Building-level exposed asset values for Germany: Supplement

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S1 Introduction: Cost Bases explanation

Replacement costs (RC) represent the amount required to replace an asset with a new one, also defined as (re-)construction costs. These include the cost of rebuilding after a damage event, factoring in the prices of construction materials and associated expenditures. However, Daniell and Wenzel [2014] argue that *reconstruction costs* should be viewed separately as they can sometimes be higher than replacement costs due to additional laws and regulations introduced as part of the reconstruction process [Daniell and Wenzel, 2014, Daniell, 2014]. *Depreciated costs*, sometimes referred to as *actual worth* or *repair costs* reflect the actual value of an asset at the time of assessment [Merz et al., 2010, Jongman et al., 2012, Daniell and Wenzel, 2014], representing the economic value of properties based on their pre-damage conditions [Gerl et al., 2016]. Depreciated costs are often defined as *net asset value* (NAV) which is usually derived from national accounting systems where fixed asset stocks are recorded. In Germany, these calculations adhere to the *perpetual inventory method* (PIM) [Schmalwasser and Schidlowski, 2006], where the stock of fixed assets is determined by annually documenting incoming and outgoing assets. In this framework, *gross fixed assets* encompass all produced assets that are utilized repeatedly or continuously in production processes for over a year, without accounting for depreciation. These include both tangible and intangible assets. Tangible fixed assets cover machinery, equipment, residential and non-residential buildings, and cultivated assets. Intangible fixed assets include mineral exploration, computer software, large databases, and original works such as entertainment, literary, or artistic creations [Schmalwasser and Schidlowski, 2006]. For *net fixed assets*, a depreciation rate is applied to account for the reduction in value over time, considering the average lifespan of the asset which is defined by many factors such as the quality of construction or the durability of building materials. While net asset values are considered for depreciated costs, gross asset values are often used for replacement/reconstruction costs [Schmalwasser and Schidlowski, 2006].
In other countries, slightly differing concepts exist where assets are quantified by the *Gross/Net Capital Stock* of a country including the *Gross Fixed Capital Formation* [Daniell and Wenzel, 2014, Daniell, 2014]. A detailed differentiation of these concepts is out of scope of the present

work, however, explanations can be found in [Schmalwasser and Schidlowski, 2006]. Market value refers to the price at which a building can be traded in the marketplace at the time of evaluation, reflecting the cost of purchasing rather than reconstructing a building. Lastly, Insured Value is the value assigned to a building for the purpose of insurance, determined by the risk portfolio of the respective insurance company, which usually apply the gross concept instead of the net concept [Daniell, 2014, p.70].

S2 Methods: Systematic search for exposure datasets on building assets

A systematic search was conducted for freely available exposure data on building locations and building assets in Europe and Germany. A range of relevant search terms was employed, and searched for in several search engines, presented in Table S1. Additionally, the website of the "Federal Agency for Cartography and Geodesy" (*Bundesamt für Kartographie und Geodäsie*, translated) [BKG, 2025] was searched for suitable datasets.

Table S1: Search engines and search terms applied in systematic search for exposure datasets on building assets

search engine	**search terms**
Google & Google Scholar & BKG website	"building asset value data Germany"; "building asset datasets Germany"; "flood risk map Germany"; "flood exposure datasets Germany"; "exposure datasets Europe"; "flood exposure Europe datasets"; "European flood risk database"; "exposure datasets for natural disasters assessment"; "european earthquake damage exposure models"; "exposure models for natural disasters assessment"; "3D building data Germany"; "building location data Germany"; "land use datasets"; "free land use data"
references:	Google [2025a] & Google [2025b] & BKG [2025]

The results were reviewed and datasets were selected upon the following criteria. The data had to be freely accessible and cover the whole national extent of Germany. In any of the datasets at least one of the following information had to be given: *building location*; *building size*; *building use type*; *building asset values*. Regionalized or disaggregated assets were preferred over aggregated national values. A list of datasets considered including those selected is given in Table S2, additionally providing justifications of the selection.

The selection resulted in 7 datasets being chosen, summarized in Table 1 and discussed in Section 2.2.

