	2.9	2.9	3	2.8			2.4	3.1	
		Standard deviation	1	0.9	0.9	0.9	0.9			1	1	
4	Pulling	Arithmethic mean	2.2	2.5	2.6	2.7	2.3			2.2	2.5	2.3
		Standard deviation	0.8	0.8	1.1	1	0.8			0.8	0.8	0.5
5	Ripping	Arithmethic mean	2.3	3	3	3	2.3	2.7	2.3	2.7		
		Standard deviation	1.5	1.7	1.7	1.7	1.5	1.5	1.5	1.5		

Material/ Method	ID_b (see Table 4-3		1	2	3	4	5	6	7	8	9	10
# (see Table 2-2)	Name		Natural stone	Brick	Sand lime brick	Aerated concrete	Precast concrete block	Reinforced concrete	Concrete	Precast reinforced concrete unit	Wood	Steel
6	Mortising	Arithmethic mean	1.7	1.7	1.7	1.8	1.8	1.8	1.8	1.8		
		Standard deviation	0.8	0.8	0.8	0.9	0.9	0.8	0.9	0.8		
7	Press-cutting	Arithmethic mean	1	1	1	1	1	1	1	1		
		Standard deviation	-	-	-	-	-	0	-	0		
8	Cutting	Arithmethic mean									2.1	1.8
		Standard deviation									0.9	0.4
19	Deconstruction by hand	Arithmethic mean	1.7	1.7	1.7	1.7	1.7	2	1.7	2	2.3	1.8
		Standard deviation	0.6	0.6	0.6	0.6	0.6	0.8	0.6	0.8	1	0.5
	Material separation	Arithmethic mean	2.3	2.4	2.4	2.5	2.4	1.8	2.4	1.8	2.3	1.8
		Standard deviation	1	0.9	1	0.9	0.9	0.6	0.9	0.6	1	0.4
	Material crushing	Arithmethic mean	1.7	1.9	1.8	2.1	2	1.9	2	1.9	2.1	2
		Standard deviation	0.5	0.4	0.4	0.7	0.6	0.8	0.6	0.8	0.7	0

Arithmetic means and the standard deviations of the evaluation categories of average pre-crushing time expenditures for 1m3 material (1, 2, 3, 4) of each combination of deconstruction method and building material type

Material/ Method	ID_b (see Table 4-3		1	2	3	4	5	6	7	8	9	10
# (see Table 2-2)	Name		Natural stone	Brick	Sand lime brick	Aerated concrete	Precast concrete block	Reinforced concrete	Concrete	Precast reinforced concrete unit	Wood	Steel
1	Gripping	Arithmethic mean	**2.1**	**2**	**2**	**1.9**	**2.1**		**2.1**		**2.1**	
		Standard deviation	**0.6**	**0.7**	**0.6**	**0.8**	**0.7**		**0.7**		**0.7**	
2	Wrecking	Arithmethic mean	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**	**2**	**1.5**	**2**		
		Standard deviation	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**0**	**0.7**	**0**		
3	Pushing	Arithmethic mean	**2.3**	**2.3**	**2.3**	**2**	**2.4**			**2.9**	**2.3**	
		Standard deviation	**0.7**	**0.7**	**0.7**	**0.9**	**0.9**			**0.6**	**0.5**	
4	Pulling	Arithmethic mean	**2**	**2.2**	**2**	**1.5**	**2**			**2.8**	**2.4**	**2.6**
		Standard deviation	**0.8**	**0.8**	**0.8**	**1**	**0.8**			**0.4**	**0.5**	**0.5**
5	Ripping	Arithmethic mean	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**	**2.3**	**1.5**	**2.3**		
		Standard deviation	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**	**0.6**	**0.7**	**0.6**		