Table S2: List of datasets considered including those selected, and justifications for the selection

dataset	reference	selected	justification
building data			
LoD1	BKG [2023]	yes	provides building location; area; height; use type, covers national extent, is produced by federal agency and therefore trusted
OSM (buildings)	OpenStreetMap contributors [2017]	no	provides similar information as LoD1 but is built and maintained by volunteers, therefore, not trusted as much as LoD1
asset value data			
BEAM	Copernicus [2020]	yes	provides building assets, already classified in economic sectors, provided by Copernicus and therefore trusted
EHRE	Nievas et al. [2023]	yes	provides asset values mapped onto OBM building features, classified into occupancy cases and structural types (construction material, structural system, ...), available at national scale
BKI	BKI [2021]	yes	provides asset values for variety of building use types, allowing very detailed cost allocation, applicable at national scale, includes regionalization factors
Eurostat	Eurostat [2025b,a]	yes	provides building assets, already classified in economic sectors, provided by the EU and therefore trusted
Destatis	Destatis [2025]	no	not necessary as it includes the same data as EUROSTAT
ESRM20	Crowley et al. [2021, 2020]	no	spatially aggregated; its data is embedded into EHRE, which further maps it onto individual buildings
land use data			
OSM (land use)	OpenStreetMap contributors [2017]	yes	provides 35 land use types, suitable for detailed classification of buildings into economic sectors, available at (inter-)national scale
CORINE	Copernicus [2018]	yes	provides 44 land use types, seamless data coverage, available at (inter-)national scale
ALKIS	AdV [2023]	no	does not provide building height
LBM-DE2018	BKG [2024]	no	not freely available

S3 Methods: Asset value models

S3.1 LoD1+Eurostat

Table S3: Statistical Classification of Economic Activities in the European Community (NACE) Rev. 2 economic sector groups [European Commission, 2008] provided in Eurostat [2025b].

sector group	NACE code	section title
agriculture	A	Agriculture, forestry and fishing
production	B	Mining and quarrying
	C	Manufacturing
	D	Electricity, gas, steam and air conditioning supply
	E	Water supply; sewerage, waste management and remediation activities
construction	F	Construction
market services	G	Wholesale and retail trade; repair of motor vehicles and motorcycles
	H	Transportation and storage
	I	Accommodation and food service activities
	J	Information and communication
corporate services	K	Financial and insurance activities
	L	Real estate activities
	M	Professional, scientific and technical activities
	N	Administrative and support service activities
non-market services	O	Public administration and defence; compulsory social security
	P	Education
	Q	Human health and social work activities
	R	Arts, entertainment and recreation
	S	Other service activities
	T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
	U	Activities of extraterritorial organizations and bodies

Table S4: asset classification subcategories of "Other buildings and structures" (AN.112) from Eurostat [2013]

Classification of assets	**Short description**	**Examples**
Buildings other than dwellings (AN.1121)	Non-residential buildings, including integral fixtures and site preparation; includes public monuments identified primarily as non-residential buildings.	"warehouse and industrial buildings, commercial buildings, buildings for public entertainment, hotels, restaurants, educational buildings, health buildings"
Other structures (AN.1122)	Structures other than residential ones; includes streets, sewers, site preparation, certain public monuments, mining works, and coastal protection works improving adjacent land.	"highways, streets, roads, railways and airfield runways; bridges, elevated highways, tunnels and subways; waterways, harbours, dams... long-distance pipelines, communication and power lines... constructions for mining... and for sport and recreation"
Land improvements (AN.1123)	Actions that improve the quantity, quality or productivity of land, or prevent its deterioration; also includes not-yet-written-off land transfer costs.	"land clearance, land contouring, creation of wells and watering holes"

Table S5: Eurostat and Insee derived national building replacement values for 2018 from Eq. 1. Note these are aggregated to the six sectors shown in Table S6 in a later step.

NACE code(s)	$RC_{n,\mathbf{AN.112}}$ [€]	$\frac{GFC_{\mathbf{AN.1121}}}{GFC_{\mathbf{AN.112}}}$
A	2.40×10^{11}	1.00
B-E	1.22×10^{12}	0.59
F	5.51×10^{10}	0.40
G-I	9.90×10^{11}	0.44
J	1.52×10^{11}	0.31
K	2.94×10^{11}	1.00
L	7.35×10^{11}	0.23
M-N	2.08×10^{11}	0.50
R-U	3.90×10^{11}	0.62
O-Q	2.42×10^{12}	0.34
TOTAL	6.71×10^{12}	

Table S6: Eurostat derived national and NUTS-3 regional (Ahrweiler [DEB12]) values for 2018 from Eq. 1. See Table S5 for additional values.

sector	**NACE code(s)**	GVA_r/GVA_n	$RC_{r,\mathbf{AN.1121}}$ [€]
agriculture	A	1.40×10^{-3}	$\mathbf{3.36 \times 10^8}$
production	B-E	7.76×10^{-4}	$\mathbf{5.53 \times 10^8}$
construction	F	1.40×10^{-3}	$\mathbf{3.11 \times 10^7}$
market services	G-J	1.00×10^{-3}	$\mathbf{4.90 \times 10^8}$
corporate services	K-N	9.64×10^{-4}	$\mathbf{5.48 \times 10^8}$
non-market services	O-U	1.28×10^{-3}	$\mathbf{1.35 \times 10^9}$
	TOTAL		$\mathbf{2.69 \times 10^9}$

S3.2 LoD1+BEAM

Sector	Total	Equipment	Buildings
Total	100.00%	15.31%	84.69%
Agriculture, forestry and fishing	1.71%	**51.06%**	**48.94%**
Manufacturing industry	12.18%	**58.36%**	**43.64%**
Service sectors	86.11%	**8.80%**	**91.20%**

Table S7: Proportions used to differentiate asset values into building and equipment assets from national accounting of fixed assets provided by the federal statistical offices of Germany [Arbeitskreis Volkswirtschaftliche Gesamtrechnungen der Länder, 2023]. Values correspond to the federal state of Rhineland-Palatinate based on the year 2018. Total column shows the shares of the respective sector compared to the total assets in the state of Rhineland-Palatinate.

S3.3 EHRE

Table S8: Reconstruction costs and replacement-cost composition by asset class in Germany from Crowley et al. [2021]

Asset class	Subcategory	Reconstruction cost (EUR m^{-2})	Replacement-cost composition (%)		
			Structural	Non-structural	Contents
residential	Rural areas	1300	30	50	20
	Urban areas	1700			
	Big cities	1900			
commercial	Offices	1600	20	30	50
	Wholesale & retail trade	1200			
	Hotels & restaurants	1680			
industrial	General facilities	800	15	25	60

The adjustment factors for different construction materials are the same for all occupancy cases, and are as follows:

- Unreinforced masonry, adobe blocks, wood: 0.95
- Reinforced concrete, masonry with unknown reinforcement: 1.05
- Steel, mixed materials (hybrid or composite), other: 1.00

S4 Methods: Benchmark dataset

The most challenging characteristic was the presence of basements in case of detached and semi-detached buildings, as this was often not possible to determine solely by inspecting the building from the outside. In many cases, however, small windows on the ground level could be observed which proved the presence of a basement. In all other cases, no basement was assumed, and an additional column was introduced to the data indicating the uncertainty of whether a basement exists or not.