Material/ Method	ID_b (see Table 4-3		1	2	3	4	5	6	7	8	9	10
# (see Table 2-2)	Name		Natural stone	Brick	Sand lime brick	Aerated concrete	Precast concrete block	Reinforced concrete	Concrete	Precast reinforced concrete unit	Wood	Steel
6	Mortising	Arithmethic mean	1.9	1.9	1.9	1.8	1.8	2	1.8	2		
		Standard deviation	0.5	0.5	0.5	0.6	0.4	0.7	0.4	0.7		
7	Press-cutting	Arithmethic mean	1	1	1	1	1	1.5	1	1.5		
		Standard deviation	-	-	-	-	-	0.7	-	0.7		
8	Cutting	Arithmethic mean									2	1.8
		Standard deviation									0.8	0.4
19	Deconstructi on by hand	Arithmethic mean	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
		Standard deviation	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
	Material separation	Arithmethic mean	2	2.1	2.1	2.1	2.1	2.7	2.1	2.7	2.4	2
		Standard deviation	0.8	0.7	0.7	0.9	0.7	0.9	0.7	0.9	0.5	0.6
	Material crushing	Arithmethic mean	2.1	2.1	2.1	1.9	2	2.3	2	2.3	2.3	2.4
		Standard deviation	0.7	0.7	0.7	0.9	0.6	0.9	0.6	0.9	0.5	0.5

A5-2 Response analysis due to the evaluation categories of average emission levels of deconstruction-method- and building-material-type-combinations

Response analysis with **median and quantiles** of the evaluation categories of average noise, dust and vibration emission levels (0, 1, 2, 3, 4) of all questions/of each combination of deconstruction method and building material type.

Median and quantiles of the evaluation categories of average noise emission levels (0, 1, 2, 3, 4) of each combination of deconstruction method and building material type

Material/ Method	ID_b (see Table 4-3)		1	2	3	4	5	6	7	8	9	10
# (see Table 2-2)	Name		Natural stone	Brick	Sand lime brick	Aerated concrete	Precast concrete block	Reinforced concrete	Concrete	Precast reinforced concrete unit	Wood	Steel
1	Gripping	Median	**1**	**1.5**	**1**	**1**	**1.5**		**1.5**		**1**	
		percentile 25	1	1	1	1	1		1		0	
		percentile 50	1	1.5	1	1	1.5		1.5		1	
		percentile 75	2	2	2	2	2		2		1	
2	Wrecking	Median	**1**	**1**	**1**	**1**	**1**	**2**	**1**	**2**		
		percentile 25	1	1	1	1	1	1	1	1		
		percentile 50	1	1	1	1	1	2	1	2		
		percentile 75	1	1	1	1	1	-	1	-		
3	Pushing	Median	**2**	**2**	**2**	**2**	**2**			**2**	**1.5**	
		percentile 25	1	1	1	1	1			1.5	0.75	
		percentile 50	2	2	2	2	2			2	1.5	
		percentile 75	2.5	2.5	2.5	2.5	2.5			3	2	
4	Pulling	Median	**1**	**1**	**1**	**1**	**1**			**2**	**1**	**1**
		percentile 25	1	1	1	1	1			1	0.75	0.75
		percentile 50	1	1	1	1	1			2	1	1
		percentile 75	2	2	2	2	2			2.5	2	2
5	Ripping	Median	**1.5**	**1.5**	**1.5**	**1.5**	**1.5**	**2**	**1.5**	**2**		
		percentile 25	1	1	1	1	1	1	1	1		
		percentile 50	1.5	1.5	1.5	1.5	1.5	2	1.5	2		
		percentile 75	-	-	-	-	-	-	-	-		

Material/ Method	ID_b (see Table 4-3		1	2	3	4	5	6	7	8	9	10
# (see Table 2-2)	Name		Natural stone	Brick	Sand lime brick	Aerated concrete	Precast concrete block	Reinforced concrete	Concrete	Precast reinforced concrete unit	Wood	Steel
6	Mortising	Median	**3**	**2.5**	**2.5**	**3**	**3**	**3**	**3**	**3**		
		percentile 25	2	2	2	2	2	3	2	3		
		percentile 50	3	2.5	2.5	3	3	3	3	3		
		percentile 75	3	3	3	3	3	3	3	3		
7	Press-cutting	Median	**1**	**1**	**1**	**1**	**1**	**2**	**1**	**2**		
		percentile 25	1	1	1	1	1	2	1	2		
		percentile 50	1	1	1	1	1	2	1	2		
		percentile 75	1	1	1	1	1	2	1	2		
8	Cutting	Median									**1**	**2**
		percentile 25									1	1
		percentile 50									1	2
		percentile 75									2	2
19	Deconstruction by hand	Median	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**2**
		percentile 25	3	3	3	3	3	3	3	3	2	1.25
		percentile 50	3	3	3	3	3	3	3	3	3	2
		percentile 75	3	3	3	3	3	3	3	3	-	2.75
	Material separation	Median	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
		percentile 25	0.75	0.75	0.75	0.75	0.75	1	0.75	1	0	0
		percentile 50	1	1	1	1	1	1	1	1	1	1
		percentile 75	1	1	1	1	1	2	1	2	2	2
	Material crushing	Median	**2**	**2**	**2**	**2**	**2**	**3**	**2**	**3**	**1**	**2**
		percentile 25	1	1	1	2	2	2	2	2	1	1
		percentile 50	2	2	2	2	2	3	2	3	1	2
		percentile 75	2	2	2	2	2	3	2	3	2.25	2