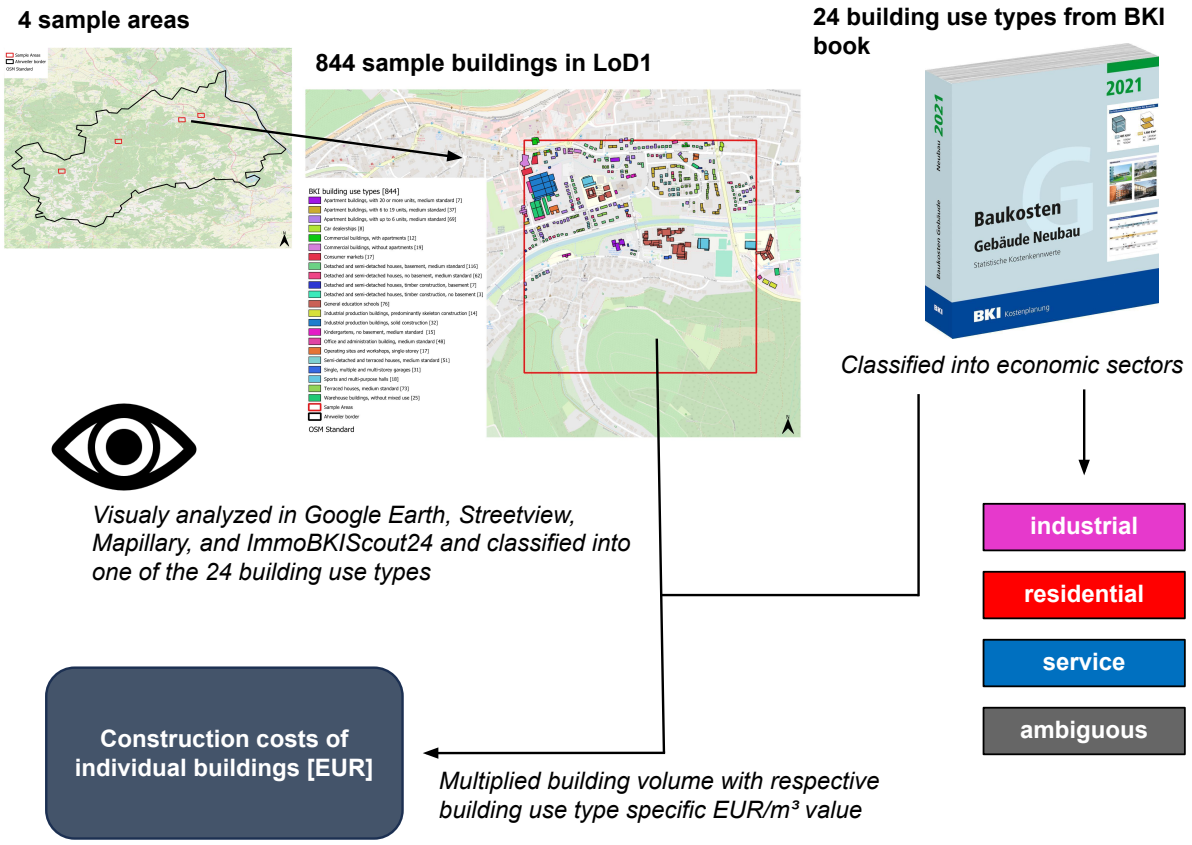

Figure S1: Workflow of benchmark dataset creation. See main text for details. © OpenStreetMap contributors 2025. Distributed under the Open Data Commons Open Database License (ODbL) v1.0. Image source: BKI [2021].

Table S9: New building unit construction costs referring to the year 2021 from BKI [2021]. Unit cost values were collected from several chapters in the book corresponding to the divers building types. €/m^3 values refer to *Bruttorauminhalt (BRI)* (translates as "gross volume") which is the measure of the total volume of a building. It is enclosed by the outer boundaries of the building, which are formed by the foundation, exterior wall, and roofs. The book also provides €/m^2 values referring to *Bruttogrundfläche (BGF)* (translates as "gross floor area") which is the sum of the net floor area and the construction floor area, and *Nutzungsfläche (NUF)* (translates as "usable floor space area") which is the total floor space with uses (the part of the net floor space that serves the use of the building based on its intended purpose) [Zschiesche, 2021]. The latter two were not applied in this analysis. Unit costs presented here were later adjusted for Ahrweiler county by applying a regionalization factor.

BKI sector	BKI building type	BKI unit costs (EUR/m^3)
ambiguous	Commercial buildings, with apartments	495
ambiguous	Warehouse buildings, without mixed use	160
ambiguous	Single, multiple and multi-storey garages	165
industrial	industrial production buildings, solid construction	250
industrial	industrial production buildings, predominantly skeleton construction	210
industrial	Operating sites and workshops, single-storey	290
residential	Detached and semi-detached houses, basement, medium standard	445
residential	Detached and semi-detached houses, no basement, medium standard	455
residential	Detached and semi-detached houses, timber construction, basement	470
residential	Detached and semi-detached houses, timber construction, no basement	495
residential	Semi-detached and terraced houses, medium standard	425
residential	Terraced houses, medium standard	370
residential	Apartment buildings, with up to 6 units, medium standard	440
residential	Apartment buildings, with 6 to 19 units, medium standard	425
residential	Apartment buildings, with 20 or more units, medium standard	410
service	Office and administration building, medium standard	495
service	General education schools	445
service	Commercial buildings, without apartments	495
service	Consumer markets	215
service	Kindergartens, no basement, medium standard	490
service	Car dealerships	315
service	Sports and multi-purpose halls	345
service	Medical facilities	545
service	Nursing homes	510