Median and quantiles of the evaluation categories of average dust emission levels (0, 1, 2, 3, 4) of each combination of deconstruction method and building material type

Material/ Method	ID_b (see Table 4-3		1	2	3	4	5	6	7	8	9	10
# (see Table 2-2)	Name		Natural stone	Brick	Sand lime brick	Aerated concrete	Precast concrete block	Reinforced concrete	Concrete	Precast reinforced concrete unit	Wood	Steel
1	Gripping	Median	**2**	**2**	**2**	**2**	**2**		**2**		**1**	
		percentile 25	0,75	1	1,75	2	1,75		1,75		0	
		percentile 50	2	2	2	2	2		2		1	
		percentile 75	3	2,25	2,25	3	2,25		2,25		1	
2	Wrecking	Median	**3**	**3**	**3**	**3**	**3**	**2,5**	**3**	**2,5**		
		percentile 25	2	2	2	2	2	2	2	2		
		percentile 50	3	3	3	3	3	2,5	3	2,5		
		percentile 75	-	-	-	-	-	-	-			
3	Pushing	Median	**3**	**3**	**3**	**3**	**3**			**2**	**1**	
		percentile 25	2	2	2	2	2			1,5	0,75	
		percentile 50	3	3	3	3	3			2	1	
		percentile 75	3,5	3,5	3,5	3,5	3,5			3	2	
4	Pulling	Median	**2**	**2**	**2**	**2**	**2**			**1**	**1**	**0**
		percentile 25	0,5	1	1	1,5	1			1	0	0
		percentile 50	2	2	2	2	2			1	1	0
		percentile 75	3	3	3	3	3			2	2	0,25
5	Ripping	Median	**3,5**	**3,5**	**3,5**	**3,5**	**3,5**	**2**	**3,5**	**2**		
		percentile 25	3	3	3	3	3	2	3	2		
		percentile 50	3,5	3,5	3,5	3,5	3,5	2	3,5	2		
		percentile 75	-	-	-	-	-	-	-	-		

Material/ Method	ID_b (see Table 4-3		1	2	3	4	5	6	7	8	9	10
# (see Table 2-2)	Name		Natural stone	Brick	Sand lime brick	Aerated concrete	Precast concrete block	Reinforced concrete	Concrete	Precast reinforced concrete unit	Wood	Steel
6	Mortising	Median	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**		
		percentile 25	1	1	1	1	1	1	1	1		
		percentile 50	2	2	2	2	2	2	2	2		
		percentile 75	3	3	3	3	3	3	3	3		
7	Press-cutting	Median	**3**	**3**	**3**	**3**	**3**	**2,5**	**3**	**2,5**		
		percentile 25	3	3	3	3	3	2	3	2		
		percentile 50	3	3	3	3	3	2,5	3	2,5		
		percentile 75	3	3	3	3	3	-	3	-		
8	Cutting	Median									**0,5**	**0**
		percentile 25									0	0
		percentile 50									0,5	0
		percentile 75									1	1
19	Deconstruction by hand	Median	**2**	**2**	**2**	**2**	**2**	**1,5**	**2**	**1,5**	**1**	**1**
		percentile 25	1	1	1	1	1	1	1	1	0	0
		percentile 50	2	2	2	2	2	1,5	2	1,5	1	1
		percentile 75	-	-	-	-	-	2	-	2	-	-
	Material separation	Median	**1**	**1**	**1**	**2**	**1**	**1**	**1**	**1**	**1**	**0**
		percentile 25	0,5	1	1	1	1	1	1	1	0	0
		percentile 50	1	1	1	2	1	1	1	1	1	0
		percentile 75	2	2	2	2	2	2	2	2	1,25	1
	Material crushing	Median	**3**	**2,5**	**2,5**	**2,5**	**2,5**	**2**	**2,5**	**2**	**1**	**0**
		percentile 25	1,5	1,75	1,75	2	1,75	1,25	1,75	1,25	1	0
		percentile 50	3	2,5	2,5	2,5	2,5	2	2,5	2	1	0
		percentile 75	3	3	3	3	3	2	3	2	2	0,75

Median and quantiles of the evaluation categories of average vibration emission levels (0, 1, 2, 3, 4) of each combination of deconstruction method and building material type

Material/ Method	ID_b (see Table 4-3		1	2	3	4	5	6	7	8	9	10
# (see Table 2-2)	Name		Natural stone	Brick	Sand lime brick	Aerated concrete	Precast concrete block	Reinforced concrete	Concrete	Precast reinforced concrete unit	Wood	Steel
1	Gripping	Median	**1**	**1**	**1**	**1**	**1**		**1**		**0**	
		percentile 25	0	0	0	0	0		0		0	
		percentile 50	1	1	1	1	1		1		0	
		percentile 75	2	2	2	1	2		2		1	
2	Wrecking	Median	**2**	**2**	**2**	**2**	**2**	**3**	**2**	**3**		
		percentile 25	1	1	1	1	1	2	1	2		
		percentile 50	2	2	2	2	2	3	2	3		
		percentile 75	-	-	-	-	-	-	-	-		
3	Pushing	Median	**2**	**2**	**2**	**2**	**2**			**3**	**1**	
		percentile 25	2	2	2	2	2			1,5	0	
		percentile 50	2	2	2	2	2			3	1	
		percentile 75	3	3	3	3	3			3	2,5	
4	Pulling	Median	**2**	**2**	**2**	**2**	**2**			**2**	**0**	**1**
		percentile 25	0,5	0,5	0,5	0,5	0,5			1,5	0	0
		percentile 50	2	2	2	2	2			2	0	1
		percentile 75	2	2	2	2	2			3	1,5	1,5
5	Ripping	Median	**1,5**	**1,5**	**1,5**	**1,5**	**1,5**	**3**	**1,5**	**3**		
		percentile 25	1	1	1	1	1	2	1	2		
		percentile 50	1,5	1,5	1,5	1,5	1,5	3	1,5	3		
		percentile 75	-	-	-	-	-	-	-	-		

6	Mortising	Median	**2**	**2**	**2**	**2**	**2**	**3**	**2**	**3**		
		percentile 25	0	0	0	0,75	1	2	1	2		
		percentile 50	2	2	2	2	2	3	2	3		
		percentile 75	3	3	3	3,25	3	4	3	4		
7	Press-cutting	Median	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**		
		percentile 25	2	2	2	2	2	1	2	1		
		percentile 50	2	2	2	2	2	2	2	2		
		percentile 75	2	2	2	2	2	-	2	-		
8	Cutting	Median									**0,5**	**1**
		percentile 25									0	0
		percentile 50									0,5	1
		percentile 75									1	1
19	Deconstruction by hand	Median	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
		percentile 25	0	0	0	0	0	0	0	0	0	0
		percentile 50	1	1	1	1	1	1	1	1	1	1
		percentile 75	-	-	-	-	-	-	-	-	-	-
	Material separation	Median	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0,5**	**1**
		percentile 25	0	0	0	0	0	0	0	0	0	0
		percentile 50	1	1	1	1	1	1	1	1	0,5	1
		percentile 75	1	1	1	1	1	2	1	2	1	2
	Material crushing	Median	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**1**	**1**
		percentile 25	1	1	1	1	1	1	1	1	0	0
		percentile 50	2	2	2	2	2	2	2	2	1	1
		percentile 75	2	2	2	2	2	3	2	3	1	1