S5 Results: Classification Comparison

We evaluated sector classification using a one-vs-rest confusion framework. Predictions outside the benchmark label universe or out of domain (OOD) (e.g. "other") were retained and treated as abstentions: they were counted as false negatives for the corresponding true class and were not assigned as false positives to any evaluated class. Assets that failed to spatially join to the benchmark ("unmatched") on the other hand are ignored. The following label equivalency is assumed for the classification evaluation metrics:

Table S10: Classification label equivalency for per-label performance metrics from Fig. 7. OOD: out-of-domain

model	**label**	**benchmark label**
EHRE	commercial	service
EHRE	other	OOD
EHRE	mixed	ambiguous
Eurostat	non-market services	service
Eurostat	market services	service
Eurostat	corporate services	service
OSM land-use	agricultural	OOD

Table S11: Per-label performance of sector-classification models from Fig. 7. See Table S10 for label mapping. EHRE "mismatched" assets are excluded while out-of-domain (OOD) predictions are retained for the metric calculations.

model	benchmark sector	TP	FP	FN	TN	OOD	precision	recall	F1
LoD1+EUROSTAT (panel a)	Residential	414	62	8	360	0	0.87	0.981	0.922
LoD1+EUROSTAT (panel a)	Service	240	128	48	428	0	0.652	0.833	0.732
LoD1+EUROSTAT (panel a)	Industrial	0	0	66	778	0	0.0	0.0	0.0
LoD1+EUROSTAT (panel a)	Ambiguous	0	0	68	776	0	0.0	0.0	0.0
LoD1+BEAM (panel b)	Residential	414	62	8	360	0	0.87	0.981	0.922
LoD1+BEAM (panel b)	Service	240	128	48	428	0	0.652	0.833	0.732
LoD1+BEAM (panel b)	Industrial	0	0	66	778	0	0.0	0.0	0.0
LoD1+BEAM (panel b)	Ambiguous	0	0	68	776	0	0.0	0.0	0.0
EHRE (panel c)	Residential	323	46	7	241	174	0.875	0.979	0.924
EHRE (panel c)	Service	3	9	212	393	174	0.25	0.014	0.026
EHRE (panel c)	Industrial	12	4	21	580	174	0.75	0.364	0.49
EHRE (panel c)	Ambiguous	4	42	35	536	174	0.087	0.103	0.094
OSM land-use (panel d)	Residential	417	319	5	103	2	0.567	0.988	0.72
OSM land-use (panel d)	Service	17	18	271	538	2	0.486	0.059	0.105
OSM land-use (panel d)	Industrial	47	24	19	754	2	0.662	0.712	0.686
OSM land-use (panel d)	Ambiguous	0	0	68	776	2	0.0	0.0	0.0

Table S12: Performance of sector-classification models weighted by the benchmark counts per sector from Fig. 7. See Table S10 for label mapping.

model	precision	recall	F1
LoD1+EUROSTAT (panel a)	0.657	0.775	0.711
LoD1+BEAM (panel b)	0.657	0.775	0.711
EHRE (panel c)	0.601	0.554	0.536
OSM land-use (panel d)	0.501	0.57	0.45

S6 Results: Weighted Scoring Model

Table S13: Criteria for Weighted Scoring Model evaluation of model candidates.

Criteria	Description
Benchmark classification	Rates the performance of the model at matching the classification of the benchmark dataset. Higher conformity with the benchmark dataset results in higher scores.
Benchmark values	Rates the performance of the model at matching the per-asset values of the benchmark dataset. Closer alignment with the benchmark dataset results in higher scores.
Sustainability (update frequency, ease of access)	Rates the barriers to access (e.g., license restrictions, data hosting) and frequency of updates of the underlying data. Easier access and more frequent updates result in higher scores.
Model parsimony	Rates the complexity required to construct the exposure model from the source data. Simpler, more parsimonious models receive higher scores.
Transparency	Rates the level of detail to which the source data pipeline is traceable and comprehensible, such as through the availability of code. Greater transparency results in higher scores.
Uncertainty handling	Rates how the model measures, quantifies, and communicates uncertainty. Higher scores relate to more robust uncertainty handling.
Breadth of asset types	Rates the relative breadth of asset value type data (e.g., building replacement, stocks in trade, household contents). Greater breadth results in higher scores.
Adaptability	Rates the ability of the model to adapt to specific regions and times. Greater adaptability yields higher scores.

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